Department of Biomass & Waste

Energibranchen

Strategy for research, development and demonstration of thermal biomass gasification in Denmark

Energiteknologisk udvikling og demonstration

Author: Morten Tony Hansen

Issued: 09-12-2011
Task: 110-33153

Title

Strategy for research, development and demonstration of thermal biomass gasification in Denmark

Author

Morten Tony Hansen

Revision: 4 (09-12-2011)

Task: 110-33153

Publisher:
FORCE Technology
Department of Biomass & Waste

Contact:
Morten Tony Hansen - mth@force.dk
FORCE Technology
Hjortekærsvej 99
DK- 2800 Kgs. Lyngby
Denmark

Web: www.forcebioenergy.dk
Telefon: +45 72 15 77 00
Fax: + 45 72 15 77 01

Preface

This report represents the outcome of the project "Strategy for research, development and demonstration of thermal biomass gasification in Denmark".

The project lasted from January to September 2011 and has been conducted by FORCE Technology for DI Bioenergy. The project steering committee consisted of:

- Jan Bünger, EDDP
- Steen Vestervang, Energinet.dk
- Hanne Skov Bengaard, The Danish National Advanced Technology Foundation
- Klaus Rosenfeldt Jakobsen, Danish Council for Strategic Research

The project is funded by EUDP, Energinet.dk, DI Bioenergy and FORCE Technology and the stakeholder companies listed below. Special thanks go to these companies as they have made it possible to develop the strategy which will not only benefit themselves, but the entire field of thermal biomass gasification.

Co-funding stakeholders

The report is the industry's contribution to the strategy for research, development and demonstration of thermal biomass gasification in Denmark. It aims to serve as inspiration and basis for administrators and applicants of funding for research, development and demonstration in future tenders including the EDDP and the ForskEL program, as the programs find it increasingly important to have a strategy covering the areas with a large potential to which funding is to be allocated.

The gasification industry is special because it has over many years been awarded funds developing the technology still without a strong commercial breakthrough. Recent results suggest that the gasification industry may face a commercial breakthrough. It is our hope that this report can help to achieve it.

A number of Danish companies and institutions have been involved in the project by responding to questionnaires and participating in telephone interviews, etc. We would like to thank for this contribution and hope the effort will return in the form of improved maneuverability in connection with applications for development programs.

A group of experts has assessed the challenges and potentials for each of the various technological development tracks. We would like to thank the participants for making their longstanding experience available for this work. The group consisted beyond undersigned of:

- Chris Higman, Higman Consulting GmbH
- Bram van der Drift, ECN
- Jesper Cramer, FORCE Technology

The report has been submitted for stakeholder consultation and comments from the consultation have been incorporated.

Thanks should be addressed to DI Bioenergy, which has contributed to a fruitful cooperation in a constructive spirit.

Morten Tony Hansen
FORCE Technology
2011-09-15

List of content

1 Short summary

Technology for thermal gasification of biomass is one of the key elements to make the vision of an energy system without fossil fuels a reality.

Gasification technology can enhance the flexibility needed to maintain a future energy system with a large share of wind power. Furthermore, gasification has advantages in terms of ash recycling and utilisation of vast but challenging biomass residues.

Danish companies are globally well advanced with this technology and the market for gasification technology is great in both Denmark and abroad.

There is a clear need for targeted technology RD&D in order to reach the last stretch to a commercial breakthrough.

CHP Technologies	Fuel Technologies	General areas
• Demonstrate operational reliability	• RD&D on gas cleaning	• Optimise O&M and production costs
• Research in fuel flexibility	• R&D on gaseous & liquid fuels	• Improve cooperation between suppliers and universities
• Demonstrate gas cleaning technology	• Demonstrate fuel flexibility	• Improve cooperation between suppliers and ATG companies
		• Interchange of data & general knowledge between suppliers

Most important RD&D focus areas for Danish biomass gasification technologies

The project "Strategy for research, development and demonstration of thermal biomass gasification in Denmark" is the Danish industrys contribution to the development of biomass gasification and goes into detail with the RD&D needs.

The project has been conducted by FORCE Technology for DI Bioenergy with funding from EUDP, Energinet.dk, DI Bioenergy and FORCE Technology and five stakeholder companies.

2 Short summary in Danish

Kort sammenfatning på dansk

Teknologi til termisk forgasning af biomasse er et af de vigtige redskaber til at føre visionen om et energisystem uden fossile brændsler ud i livet.

Forgasningsteknologien kan styrke den fleksibilitet, der skal til at opretholde et fremtidigt energisystem med en stor andel vindkraft. Desuden har forgasningsteknologi fordele i form af askegenbrug og energiudnyttelse af de omfattende, men udfordrende biomasse-restprodukter.

Danske virksomheder ligger på verdensplan langt fremme med denne teknologi og markedet for forgasningsteknologi er stort i både Danmark og i udlandet.

Der er et tydeligt behov for målrettet forskning, teknologiudvikling og demonstration for at biomasseforgasning kan nå det sidste stykke til et kommercielt gennembrud.

Kraftvarmeteknologier	Teknologier til energibærere	Generelle områder
• Demonstrere driftssikkerhed	• FU&D indenfor gasrensning	• Mindske omkostninger til fremstilling samt drift og vedligehold
• Forske i brændsels-fleksibilitet	• F&U indenfor gas-formige og flydende brændsler	• Forbedre samarbejdet mellem leverandører og universiteter
• Demonstrere teknologi til gasrensning	• Demonstere brændselsfleksibilitet	• Forbedre samarbejdet mellemleverandører og GTS-institutter
		• Udveksle data og generel viden mellem leverandører

Vigtigste FUD indsatsområder for danske biomasseforgasningsteknologier

Projektet "Strategy for research, development and demonstration of thermal biomass gasification in Denmark" er industriens bidrag til en strategi for forskning, udvikling og demonstration af termisk biomasseforgasning i Danmark. Rapporten går i dybden med området og FUD-behovet.

Projektet er gennemført af FORCE Technology for DI Bioenergi og er finansieret af EUDP, Energinet.dk, DI Bioenergi og FORCE Technology samt fem virksomheder i branchen.

3 Summary

Technology for thermal gasification of biomass is one of the key elements to make the vision of an energy system without fossil fuels a reality. Danish companies are globally well advanced with this technology and the market for gasification technology is great in both Denmark and abroad.

There is a clear need for targeted technology development in order to reach the last stretch to the market and the technology suppliers expect that half the development costs can be financed with public funds.

Gasification technology can enhance the flexibility needed to maintain a future energy system with a large share of wind power, and the technology may be the heart of the balance the fluctuating wind power needs. Also, in the current energy system gasification technology is an effective way to provide electricity and heat for district heating networks and industry - even based on difficult solid biofuels. Unlike combustion gasification enables recycling of nutrients to agriculture, which is especially important when using challenging fuels, including straw and new fast growing energy crops like salix and miscanthus, where the ash content is high.

The palette of technologies for thermal gasification of solid biomass from Danish companies cover a wide spectrum. It includes a number of technology tracks and covers the whole gamut from small installations which can heat large buildings and simultaneously produce electricity over larger CHP plants for district heating networks and up to potentially very large plants for cofiring power station units for producing electricity and heat.

Pyroneer A/S gasilfier is demonstrated at DONG Energy A/S in Kalundborg, Denmark

Technologically, the palette spreads from technologies targeting CHP plants for direct generation of electricity and heat to gasification technology producing liquid fuels and synthetic natural gas that can be used for transportation purposes or stored and used to produce electricity and heat. Some of the technologies may eventually be used for both purposes.

The Danish gasification technologies are at different stages of maturity. Some technologies for CHP generation have many operational hours in the book and are marketed as commercial plants, other technologies are new and on a conceptual level at universities or in companies. Inbetween are technologies - both targeted small scale and large scale - at the pilot stage and a few having demonstration plants in operation.

Education Basic research	Research and development	Pilot plant	Demonstration plant	Market introduction

Development stages for Danish gasification technologies

Overall, the Danish technologies represent a strong technical base for gaining future international market shares. Although only a few of the technologies can be bought off the shelf, Danish suppliers are advanced in relation to foreign competitors within the applications on which the technologies focus.

The Danish suppliers represent a wide range of different types of companies that have a strong focus on gasification technology in common. Some companies only have one or a few employees and largely stems from an academic background. They are driven by the founder's personal drive and enthusiasm. Foreign experts believe that a number of Danish success stories to a high extent are borne by this Danish type of business model. Other actors are industrial companies, often with a large owner in the back. This gives the companies the strength needed to bring a technology to the market.

Stirling engine operated on gas from a wood chip gasifier

Common to all the technologies - including the almost commercial ones - is a continuing need for development. There is a need to strengthen the basic understanding of the gasification processes as well as to show that the technologies can deliver the promised performance while maintaining a good reliability. The basic understanding is essential to understand what is going well and - especially - if something goes wrong in the development process or during scaling and thus enabling quick solutions and move on. If the technologies are not reliable, an investor risks being left with a plant that does not operate enough hours to recoup the investment.

Danish gasification technology as described in this report has over 10 different tracks covering a range of different processes, each with unique characteristics and specific advantages. There is no large overlap between the technologies because they differ in either scale or purpose. The table below gives an overview of the technology tracks.

Name and stakeholder(s)	Technology type	Main purpose	Scale MW_{th}	Stage
Alternating Gasifier Ammongas A/S, Babcock & Wilcox Vølund A/S	Twin bed filter	Fuel (gas)	200+	Pilot
Vølund Updraft Gasifier Babcock & Wilcox Vølund A/S	Up-draft	CHP - IC engine	15-200	Commercial
The CHP system of BioSynergi BioSynergi Proces ApS	Open core down-draft	CHP - IC engine	0-15	Demonstration
Staged Down Draft Gasification Risø DTU, Weiss A/S, Dall Energy, COWI A/S	Multiple steps down-draft	CHP - IC engine	0-15	Demonstration
Pyroneer A/S DONG Energy A/S, Risø DTU, Danish Fluid Bed Technology ApS	Low temp. circulating fluid bed	CHP - cofiring Fuel (gas & liquid)	1-200	Demonstration
Close Coupled Gasification (CCG) EP Engineering ApS	Vibrating grate fluid bed	CHP - Steam engine	0-1	Pilot
Tar reforming etc. Haldor Topsøe	n.a. / "any"	Fuel (gas & liquid)	15-200+	Commercial
Catalytic low temp. pyrolysis process Organic Fuel Technology A/S	Catalytic low temperature pyrolysis	Fuel (liquid)	1-15	New/Pilot
Stirling engine with up-draft gasifier Stirling DK ApS	Up-draft	CHP - Stirling engine	0-1	Commercial
BlackCarbon Stirling DK ApS	Pyrolysis	CHP - Stirling engine	0-1	Demonstration
Biomass Gasification Gas Engine Aaen Consulting Engineers, Skive District Heating, Carbona	Circulating fluid bed	CHP - IC engine	15-200	Demonstration

Danish biomass gasification technologies

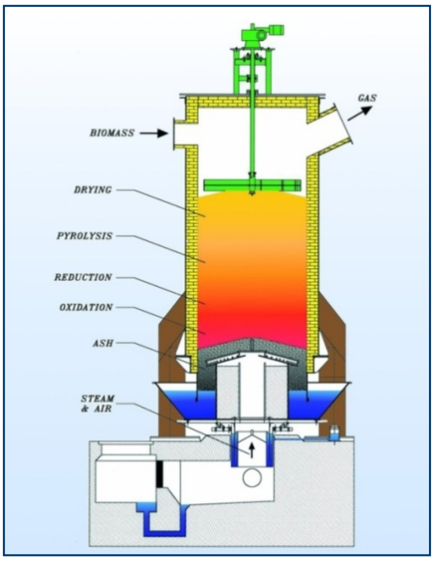
The market for these Danish technologies is large and growing. Both in Denmark and abroad there is an increasing focus on replacing fossil fuels. With the 20-20-20 plan, the member states of the European Union have set targets for renewable energy, of which a a share will be based on biomass.

Gasification technology fits perfectly into a future energy system, especially when it involves biomass resources that are more challenging than clean wood. There is reason to believe that gasification technologies could become a large part of that future. The Danish supplier companies' overall expectations for the market are quite high. For 2020, the companies expect that over 2,000 gasification plants are in operation worldwide.

In order for this expectation to become a reality, there is a need for targeted research and development, and not least for demonstration activities. With an appropriate effort the technology can reach the market. The gasification industry stakeholders agree that there is a need for action and a poll conducted in the project indicates a need for development in a wide range of areas. The industry's overall priority areas that should be focused on, appear from the table below.

	Focus area	Aim
CHP:	Demonstration of operational reliability	Demonstrate ability to operate continously i.e. convince investors that investment is returned
CHP:	Research in fuel flexibility	Increase the applicability in a broad range of industries
CHP:	Demonstration of gas cleaning technology	Improve upscaling ability
Fuel:	RD&D on gas cleaning	Essential for fuel generation
Fuel:	R&D within gaseous & liquid fuels	Gain deeper understanding of correlation between technology and fuel quality
Fuel:	Demonstration of fuel flexibility	Proving the technology
General:	Optimisation production and O&M costs	Improve feasibility for customer
General:	Improve cooperation between suppliers and universities	Improve understanding of basic processes and enable swift problem solving
General:	Improve cooperation between suppliers and ATG companies	Improve demonstration, monitoring and proving of technologies
General:	Interchange of data & general knowledge between suppliers	Improve general problem solving on gasifier technology development

Most important RD&D focus areas for Danish biomass gasification technologies



Sectional view of the Babcock & Wilcox Vølunds gasifier in Harboøre, Denmark

The project has made a rough estimate of the cost of such a development - of the need for public financing in connection with bringing two types of technology from its current state to a commercial level. The estimate focuses on gasification technology for power generation in small scale and gasification technology for generating gas for co-firing in large CHP plants. The estimate suggests an annual funding need of around EUR 13 million over four years for each application type.

4 Summary in Danish

Sammenfatning på dansk

Teknologi til termisk forgasning af biomasse er et af de vigtige redskaber til at føre visionen om et energisystem uden fossile brændsler ud i livet.

Danske virksomheder ligger på verdensplan langt fremme med denne teknologi og markedet for forgasningsteknologi er stort i både Danmark og i udlandet.

Der er behov for målrettet teknologiudvikling for at nå det sidste stykke ud til markedet, og teknologivirksomhederne forventer, at halvdelen af udviklingsomkostningerne kan finansieres med offentlige midler.

Forgasningsteknologien kan styrke den fleksibilitet, der skal til at opretholde et fremtidigt energisystem med en stor andel vindkraft, og teknologien kan være hjertet i den balance, den fluktuerende vindkraft behøver. Også i det nuværende energisystem kan forgasningsteknologi være en effektiv måde at levere el og varme på til fjernvarmenettene og til industrien - også på basis af vanskelige biobrændsler. I modsætning til forbrænding muliggør forgasning recirkulering af næringsstoffer til jordbruget, hvilket især er vigtigt, når der benyttes besværlige brændsler, herunder halm og nye hurtigvoksende energiafgrøder som pil og elefantgræs, hvor askedelen er høj.

Paletten af teknologier til termisk forgasning af fast biomasse fra danske virksomheder dækker bredt. Den omfatter en række teknologispor og dækker hele skalaen fra små anlæg, der kan opvarme større bygninger og samtidig fremstille elektricitet over større anlæg til fjernvarmeværker og op til potentielt store anlæg, der fungerer forkoblet store kraftværksblokke til fremstilling af el og varme.

Pyroneer A/S forgasser demonstreres hos DONG Energy A/S i Kalundborg

Teknologisk spreder paletten sig fra teknologier målrettet kraftvarmeanlæg, hvor el og varme fremstilles direkte og sendes ud i fjernvarmenet og elektricitetsnet, til forgasningsteknologi til fremstilling af flydende brændsler og syntetisk naturgas, der kan bruges til transportformål eller lagres og bruges til fremstilling af el og varme. Nogle af teknologierne kan med tiden benyttes til begge formål.

De danske forgasningsteknologier befinder sig på et varierende stade af modenhed. Enkelte teknologier til kraftvarme har mange driftstimer i logbogen og er nået frem til at kunne markedsføres som kommercielle anlæg, mens andre teknologispor er helt nye og befinder sig på konceptniveau på universiteter eller i virksomhederne. Midt imellem befinder sig teknologier - både målrettet lille og stor skala - på pilotstadet og enkelte med demonstrationsanlæg i drift.

Uddannelse og grundforskning | Forskning og udvikling | Pilotanlæg | Demonstra-tionsanlæg | Markeds-introduktion

Udviklingstrin for danske forgasningsteknologier

Samlet set, repræsenterer de danske teknologier et stærkt teknisk udgangspunkt for fremtidige internationale markedsandele. Selvom kun få af teknologierne kan købes fra hylden, ligger danske leverandører langt fremme i forhold til udenlandske konkurrenter indenfor de anvendelser, teknologierne fokuserer på.

De danske leverandører repræsenterer en bred vifte forskellige virksomhedstyper, der har det stærke fokus på forgasningsteknologien til fælles. Nogle virksomheder har én eller få medarbejdere og er i overvejende grad udsprunget af en akademisk baggrund. De er i høj grad drevet af grundlæggerens personlige drivkraft og entusiasme. Udenlandske eksperter mener, at en række danske succeshistorier i vid udstrækning er båret af denne danske type virksomhedsmodel. Andre aktører er større industrivirksomheder, ofte med endnu større ejere i ryggen. Det giver virksomhederne den fornødne styrke til at bringe teknologien frem til markedet.

Stirlingmotor drevet på gas fra flisforgasser

Fælles for alle teknologierne - også de næsten kommercielle - er et fortsat behov for udvikling. Der er både behov for at styrke den grundlæggende forståelse af forgasningsprocesser og for at vise, at teknologierne kan præstere den lovede ydelse og samtidig præstere en god driftssikkerhed. Den grundlæggende forståelse er essentiel for at kunne forstå hvad der går godt og - ikke mindst - hvis noget går galt i udviklingsforløbet eller under opskalering og dermed hurtigt kunne finde en løsning og komme videre. Og hvis teknologierne ikke er driftssikre, risikerer en investor at stå med et anlæg, der ikke kører i tilstrækkeligt mange timer til at forrente investeringen.

Dansk forgasningsteknologi beskrevet i dette notat har over 10 forskellige spor, der dækker over en række forskellige teknologier med hver deres unikke kendetegn og specifikke fordele. Der er ikke et stort overlap mellem de enkelte spor, fordi de enten adskiller sig i skala eller i formål. Tabellen nedenfor giver et overblik over teknologisporene.

Navn og aktør(er)	Forgasser-teknologi	Hovedformål	Skala (MW_{th})	Stade
Alternating Gasifier Ammongas A/S Babcock & Wilcox Vølund A/S	Twin bed filter	Brændsel (gas)	200+	Pilot
Vølund Updraft Gasifier Babcock & Wilcox Vølund A/S	Modstrøm	Kraftvarme - forbrændingsmotor	15-200	Kommerciel
The CHP system of BioSynergi BioSynergi Proces ApS	Open core medstrøm	Kraftvarme - forbrændingsmotor	0-15	Demonstration
Staged Down Draft Gasification Risø DTU, Weiss A/S, Dall Energy, COWI A/S	Trindelt medstrøm	Kraftvarme - forbrændingsmotor	0-15	Demonstration
Pyroneer A/S DONG Energy A/S, Risø DTU, Danish Fluid Bed Technology ApS	Lavtemperatur cirkulerende fluid bed	Kraftvarme Brændsel (gas & flydende)	1-200	Demonstration
Close Coupled Gasification (CCG) EP Engineering ApS	Vibrationsrist med fluid bed	Kraftvarme - Dampmotor	0-1	Pilot
Tjære reforming etc. Haldor Topsøe	n.a. / "alle"	Brændsel (gas & flydende)	15-200+	Kommerciel
Catalytic low temp. pyrolysis process Organic Fuel Technology A/S	Katalytisk lavtemperatur pyrolyse	Brændsel (flydende)	1-15	Ny/Pilot
Stirlingmotor med modstrømsforgasser Stirling DK ApS	Modstrøm	Kraftvarme - Stirlingmotor	0-1	Kommerciel
BlackCarbon Stirling DK ApS	Pyrolyse	Kraftvarme - Stirlingmotor	0-1	Demonstration
Biomass Gasification Gas Engine Aaen Rådgivende Ingeniører, Skive Fjernvarme, Carbona	Cirkulerende fluidiseret bed	Kraftvarme - forbrændingsmotor	15-200	Demonstration

Danske biomasseforgasningsteknologier

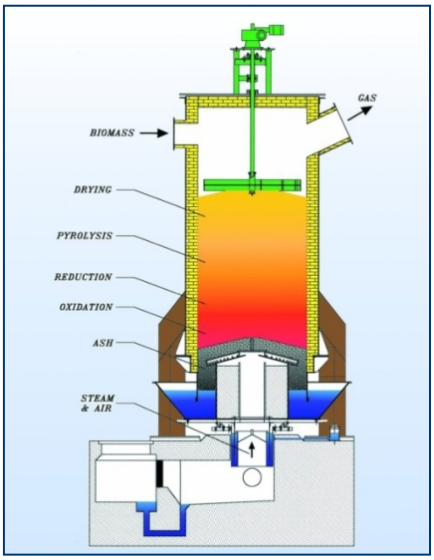
Markedet for disse danske teknologier er stort og stigende. Både i Danmark og i udlandet er der øget fokus på at forlade fossile brændsler. EU-landene har med 20-20-20-planerne sat et mål for den vedvarende energi, hvor en stor del baseres på biomasse, selv med en meget ambitiøs udbygning med vindenergi, solenergi og vandkraft.

Forgasningsteknologien passer perfekt ind i energisystemerne, ikke mindst når biomasseressourcer, der er mere vanskelige end rent træ, skal tages i brug. Der er ingen grund til, at forgasningsteknologierne ikke kunne blive en stor del af denne fremtid. Adspurgt er leverandørvirksomhedernes samlede forventning til markedet høj - i 2020 forventer virksomhederne at over 2.000 anlæg er i drift over hele verden.

For at denne forventning kan blive til virkelighed, er der behov for målrettet forskning og udvikling samt ikke mindst demonstrationsaktiviteter. Med en passende indsats kan teknologierne nå helt ud til markedet. Forgasningsbranchens interessenter er enige i at der er behov for en indsats og en afstemning, der er gennemført i projektet peger på et behov for udvikling på et bredt udsnit af områder. Branchens prioritering af områder, der bør fokuseres på, fremgår af tabellen nedenfor.

Område	Fokus	Mål
Kraftvarme:	Demonstrere driftssikkerhed	Demonstrere evne til kontinuert drift, dvs. overbevise investorer om, at investeringen betaler sig
Kraftvarme:	Forske i brændselsfleksibilitet	Øge anvendeligheden i en bredere vifte af brancher
Kraftvarme:	Demonstrere teknologi til gasrensning	Forbedre teknologiens skalerbarhed
Brændsel:	FU&D indenfor gasrensning	Opnå essentielt viden til at kunne fremstille brændsel
Brændsel:	F&U indenfor gasformige og flydende brændsler	Få dybere forståelse for forbindelsen mellem teknologi og brændselskvalitet
Brændsel:	Demonstere brændselsfleksibilitet	Eftervise teknologiens evne til at benytte forskellige brændsler
Generelt:	Optimere fremstillingsomkostninger samt drifts- og vedligeholdelsesomkostninger	Forbedre lønsomheden for kunden
Generelt:	Forbedre samarbejdet mellem leverandører og universiteter	Forbedre forståelsen for grundlæggende processes og sørge for hurtig problemløsning
Generelt:	Forbedre samarbejdet mellem leverandører og GTS-institutter	Forbedre demonstration, overvågning og eftervisning af teknologiernes drift
Generelt:	Udveksle data og generel viden mellem leverandører	Forbedre løsning af generelle problemer indenfor udvikling af forgasningsteknologi

Vigtigste FUD indsatsområder for danske biomasseforgasningsteknologier



Princip for Vølunds forgasser i Harboøre

For at give et bud på omkostningerne ved en sådan udvikling er der gennemført en grov vurdering af behovet for offentlig finansiering i forbindelse med at bringe to teknologityper fra det nuværende stade frem til et kommercielt niveau. Estimatet omhandler forgasningsteknologi til kraftvarmeproduktion i lille skala henholdsvis forgasningsteknologi til generering af gas til samfyring i kraftværksblokke. Estimatet peger på årlige finansieringsbehov på omkring 100 millioner kroner i fire år for hvert af forgasningssporene.

Forgasning er en proces, hvor et brændsel - for eksempel biomasse - opvarmes, men hvor man tilfører så lidt luft, at der ikke kan ske en egentlig forbrænding. I stedet fordamper først vand, og dernæst frigives flygtige forbindelser fra brændslet.

De flygtige forbindelser afgår som forgasningsgas, også kaldet produktgas. Den består typsik af brint (H), lettere kulbrinter såsom methan (CH_4) kulmonoxid (CO) og kuldioxid (CO_2). Desuden kan den også indeholde andre kulbrinteforbindelser, hvoraf nogle kan være problematiske for den efterfølgende udnyttelse af forgasninsgassen, medmindre der tages særlige foranstaltninger.

Forgasningsgassen har en positiv brændværdi og kan enten indfyres direkte i en motor, der kan producere el og varme, den kan indfyres i en kedel, der producerer damp til en dampturbine, som derefter kan producere el og varme. Gassen kan også oprenses og bruges i stedet for naturgas eller omformes og bruges i stedet for flydende brændstof.

Nyere undersøgelser tyder desuden på, at den aske, der bliver tilbage efter forgasning, kan have nogle fordele fremfor aske fra anlæg, der anvender forbrændingsteknologi.

Forgasnings pilotanlæg på DTU

Nærværende rapport repræsenterer resultatet af projektet "Strategi for forskning, udvikling og demonstration af termisk biomasseforgasning i Danmark".

Rapporten er industriens oplæg til strategi for forskning, udvikling og demonstration af termisk biomasseforgasning i Danmark. Den har til formål at virke som inspiration og grundlag for administratorer og ansøgere af støttemidler til forskning, udvikling og demonstration i forbindelse med kommende udbud fra bla. EUDP og ForskEl programmerne, idet programmerne i stigende grad ser det som en nødvendighed at have en strategi for de områder, der tildeles midler.

Forgasningsområdet er specielt fordi der over en længere årrække er tildelt midler til teknologien, uden der er kommet et stærkt kommercielt gennembrud. Men de seneste års resultater tyder på, forgasningsområdet måske står over for en ny begyndelse.

Projektet har strakt sig fra januar til september 2011 og er gennemført af FORCE Technology for DI Bioenergi. Projektets styregruppe bestod af:

- Jan Bünger, EUDP
- Steen Vestervang, Energinet.dk
- Hanne Skov Bengaard, Højteknologifonden
- Klaus Rosenfeldt Jakobsen, Det Strategiske Forskningsråd

En række danske virksomheder og institutioner har medvirket i projektet og leveret input ved at svare på spørgeskemaer og deltage i telefoninterviews m.v.

En fokuseringsgruppe har stillet sine mangeårige erfaringer til rådighed for projektet og vurderet de forskellige teknologiske udviklingsspors udfordringer og potentialer. Fokuseringsgruppen bestod ud over forfatteren af:

- Chris Higman, Higman Consulting GmbH
- Bram van der Drift, Energy research Centre of the Netherlands (ECN)
- Jesper Cramer, FORCE Technology

Projektet er finansieret af EUDP, Energinet.dk, DI Bioenergi og FORCE Technology samt de nedenfor nævnte interessenter.

Medfinansierende interessenter

5 Introduction

This chapter contains a description of the context in which the strategy project has been concieved and how the work has been carried out.

5.1 Background

For many years different stakeholders have been working on the development of thermal gasification of solid biomass in Denmark.

Particular attention has been given to decentralized gasification of wood chips to produce electricity and heat. Some of the concepts developed so far are approaching the commercial stage, but there is still no genuine commercial breakthrough for the gasification technology.

In recent years there has been an increased Danish interest in several other gasification technologies: production of liquid biofuels and bio-SNG, biorefineries, addition of gasifiers for power plant boilers, flexible gasification plants that can switch between power generation and second generation liquid fuels, interaction with fuel cells, etc.

The development of Danish based gasification technology has been described in the "Strategy for research, development and demonstration of biomass technologies for electricity generation and CHP in Denmark" (The Biomass Strategy) from 2003. The strategy does not address the gasification in detail, but it is indicated that the Danish development effort on small scale gasification plants should be focused on few development tracks, just as priority should be given to implementation of long-term testing and demonstration of a few technologies. In the strategy R&D is expected to deal with solving current operational problems. The Biomass Strategy has not been updated since 2003.

Use of biomass is expected to play a central role in the Danish energy supply, and thermal gasification of biomass is a technology that could contribute to this. In an energy system with a very large windpower generation capacity thermal biomass gasification can be the perfect match in terms of balancing the fluctuating nature of the wind and thus providing for a high coverage from renewable energy sources.

Because of the increased focus on a wider application and development of gasification technology in Denmark, there is a need for a separate RD&D strategy that can help prioritise the areas where, in Danish eyes, the greatest needs and perspective of development exist.

On this background the Bioenergy section of the Confederation of Danish Industries has initiated the strategy work and asked FORCE Technology for assistance. The energy funds EUDP and PSO at Energinet.dk have been asked to support the strategy work.

5.2 Aim

The purpose of the strategy project is to prepare a Danish RD&D strategy for thermal biomass gasification. The aim is to focus and target the Danish technological development efforts within gasification, so the technologies can help to meet national targets for the use of renewable energy, independence from fossil fuels and CO_2 mitigation while promoting Danish industry growth and export potential in the field.

The strategy will:

- provide an overview of the Danish competences, strengths and the framework for gasification technologies
- identify the RD&D needs of the area and focus the development effort
- be usable by Danish companies and research and development institutions for a targeted effort
- be usable by public funders to prioritize funding
- be usable by regions, growth fora and municipalities to prioritize efforts
- visualise the long term Danish development efforts
- facilitate coordination of the Danish development efforts with the international efforts in this area.

5.3 Scope

The strategy is limited to address the technical development needs within thermal gasification of biomass with the primary aim of generating electricity and heat or energy carriers - fuels. Technology for conversion of producer gas to an energy carrier falls within the strategy.

The strategy does not cover:

- Manufacture and use of biogas (gas produced by biological processes). A Danish biogas strategy was prepared in 2009
- Gasification of coal or other fossil fuels
- Combustion of biomass
- Recommendations for the framework conditions for promotion of the technology.

5.4 Methodology

The strategy project has been divided into four main activities as follows:

1. Organization and project management
2. Mapping process - technology description
3. Analysis of potentials and focusing - RD&D priorities, funding need
4. Reporting and dissemination

The strategy work is based on a high degree of participation from the gasification business in Denmark. Activity 1 built the group of technology suppliers that was assumed to provide the written content for activity 2 and dealt with gathering funding for the project from the suppliers. The funding work has been ongoing throughout the project period.

It has been the aim to contact all Danish stakeholders dealing with biomass gasification technology. The basis has been a list of stakeholders from the Danish Energy Agency coupled with a small survey of new stakeholders.

Activity 2 has dealt with mapping of Danish technologies, RD&D priorities, funding needs and current Danish projects. The main tool in this activity was the questionnaire that can be seen in the Annex 5 – Questionnaire used in the survey. The input from the suppliers and other actors has been reproduced directly in this report. There has been no ressources allocated for a critical assessment of the input.

In part 3 each technology was assessed based on the input from activity 2 and an independent focusing of objectives, priorities and funding for Danish biomass gasification is made. In order to do this, a small focus group attended by two international gasification specialists besides FORCE has been assembled. The idea is to ensure professionalism and independence in the focusing exercise. The working language of the project is English.

Activity 4 was the reporting of the gathered material and the technology assessment and handling the public stakeholder consultation of the report as well as dissemination of the results.

6 The Danish based gasification technology industry

Passionate researchers and engineers at Danish universities, Advanced Technology Group companies and technology supply companies have been working on developing thermal biomass gasification technology for decades. The primary focus has been to find efficient solutions to generate electricity within the widespread Danish district heating systems. Lately focus has also been at generating biomass based gaseous and liquid fuels.

The following paragraphs describe the Danish biomass gasification stakeholders based on input from the stakeholders themselves. A list of stakeholders can be found in Annex 4 - List of Danish gasification stakeholders.

6.1 The Danish suppliers

The suppliers that have responded to the questionnaire respresent very different types of companies. Roughly, they can be divided into two groups: Half of the companies are very small with one to maximally 4 employees. The other half can be categorized by their size being larger than 25 employees.

The small companies are often very young and have an academic background, they are often founded as a spin-off from research and development institutions. The small companies are mostly Danish owned.

The larger companies do not have much in common. The group comprises two technology suppliers with 27 and 39 employees, one large supplier of energy plants owned by a large American industry group and two (to Danish conditions) large players: a state owned utility company and a strong and independent family owned technology supplier.

6.2 The Danish R&D environment

R&D in thermal biomass gasification technology and auxiliary equipment as well as in its application in society is taking place at a number of places, amongst others at the Danish Technical University and in companies in the Advanced Technology Group. The following is a description of actors and activities based on input from the actors themselves.

6.2.1 Danish Gas Technology Centre (DGC)

DGC is a company in the Advanced Technology Group that focuses on gas utilisation. All activities within gasification are related to bio-SNG production. Bio-SNG in the natural gas grid would make the natural gas greener and gradually more and more CO_2-neutral.

DGC has recently been awarded support for a "Green Gas Test Center" that will test new green gases such as biogas before being sent out into the natural gas network, eg biogas. Focus is initially on biogas, but in the longer term it will also focus on other renewable energy gases as hydrogen and gasified biomass.

DGC considers different process technologies for being the optimum process. The AER technology of the company ZSW in Germany followed by a methanation process seems to be very promising. It has a dual fluid bed with CaO as the circulating bed material. The

CaO absorbs CO2 and makes a H2-rich product gas, which by methanation can be converted directly to line quality bio-SNG.

6.2.2 Danish Technological Institute (DTI)

DTI is a company in the Advanced Technology Group.

Within gasification, DTI focuses at:

- Lab scale pyrolysis
- Lab scale updraft gasifier
- Torrefaction pilot plant
- Thermal and catalytic partial oxidation gas cleaning unit

The focus of the work is at both CHP generation and production of fuels, including production of fuel with low volatile organic content for long term storage.

6.2.3 DTU Chemical Engineering (CHEC)

DTU Chemical Engineering and its Center for Harmful Emissions Control (CHEC) is dealing with research, education and development with respect to entrained flow and fluidized bed gasification. Additionally subjects as gas conditioning, synthesis of liquid fuels and pre-treatment of biomass are also included in research projects conducted at DTU Chemical Engineering.

Some technologies presently under investigation at DTU Chemical Engineering:

- Entrained flow gasification. Studies are conducted with respect to biomass conversion and gas products characterisation as a function of feedstock and operating conditions
- LT-CFB. Gasifier for high alkali biomass that supply the gas to a boiler. A PhD project regarding ash transformation is initiated together with DONG energy and DTU Risø
- Development of catalysts for the synthesis of liquid fuels
- Pre-treatment of biomass with the objective to provide a product that easily can be injected into a pressurised gasifier

DTU Chemical Engineering has given a perspective on the background for their work including their view on the market development, please refer to Annex 3 - List of Danish gasification R&D projects.

6.2.4 FORCE Technology

FORCE Technology is a private non-profit company in the Advanced Technology Group and has over the years participated in a number of R&D projects within gasification of biomass. FORCE Technology has often been monitoring the process or technology operation as well as the technology feasibility and market opportunities. The list of R&D projects in Annex 3 - List of Danish gasification R&D projects holds more information.

6.2.5 Risø DTU

The Biomass Gasification Group at the technical university has played a major role in the development of gasification technologies and more concepts have been conceived here during a period of around 20 years. The group has a practical approach to development and develops the necessary scientific knowledge as the concepts develop.

6.2.6 Other R&D institutions

Other institutions than the above mentioned work with biomass gasification or aspects or perspectives within biomass gasification. At the University of Copenhagen (KU Life) there is research in handling and recycling of ash from biomass conversion technologies. Some of the other companies in the Advanced Technology Group are planning to enter into the gasification area.

7 Market for biomass gasification technologies for energy purposes

Thermal biomass gasification technology has historically been developed to meet a local or regional demand for generation of biomass based electricity and possibly on the basis of a heat demand - for district heating.

In an energy system which increasingly focuses on becoming independent from fossil fuels and thus applies a large share of inconstant energy sources like wind energy, balancing power becomes even more interesting. Ultimately, biomass gasification technologies might be close to the perfect match in such an electricity based energy system with a clever application of the gas grid and gas storage facilities as backup.

Figure 1 shows (in Danish) a vision of how such a system could be designed and how the flexibility of gasification technologies can make it all work. The blue flow is electricity, the yellow is gas storage and transmission, the green flow is biomass, waste and biofuel and the red is heat - district heating. When the electricity price is low (when the wind blows), electricity is used to generate gas to be stored. Depending on the demand and the situation at the fluctuating supply technologies (wind), gas is used to generate electricity, liquid fuel or methane (bioSNG) and heat.

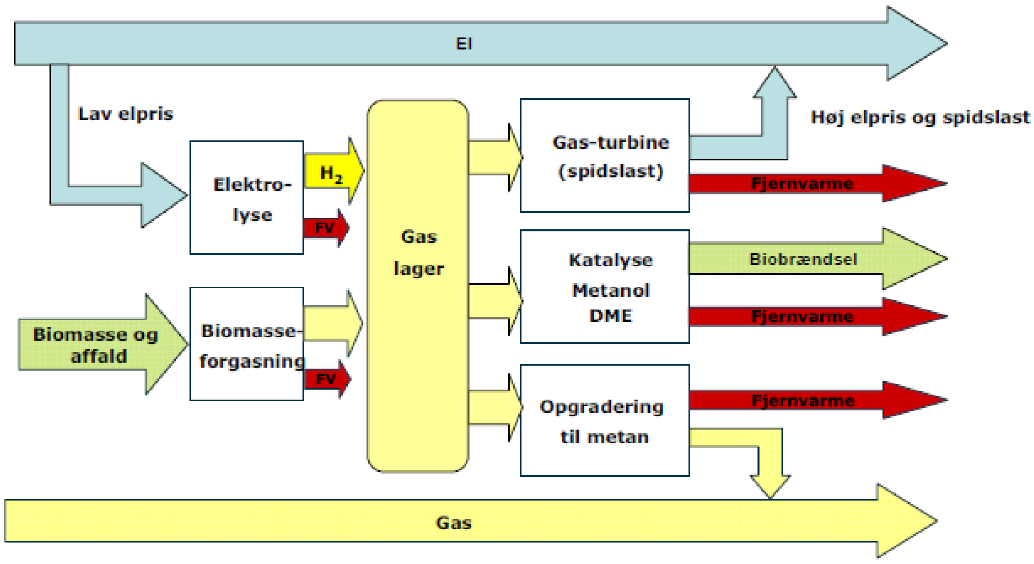


Figure 1. Perspectives for integration of renewable energy sources in the gas system (Energinet.dk, 2010).

Gasification technology can furthermore be a key to substitute fossil fuels by biomass in industry. Apart from using the synthesis gas in a gas engine to produce electricity, the synthesis gas can also be used as fuel in an existing boiler, producing steam for the process or for electricity via a steam turbine. Depending on the biomass type available, different gasification processes with high or low temperature can be used.

The following paragraphs go into detail with the markets for CHP technologies and technologies for fuel generation.

7.1 Market feedback from the suppliers

In the questionnaire the technology suppliers have indicated the immediate market size by mentioning how many plants they expect to have delivered by 2020 and to which contries or regions.

Accumulated, these indications show a large market. Seven suppliers of CHP technology expect to sell a total of 2,200 plants the majority being small plants and around 100 medium sized and large plants. Only two suppliers in the group of suppliers of gasifiers and auxiliary technology for fuel generation have replied to this point. They expect to sell a total of around 50 plants. The markets mentioned are worldwide.

In (Hansen, 2010) the suppliers of CHP technology along with the interviewed technology users of mention that there is a very big interest of plants in the lower part of the scale:

- We get incredibly many inquiries regarding power production from biomass-fuelled plants
- The framework conditions are good in many countries
- Enormous need in the developing countries for stand-alone power plants which can function in places with no electricity network.

The expectation to the development of the market is positive from all respondents who answer the questions

7.2 Market for biomass CHP technologies

The global production of electricity at electricity plants was 62 EJ (10^{18} Joule). In the OECD countries the production was app. half of the global production (IEA, 2010). The Danish production of electricity was 124 PJ in 2009 (Danish Energy Agency).

A large part of the Danish electricity production has traditionally been coal dust fired central power plants and CHP plants and natural gas fired decentral CHP plants. Wood pellet combustion replaces coal in dust fired central plants but when it comes to the smaller decentralized CHP plants fired with natural gas, a renewable energy technology is still missing.

Gasification of biomass is a possible technology to replace the natural gas in these plants but a commercial break through is still to come. Another part of the market for biomass CHP is the industry. The industry can use own-produced electricity, steam and heat for heating of buildings and water and for the industrial processes such as direct drying by natural gas burners. The industry is using coal, oil and natural gas for these purposes. It can be interesting for the industry to use own biomass residues as a fuel to replace the fossil fuels and gasification can be a relevant technology for instance by feeding an existing boiler with syn-gas from a separate gasifier.

The market is at the moment in its first stages. In Denmark, DONG Energy has built and initially operated a demonstration plant comprising a 6 MW gasifier for co-firing a coal fired power plant boiler, and intend to build a full scale version during the next 4 years. On basis of recent tests in lab scale, DONG Energy expects that the same type of gasifier, with just a little more intensive gas cleaning can be used in combination with natural gas fired boilers. Both of the concepts can also be implemented at smaller industrial boiler plants.

In Sweden, a contract on 12 years delivery of synthesis gas to a cement factory, Nordkalk, in Köping was signed recently. A test plant of 500 kW is being built and the first plant at the cement factory will be 5 MW and cost app. 60 mio SEK. In order to fulfill the contract, the plant shall be expanded to 25 MW. It is expected to give savings to the cement factory of 10 mio SEK per year and reduce the CO2-emission with 70 000 tons compared with the present emission from use of oil.

(Hansen, 2010) describes the market for solid biomass CHP technologies seen from a Danish perspective. A part of the market description is translated below. The purpose of the paragraph is to indicate the market for biomass CHP technologies. There is no specific focus on gasification, the logic being that a large share of this market can be covered by technologies applying thermal gasification of biomass.

7.2.1 The market in Europe seen from above

The market for CHP technology for solid biomass can be illustrated in many ways and is very varied with many sizes of plants, many different technologies and many different types of fuel. But generally and in a top-down approach, the EU renewable energy directive and the target for 2020 set the agenda.

The RE directive lays down a common framework for the promotion of energy from renewable energy sources. It sets compulsory national targets for the total share of energy from renewable energy sources in the final gross energy consumption as well as for the share of energy from renewable energy sources within transport.

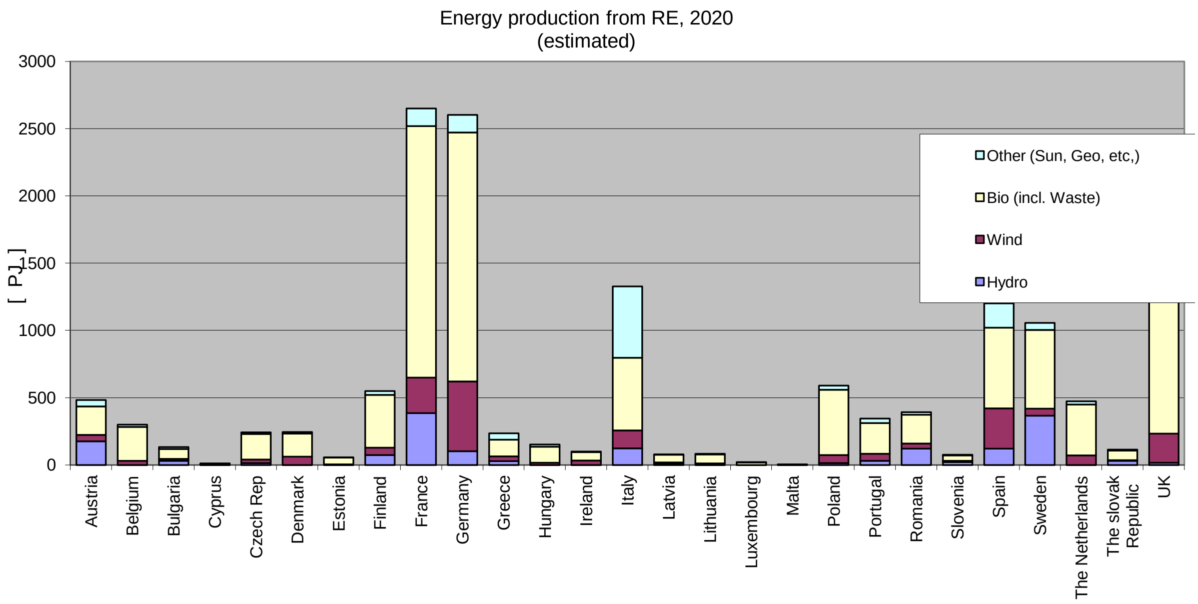


Figure 2. Analysis of how the RE sources can contribute to reach the 20-20-20 targets. Source: FORCE Technology

For each country, the directive decides concrete targets for the size of the energy consumption which has to be covered by RE in 2020. FORCE Technology has analyzed the conception of how the energy mix will be in each country and thus which consequences the RE target might have for the use of solid biomass in the EU countries.

The analysis lists how hydro power, wind power, solar energy, geothermal energy and biomass including waste all together can contribute to reach the target. The analysis is rather conservative with regard to the biomass as it calculates with very high rates of increase in the other categories.

Figure 2 shows how much energy the countries have to generate from renewable energy sources and how the energy sources might be divided. The figures are gross figures including electricity as well as heat production.

As mentioned, the analysis operates with heavy increases on the alternatives to solid biomass but it also lays down the approach that it might be less likely that we will see a heavy and fast increase within this RE type here if nothing has happened earlier within the area in a certain country.

This approach implies of course the risk that new ambitious changes of the framework conditions in certain countries can disturb the picture. But as even very large increases in the contribution from alternative RE technologies still leaves an enormous need for energy from biomass and waste, the picture can be described as very robust. In any case, there will be a very large need for energy from biomass and thus for the technology.

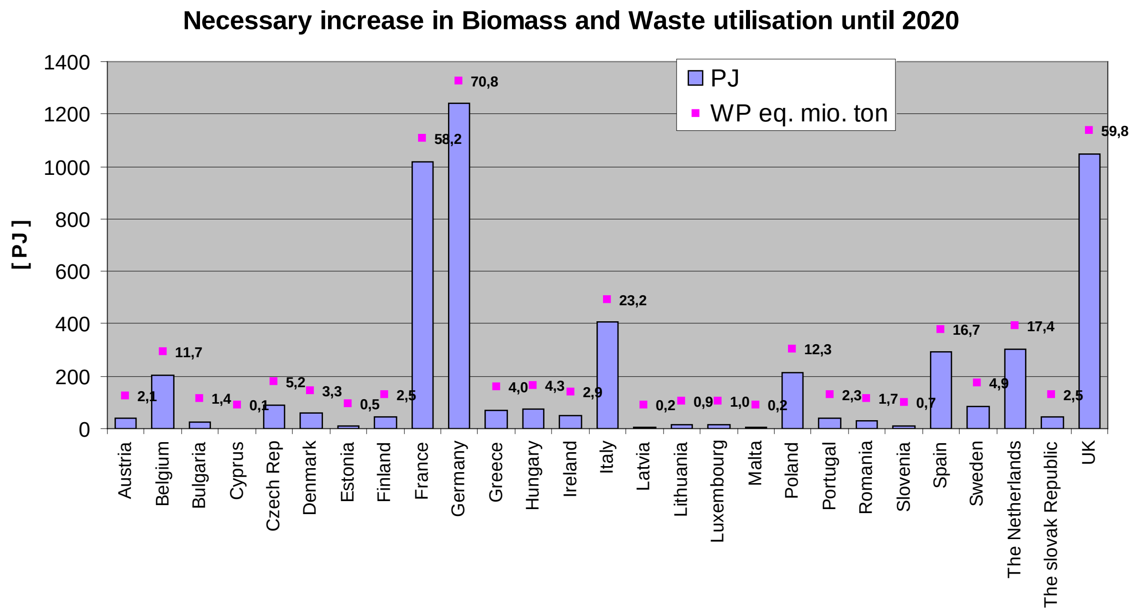


Figure 3. Analysis of the possibly necessary increase in the utilisation of biomass and waste in order to reach the 20-20-20 targets (WP eq.: wood pellet equivalents). Source: FORCE Technology

In Figure 3, it is stated how big an increase in the utilisation of biomass and waste which is needed in order that every country can meet the need in Figure 2. For the EU 27, there is as a whole a need for an increase of well over 4,000 PJ from biomass until 2020.

In the figure, it is furthermore stated how many million tons of dried wood this would correspond to. For the EU 27, as a whole, there is a need for an increase of approx. 240 million tons. By way of comparison, the present global consumption of wood pellets is approx. 12 million tons annually.

7.2.2 The renewable energy action plans of the EU countries

30 June 2010 was the deadline where each EU country had to deliver their action plan for how they will comply with the 20-20-20 target.

To some extent, the renewable energy action plans concretise the markets for biomass CHP technologies. A short review of the plans from the countries which Danish CHP suppliers have appointed as particularly interesting can be seen in (Hansen, 2010).

Seen as a whole, the nine countries for which the RE action plans have been referred plan an increase in the installed power capacity based on solid biomass of 7.2 GW(e) and an increase in the electricity production of 153 PJ towards 2020. In these totals, contributions are still missing from countries which are expected to contribute considerably to further increases.

At the anniversary of DI Bioenergi 6 October 2010 the European biomass association, AEBIOM, presented the temporary situation for the national renewable energy action plans (AEBIOM, 2010).

AEBIOM expects that district heating as well as CHP will grow in Germany, Italy, Sweden, and the UK. Furthermore, a big market for individual heating with bioenergy is expected in the four countries. For AEBIOM as a whole with its twenty national member organizations it means more than 24 million ton of biomass of which the major part is expected to come from agriculture rather than forestry.

Even if it will be the market conditions that decide whether the individual EU countries will have to import biomass it is interesting to note that a number of countries will be able to cover their fuel needs with domestic resources while other countries seem to have to be prepared for import of biomass. Seen as a whole it can be noted that the annual electrical efficiency is important for how much the domestic resources will be sufficient to cover the electricity need. An increase from an average of 20% to an average of 30% will have a substantial effect.

For detailed information about the plans, it can be recommended to visit the Commission's homepage (EC, 2010) where the plans are available. The page is called the transparency platform and can be found via the link in the reference list.

7.2.3 Markets outside the EU

Russia and the North American countries have enormous forest resources and are typically seen as important suppliers of wood fuels, including especially wood pellets, to among others the European consumers.

7.2.3.1 The USA and Canada

In the USA, during the recent years, enormous wood pellet factories have been commissioned. The large factories are primarily situated in the southeastern states which are rich of forests and plantations and at places where the logistics for the raw material are established in connection with the paper industry and where the logistics are in place for the finished product - easy access to the Atlantic Ocean and transport to Europe.

A number of the factories are built with European-based capital (among others by Swedish and German investors) and with the aim to supply the European market with fuel for co-firing with coal at large power stations in the Netherlands, Belgium, Sweden, and Denmark. At the same time, the factories are well placed to be able to supply a growing home market which especially develops along the east coast.

Also in Canada, a large, new pellet production capacity shoots up. The total annual production capacity in North America reached in 2009 6.2 million ton – an increase from 1.1 million ton in 2003 through 4.2 million ton in 2008.

The factories in Canada are mainly placed in the western part and the production is highly based on the enormous amount of wood which is affected by beetle attacks and will not survive. The market for the Canadian pellets is also power stations in the western part of Europe but British Columbia is for example hampered by substantially higher transport costs (through the Panama Canal or south of South America).

The home market for biomass in North America is growing. This development is not that visible at the federal level where there only exist a few coordinated activities but on the state level activities are increasing. Several Danish-based suppliers report about an increasing number of inquiries and Danish-based companies have initiated cooperation with North American partners (BWE, 2010). Both power plant technology and auxiliary equipment are in great demand and many inquiries include complete energy systems and therefore there is a need of system consultancy in which Danish companies are experienced. Thus, the established cooperations are also found both at suppliers of CHP technology and at consultants within for instance the district heating area. A focus on precisely the district heating area will contribute to increase the demand for CHP solutions.

Even if Canada is a large coal consuming country and some states are very reluctant to use biomass, several states work with large biomass plans. As an example of this, Ontario will phase out the use of coal during 20 years according to (WPAC, 2009). One of the ways to do this is biomass. In this connection, the largest coal-fired power station, Ontario Power Generation - Nanticoke Generating Station having an installed capacity with a size of the total capacity in Denmark, shall among others be fully changed to biofuels during the next four years (IEA-Bioenergy, 2009).

Also in the USA, large coal-fired plants work with total or partly change to biomass heating. As an example, Ohio Edison wants to change one plant to 80% biomass in 2012 (WPAC, 2009).

7.2.3.2 Russia

In the north-western Russia there are huge wood resources which among others can be seen in Figure 4. The picture shows the forest stand in Europe and it is clear that there are massive wood resources in the North and Russia. For the time being a number of activities take place within the fuel area, among others many new wood pellet producers shoot up, including the world's largest wood pellet factory in Vyborg close to St Petersborg. The factories are to provide the growing Western European wood pellet market.

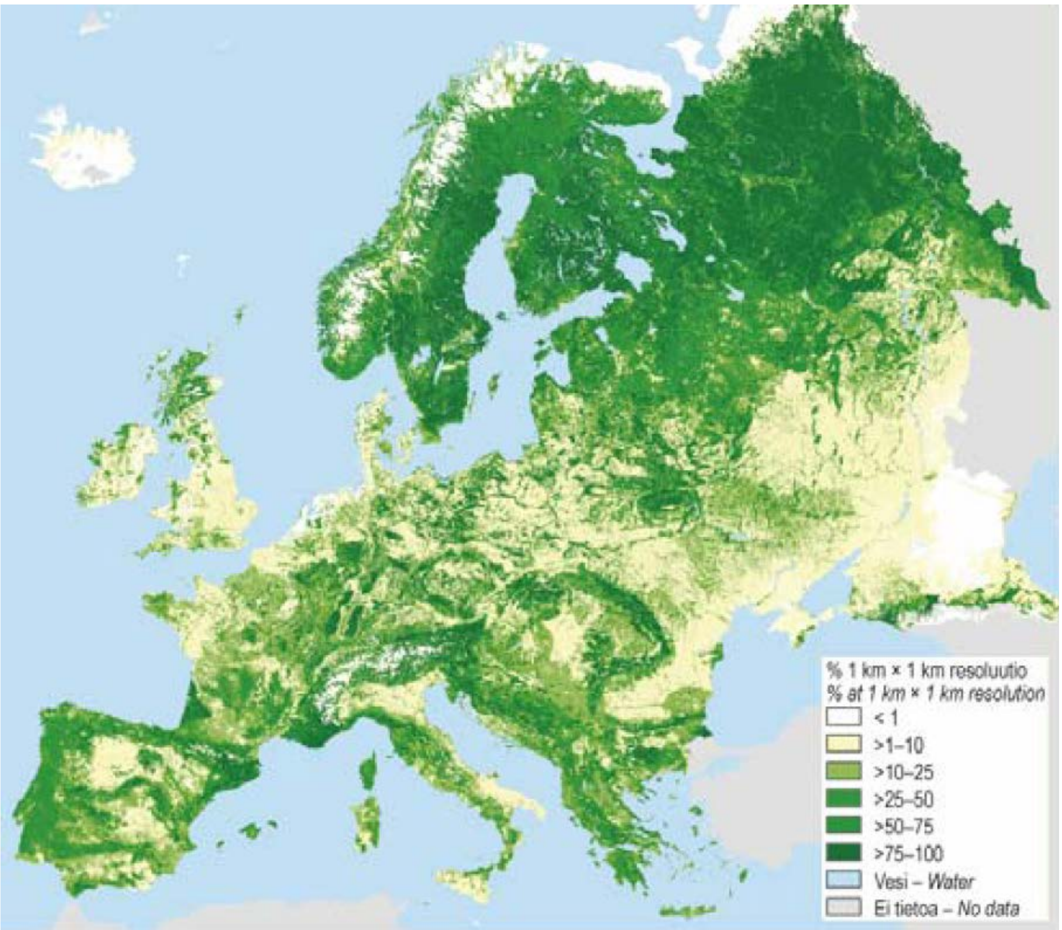


Figure 4. Forest stand in Europe. Source: Andreas Schuck, European Forest Institute, 2002

There is no big tradition to exploit the Russian biomass resources for energy purposes nationally. However, there is increasing interest in renewable energy after Russia has prepared an energy strategy and has passed a law of energy efficiency as well as introduced reporting on savings on energy.

Foreign investors are often reluctant to start up activities in Russia where the business culture according to (Grove, 2010) can appear different than in other parts of the world.

7.2.3.3 The East

India and China are important future biomass consumers and just like other countries they would have to use modern and effective technology. However, the question is whether the markets are interesting for Danish-based companies. As it can be seen in (Hansen, 2010), Chinese companies with purchase of Danish companies are far ahead when it comes to use of Danish core discipline within biomass conversion.

For the time being, this technology has been taken into use in 19 commercial power stations in China. Further ten stations are under construction and 13 stations are planned to be started in 2010. In 2013 Dragon Power expects that 100 biomass plants with a total capacity of 3 GW are in operation (Information, 2010).

Indian companies follow a similar development by buying access to Danish energy technology. The Indian Thermax has thus in 2010 bought the Danish Danstoker says (Energy-Supply, 2010). At least one Danish gasification concept – the staged down-draft gasifier - has been transferred to an Indian university.

7.3 Market for gasification technologies for production of energy carriers

Apart from producing heat and power, gasification gas and pyrolysis oil can be used as energy carrier. Synthetic Natural Gas, biofuel for transport and compressing gasification gas in gas store tanks for household use are examples.

(Hofbauer, 2009) gives a simple overview of products that can be generated by gasification of biomass, see Figure 5. Today, the products are generated from fossil fuels. Biomass can by gasification be transformed to products that may be easier to handle than the biomass itself. By choosing the right type of gasification process and after treatment, different products can be obtained. The treatment can include gas cleaning, not only for removing particles and tar, but also for removing chlorine and sulphur compounds. This makes of course the process more complex.

As gasification is a thermal conversion process heat is always generated and should be one of the products. This however can be considered a challenge. Experience from heat and power generation shows that finding a heat market is not always possible. Apart from heat, an off-gas is also produced from many of the processes, and this can be used for power production. Gasification plants where biofuels or other gasification products are produced along with heat and electricity is referred to as “polygeneration” plants.

In 2009 it was concluded by (Hofbauer, 2009) that “electricity production from gasification of biomass cannot compete at the market especially with combustion based technologies, since the production costs for electricity are not lower than for the more reliable combustion technology”. But that “the situation was different for synthetic bio-products such as synthetic bio-fuels. In this area there is no comparable competitor from the renewable side and the gap to the market price is even smaller than for electricity”.

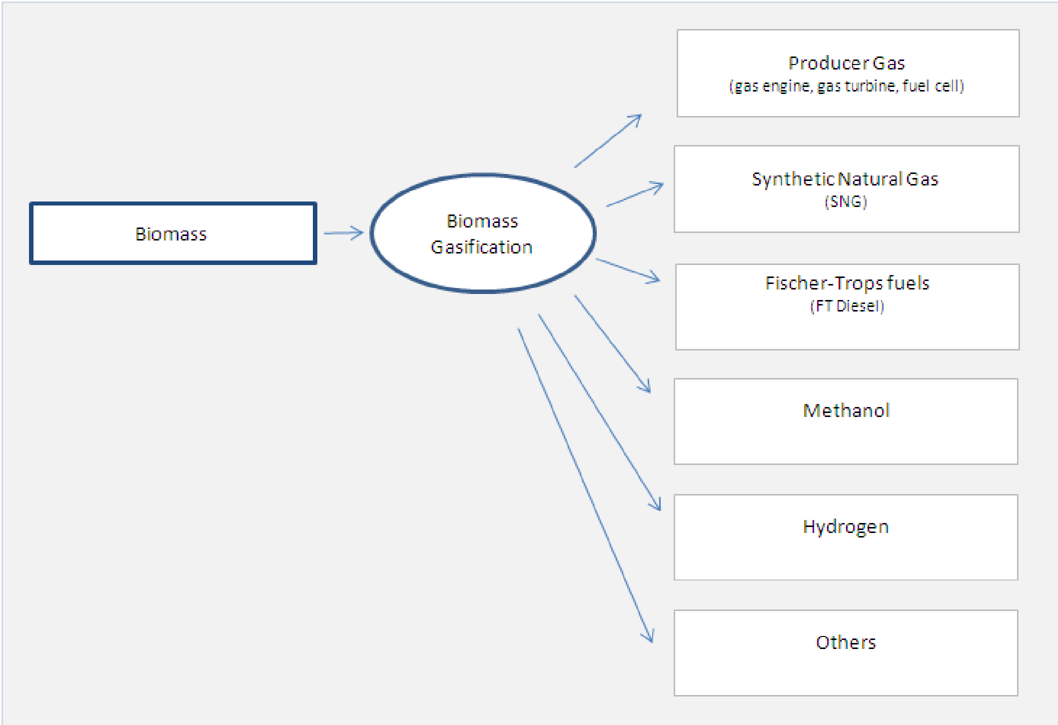


Figure 5. Simple overview of products that can be generated from gasification of biomass. After (Hofbauer, 2009)

7.3.1 Synthetic Natural Gas, SNG

Natural gas is widely used today in stationary installations producing power, heat and steam and in cities for kitchen gas stoves and heaters for hot utility water. Natural gas is also used for transport, in Sweden for instance natural gas buses are used in some of the larger cities. Natural gas is not as widely used for transport as it is used in stationary installations.

The world market for natural gas expressed as Total Primary Energy Supply was according to (IEA, 2010) 2,591 Mtoe or 108 EJ (ExaJoule, 10^{18} Joule). Approximately half of this was in the OECD countries. The Danish market for natural gas was 165 PJ in 2009.

Synthetic natural gas, SNG, can be produced by gasification of coal. When phasing out fossil fuels biomass gasification gas is seen as a possible substitute for natural gas. Gasification gas however has to undergo purification and up grading such as methanisation before it can replace natural gas.

New routes for the production from SNG from renewable energy are described by (Sterner, 2011). Two routes involving biomass are described.

Fermentative route:

Digestive biomass ⟶ Biogas ⟶ Gas cleaning/conditioning ⟶ SNG

Thermo-chemical route:

Biomass → Gasification gas/Synthesis gas → Upgrading/ Methanisation of COx → SNG

An argument for introducing gasification gas in the natural gas system is that large amounts of energy can be stored across seasons in the existing gas storage system.

(Sterner, 2011) studied the German natural gas system. The storage capacity of the German natural gas system was 217 TWh, leading to a calculated operating range of installed capacity of 2,000 hours. For comparison, Electricity storage capacity by pumped hydro storage was only 0.04 TWh which lead to a calculated range of installed capacity of 0.6 hours. The storage capacity of liquid fuels was 250 TWh giving 3,100 hours of calculated range of installed capacity. It is obvious that liquid fuels and gas fuels can be stored for longer time than electricity.

Denmark also has a well established natural gas system with larger storage capacities and a calculation could show the potential for storage of gasification gas in Denmark but it is not made in this report. The storage capacity in Denmark is app. 10^9 Nm^3 natural gas or app. 11 TWh (Vestervang, 23/6-2011) or app. 40 PJ. The cost for storing is app. 0,5 DKK per kWh of methane. Compared with the yearly comsumption of 165 PJ natural gas, the storage capacity in Denmark is app. 2,100 hours or nearly 3 months.

In (Ahrenfeldt, et al., 2010) the Bio-SNG potential in Denmark is assessed. The consumption of natural gas was 165 PJ in Denmark in 2009 out of a total energy consumption of 810 PJ. The authors evaluated different scenarios for the biomass potential in 2020. A scenario based on a more environmentally concerned and sustainable agricultural management would according to their evaluations be able to deliver almost 145 PJ of biomass from Danish sources.

Another study (Evald, 2010) questions the realism of resource studies since they often only look at the technological aspect. That means they count the available resources without looking into questions of whether it is economically feasible and environmentally sustainable to utilize the resource. He concluded that it is most likely that a large share of the biomass necessary for energy in Denmark will be imported in the years to come. In the Danish RE action plan the expected domestic resources are estimated to approx. 90 PJ in 2015 and approx. 100 PJ in 2020. To this must be added an expected import of biomass from forestry of approx. 30 PJ in 2015 and of approx. 40 PJ in 2020.

Even if all 100 PJ of Danish biomass forecast for 2020 was converted to bio-SNG it would not cover the natural gas consumption of 2009 of 165 PJ.

(Ahrenfeldt, et al., 2010) refer a Swedish study of the efficiency of different gasifiers, methanisation systems and upgrading technologies combined in different ways. The combinations were evaluated by literature study and detailed calculations. The SNG efficiency was defined as the energy in the SNG product divided by the total input to the system from biomass, drying and oxygen production. The efficiency varied between app. 50 and 70%. The energy loss and use of energy in percent of total input varied between

10% and 25%. It seems that tar removal was not included in the calculations. When the produced SNG is used for electricity or heat generation, energy loss similar to energy loss from conversion of natural gas must be expected.

The solid biomass itself can also be stored for longer time. So why gasify the solid biomass and then store the gas, instead of storing the biomass itself, and then burn or gasify directly to produce electricity when electricity is needed?

Gas-fired installations can be faster to regulate than installations fired with solid biomass. Furthermore the industry and households already invested in gas installations. From a society point of view it may be attractive to build fewer installations to gasify solid biomass, to purify and eventually upgrade the gasification gas to synthetic natural gas than to replace all the gas installations with installation for solid biomass.

From the plant owners point of view, gasifying biomass and storing the the gas in some form provides for many annual operational hours of a plant. This is important for the feasibility of the investment. In a wind energy based energy system back-up capacity would otherwise have to operate only at a limited number of hours through a normal year.

A combination of the two ways may be an advantage, having both facilities for burning solid biomass producing electricity and heat directly and having facilities for gasifying solid biomass producing a gas that can be stored before converted to electricity or heat at the end consumer.

A large scale project in Sweden is an example of SNG production from gasification of solid biomass including residues from the forestry. The project is called Gothenburg Biomass Gasification Project, in short GoBiGas.

Göteborg Energi cooperates with E.on in the project. Göteborg Energi is an energy company in the city of Gothenburg (Göteborg) in Western Sweden providing district heating, ready heat, energy services, cooling, gas, optical fibres and Electricity supply network.

The gasification gas from the project GoBiGas will be used as fuel for vehicles, industrial processes and combined heat and power (CHP). The gasification facility will be designed for app. 100 MW gas and an expected yearly production of app. 800 GWh/year.

The gasification facility is planned to be built in two steps, the first step (app. 20 MW) is built in 2009–2011 and starting operation in 2012. The second step (app. 80 MW) is planned to be built in 2013–2015 and starting operation in 2016.

7.3.2 Liquid biofuels for transport

The total primary energy supply of crude oil in the world was 4,145 Mtoe or 174 EJ in 2008 according to (IEA, 2010). The main part was transformed to oil products in refineries and 2,150 Mtoe or 90 EJ was then used for transport, including aviation and marine transport. App. half of this was in the OECD countries. In Denmark 208 PJ oil products were used for transport (Danish Energy Agency).

When phasing out fossil fuels the transport sector will need alternatives. One alternative is SNG as described above. Electric vehicles and hydrogen driven vehicles are other possible alternatives, but both will demand larger changes in the infra structure in order to fuel or load the vehicles with electricity or hydrogen. Loading with electricity takes several hours unless one changes the whole battery and hydrogen is an explosive gas that needs to be stored either under pressure or in other ways that takes up less space and is secure. Furthermore electricity and hydrogen may not be ideal energy sources for ship transport and air traffic.

Liquid fuels produced from solid biomass are seen as an important alternative to fossil fuels in the transport sector. Liquid biofuels can quite uncomplicated fit into the existing infra structure for the transport sector since it can be stored and tanked in the same way as gasoline and diesel. The transport sector of Brazil uses a very high share of ethanol produced from sugar cane and is an example of how the technological and practical problems of fitting liquid biofuels into the infra structure can be overcome.

By gasification or pyrolysis of biomass a gasification gas or a liquid pyrolysis oil is produced. By further treatment the gasification gas or the pyrolysis oil can be formed into liquid biofuels such as ethanol, methanol, DME, biodiesel or other liquid products. The biofuels can replace the fossil gasoline and diesel used in combustion engines, diesel engines and turbines in the transport sector.

(Hofbauer, 2009) mentions a demonstration project for biomass to Fischer-Tropsch liquids carried out by Chroren Industries together with Shell. They offer large scale plants and intend to realize the first industrial plant within 2014. The process consists of a three stage gasifier, a gas cleaning and treatment section for syngas and the Fishcer-Tropsch synthesis followed by a hydro-cracking step to get a biofuel ready for diesel engines. The Fischer-Tropsch is operated at a pressure of app. 30 bars and converts a mixture of hydrogen and CO to a mixture of hydrocarbons, mainly straight-chained alcanes. During 2011 the company has been declared insolvent due to funding difficulties at the commission of the syngas demonstration plant.

Biofuels can also be produced from biomass by enzymatic processes.

(Slade, et al., 2009) describe the market deployment of a liquid biofuel: Lignocellulosic ethanol. When looking at the market for biofuel several questions are relevant.

The question of whether it is possible to use residual products from agriculture and forestry is relevant for all uses of biomass for energy. In the case of producing liquid biofuels, the choice of technology depends on the choice of raw material. Technology is well known and demonstrated for so called first generation biofuels, where sugar rich or starch rich food products as sugar cane, wheat grain or maize is used as raw material.

Technologies for second generation biofuels, where residue products like straw, thinning wood, shells and the like is used, is currently under development and demonstration.

Turnkey solutions for second generation biofuel production are not yet offered by any large well established engineering companies.

Investors tend to be less interested in investing in demonstration projects since it can be expensive and high-risk investments. More investors are seen to invest in the bio-tech side: new bacteria, enzymes, fermentations processes etc.

The price of the finished biofuel product is essential to the down stream market such as oil companies. They have to see if the price of biofuel can compete with fossil fuel. Political protection of the market for green biofuel can increase the interest and competitiveness.

In Denmark, the oil company Statoil now buys second generation bioethanol from the Danish company Inbicon, owned by DONG Energy, one of the large energy companies in Denmark. Statoil blends the ethanol into their gasoline.

7.3.3 Liquid biofuels in national renewable action plans

Article 4 of the renewable energy Directive (2009/28/EC) required Member States to submit national renewable energy action plans by 30 June 2010. These plans, to be prepared in accordance with the template published by the Commission, provide detailed roadmaps of how each Member State expects to reach its legally binding 2020 target for the share of renewable energy in their final energy consumption. For selected countries we look at how liquid biofuels are mentioned.

7.3.3.1 Germany

Germany has legislation to implement the political targets for biofuels, called the Biofuels Quota Act (BioKraftQuG). It legislates on the minimum share of biofuels of total fuel put into circulation, and tax incentive for certain biofuels. The target group is companies bringing fuel to market. The BioKraftQuG Started in 2007 and will have a duration beyond 2020. Tax intensives for certain biofuels will be a part until the end of 2015.

The consumption of energy from renewable sources in the transport sector was 3,749 ktoe in 2010 and is expected to be 3,479 (less than 2010!) in 2015 and 6,140 ktoe in 2020 in Germany, see Table 1 below. The figures include all renewable sources in the transport sector, including electricity, hydrogen, renewable gas and biofuels not meeting the sustainability criteria of Directive 2009/28/EC. Biofuels meeting the sustainability criteria had a share of 98 ktoe in 2010 and are expected to rise to 133 and then 155 ktoe in 2015 and 2020.

Table 1. Renewables in the transport sector in Germany

Germany. Transport sector	2010	2015	2020
	Ktoe		
Expected final consumption of energy from renewable sources in transport *(1)*	3749	3479	6140
Biomass: Liquid biofuels from wastes, residues, non-food cellulosic material and lignocellulosic material in transport *(2)*	98	133	155

(1) *Here all renewable energy sources used in the transport sector are considered, including electricity, hydrogen, renewable gas and biofuels only that do not meet sustainability criteria. Actual values are specified without applying multiplication factors*

(2) *Here actual figures are specified without applying multiplication factors*

In Germany, liquid biofuels are used in the electricity sector as well, but the consumption is not expected to rise to more than the 2010-level, see Table 2 below.

Table 2. Renewables in the electricity sector in Germany

Germany. Electricity sector	2010		2015		2020	
	MW	GWh	MW	GWh	MW	GWh
Liquid biofuels *(1)*	237	1450	237	1450	237	1450

(1) Only those are taken into account which meet the sustainability criteria, Directive 2009/28/EC, Article 5(1), last subparagraph

7.3.3.2 UK

Regarding measures for achieving the targets on liquid biofuels UK has a Renewable Transport Fuel Obligation (RTFO). It is a regulatory measure and the expected result is to increase the proportion of renewable fuel in road fuel. The target group is fuel suppliers. The RTFO started in 2008 and is ongoing. Another initiative is the Green Bus Fund which is a financial measure with investors and end users as target group. The Green Bus Fund started 2009 and ends 2012.

The expected final consumption of energy from renewable sources in transport is shown in Table 3 below. The liquid biofuel is expected to consist of bioenthanol/bio-ETBE and biodiesel, mainly imported.

Table 3. Renewables in the transport sector in the UK

UK. Transport sector	2010	2015	2020
	Ktoe		
Expected final consumption of energy from renewable sources in transport	1066	2581	4251
Biomass: Liquid biofuels from wastes, residues, non-food cellulosic material and lignocellulosic material in transport	0	0	0

Regarding biofuels used in the electricity sector, it has not been possible for UK to give estimates.

Table 4. Renewables in the electricity sector in the UK

UK Electricity sector	2010		2015		2020	
	MW	GWh	MW	GWh	MW	GWh
Liquid biofuels	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.

n.e. No estimates are currently available for biofuels

7.3.3.3 Italy

A minimum qutoa for transport biofuel use is one of the measures used in Italy to promote the use of energy from renewable sources. The regulatory measure was started in 2007 and no end date is set. The expected result is that 4.5% of transport biofuels are fed into the network in 2012 and the target group is parties which make fuels available for consumption for automotive purposes. Another initiative is a reduction in excise for biofuels. This regulatory initiative started in 1995 and ends in 2010 and is addressing investors.

Italy expects the final consumption of energy from renewable sources in transport to increase from 1,020 in 2010 to 2,530 in 2020. When detailing this, Italy has stated the gross consumption in a table above in the report. FORCE Technology has calculated the final consumption for liquid biofuels assuming same efficiency factor of 0.85 as Italy has used for the overall consumption.

Table 5. Renewables in the transport sector in Italy

Italy. Transport sector	2010	2015	2020
	Ktoe		
Expected final consumption of energy from renewable sources in transport	1020	1775	2530
Biomass: Liquid biofuels from wastes, residues, non-food cellulosic material and lignocellulosic material in transport *(calculated by FORCE)*	83	213	343

In Italy biofuels are expected to be used in the electricity sector as shown in Table 6 below. The major part is expected to be biodiesel and a smaller part bioethanol/bio-ETBE.

Table 6. Renewables in the electricity sector in Italy

Italy. Electricity sector	2010		2015		2020	
	MW	GWh	MW	GWh	MW	GWh
Liquid biofuels	439	1758	710	3309	980	4860

7.3.3.4 Sweden

In order to promote the use of energy from renewable sources, Sweden has several initiatives. A sulphur tax indirectly supports use of biomass since biomass usually has low sulphur content. A more direct regulation towards liquid biofuels is the obligation to supply renewable fuels, which addresses retail outlets for fuel. The regulation has existed since 2006. A financial initiative in 2007 - 2009 was grants to fuel retail outlets for investment in pumps other than ethanol. For vehicle owners there is a financial initiative in exemption from vehicle tax for environmental cars with duration from 2009 - 2012. Furthermore a regulation on environmental cars in government procurements since 2005 and parking benefits in certain towns promote liquid biofuels.

Investment support for biogas and other renewable gases gives financial support to projects that contribute to increased generation, distribution and use of renewable gases. The target group is production centres, distributors and consumers and the duration is 2009 - 2011.

Sweden expects the major part of liquid biofuels to be bioethanol/bio-ETBE and biodiesel to be a minor part. Ethanol production will take place in Sweden by Agro-ethanol in

Norrköping (estimated production of 210,000 m3 in 2010). For 2012 it is assumed that Nordisk Etanolproduktion will start production at full capacity in Karlshamn (130,000 m3). The remainder will be imported. Liquid biofuel from gasification is not mentioned.

Table 7. Renewables in the transport sector in Sweden

Sweden. Transport sector	2010	2015	2020
	Ktoe		
Expected final consumption of energy from renewable sources in transport *(1)*	528	768	1008
Biomass: Liquid biofuels from wastes, residues, non-food cellulosic material and lignocellulosic material in transport	40	67	94

Table 8. Renewables in the electricity sector in Sweden

Sweden. Electricity sector	2010		2015		2020	
	MW	GWh	MW	GWh	MW	GWh
Liquid biofuels	-	65	-	65	-	65

7.3.3.5 Netherlands

In the Netherlands there are several initiatives to increase the use of biofuels in the transport sector: The Biofuels obligation, a regulatory measure, addressing traders in transport fuels. Financial support to filling stations for alternative fuels has the target to increase the installed capacity and has the sales organizations for transport fuels as target group. Financial support for innovative biofuels addresses producers of biofuels and likewise aims at increasing the installed capacity.

The expected final consumption of energy from renewable sources in transport increases from 319 Ktoe in 2010 to 905 Ktoe in 2020. The main part of this is expected to be bioethanol/bio-ETBE and biodiesel, the latter is expected to increase the most.

No liquid biofuels are expected to be used in the electricity sector of the Netherlands.

Table 9. Renewables in the transport sector in the Netherlands

Netherlands. Transport sector	2010	2015	2020
	Ktoe		
Expected final consumption of energy from renewable sources in transport	319	591	905
Biomass: Liquid biofuels from wastes, residues, non-food cellulosic material and lignocellulosic material in transport	156	92	155

Table 10 Renewables in the electricity sector in the Netherlands

Netherlands. Electricity sector	2010		2015		2020	
	MW	GWh	MW	GWh	MW	GWh
Liquid biofuels	0	0	0	0	0	0

7.3.3.6 Denmark

In Denmark different initiatives aim at stimulating the use of liquid biofuels. The Act on Sustainable Biofuels is a regulation on mixing sustainbal biofuel with petrol and diesel that was started up in 2010. It addresses importers, producers and sellers of petro or diesel. Exemption from CO2 tax for biofuels addresses producers and consumers of petrol or diesel and is an existing economic measure. In order to stimulate research in biofuels and other energy technologies economic support to projects are given through the Energy Technology Development and Demonstration Programme. It started in 2008 and is ongoing. A planned initiative is changes in vehicle taxation.

The expected final consumption of energy from renewable sources in transport is expected to increase from 42 Ktoe in 2010 to 266 ktoe already in 2015 and 291 Ktoe (12 PJ) in 2020. The total consumption of fossil oil products for transport was 208 PJ in Denmark in 2009. That means the expected final consumption of energy from renewable sources in Danish transport of 12 PJ in 2020 corresponds to app. 6% of of fossil oilproducts sonsumed for transport in 2009.

Of the final consumption of energy from renewable sources in 2020, liquid biofuels from wastes etc. was 0 in 2010 but is expected to increase especially in the years after 2015. Of this the main part is expected to be bioethanol/bio-ETBE and Biodiesel while a minor part is expected to be renewable electricity in the transport sector.

In the electricity sector a minor use of liquid biofuels is expected.

Table 11. Renewables in the transport sector in Denmark

Denmark. Transport sector	2010	2015	2020
	Ktoe		
Expected final consumption of energy from renewable sources in transport	42	266	291
Biomass: Liquid biofuels from wastes, residues, non-food cellulosic material and lignocellulosic material in transport	0	21	131

Table 12. Renewables in the electricity sector in Denmark

Denmark. Electricity sector	2010		2015		2020	
	MW	GWh	MW	GWh	MW	GWh
Liquid biofuels	0	0	26	1	26	8

7.4 Sustainability

Sustainability of biomass gasification as a technology will remind in many ways of sustainability of other energy utilization technologies for biomass.

In a life cycle perspective we want to point out perspectives we find of special relevance for the suppliers of gasification technology. In (Nielsen, et al., 2010) the environmental impact of technologies in the Danish production of electricity and combined heat and power is described. The report concludes that for thermal energy technologies, the production of the raw materials (the fuel) and the construction of the facility only count for a minor part of the environmental impact through the life cycle.

Raw materials for gasification facility: As for many other energy technologies mentioned in (Nielsen, et al., 2010), it must be assumed that the production of steel, concrete and other raw materials for gasification facilities only counts for a minor part of the environmental impacts in the life cycle.

Construction of gasification facility: As for many other energy technologies, it must be assumed that this counts for a minor part of the environmental impacts.

Operation of gasification facility: As for many other energy technologies, it must be assumed that this is the most important part of the life cycle regarding environmental impacts. Relevant aspects are:

Sustainability of the biomass used for energy: As for other energy utilizations of biomass, sustainability is an issue. It will mainly be the owner of the gasification facility that can decide if sustainable biomass is used.

Energy efficiency: Gasification of biomass has positive environmental impact when energy utilization of fossil fuels as coal or oil is replaced. This means that the overall energy efficiency from biomass to final product (electricity, heat, energy carrier) is very important in order to replace as much fossil fuel as possible. Both the design and construction of the gasification facility, the choise of fuel type and quality and the operation of the gasification facility will influence the energy efficiency.

Emissions: Gasification of biomass has, like other energy facilities, negative environmental impacts from emission of air pollution in the flue gas. The supplier of gasification technology and technology for emission reduction has influence on this.

Residues: Negative environmental impacts come from impurities in ash and slag. Mainly heavy metal as cadmium (Cd) is a challenge, both when combusting and gasifying biomass.

Recycling of nutrients: Regarding recycling of nutrients in ashes, this is a point where biomass gasification can be substantially different from biomass combustion. In biomass ash there is a content of plant nutrients such as phosphorus (P) and potassium (K). If the content of impurities in the ash is sufficiently low, the ash can be recycled and used as fertilizer. But the fertilizing value of the ash is typically lowered by higher combustion temperatures. Some gasification technologies are able to operate at temperature levels that are lower than normally seen at combustion and traditional gasification technologies. This seems to improve the availability of P to the plants and thereby maybe the plant utilization of the nutrients if the ashes are spread on agricultural land (Rubæk, 2007). There is a concern for phosphorus depletion which may be slowed down if phosphorus can be recycled more efficient.

Storing of carbon: Pyrolysis technologies and some gasification technologies will produce an ash with a higher content of carbon than ash from combustion.

Ash from pyrolysis reminds of char coal and can have a carbon content of 60 – 70 w%. It is often called “biochar”. (Bruun, 2009) gives an overview of effects from bringing out biochar on agricultural land. It seems that biochar has positive effects on the productiveness of the soil. It is assumed that one of the mechanisms is that biochar is very porous and the surface very large which increases adsorption ability. Another mechanism is assumed to be that the biochar through oxidation by micro organisms forms organic acids, and when positive acid ion, H^+, is split off, leaves negative ions in the soil. The negative ions are increasing the ability to bind positive nutrition ions such as K^+ and NH_4^+. This improves water retention, improves the number of micro organisms and improves the structure of the soil which again reduces leaching of nutritions and pesticides and reduces the emission of laughing gas, N_2O, and methane, CH_4 from the soil.

Ash from gasification will, as mentioned, normally have lower carbon content, the effects on agricultural land may thus be different.

There are still issues that need to be investigated before it can be said whether biochar on soil is an advantage or disadvantage. For instance it has to be considered that the more carbon content there is in the ashes, the less fossil fuel can be replaced with the biomass. There may be a balance where an increased growth of biomass and reduced greenhouse gas emissions from the soil due to biochar can “pay” for the carbon amount that goes to the biochar instead of producing energy and replacing fossil carbon.

Another issue is PAH, PolyAromatic Hydrocarbons, which can be formed during pyrolysis and gasification. Many PAH compounds are carcinogenic and there is a limit value for PAH in bio-ashes for agricultural purposes. It may be possible to control the pyrolysis and the gasification in a way that allows the limit value to be fulfilled, but more experience is needed.

End of life: As for many other energy facilities there are possibilities of recycling the materials from the construction to a large extend. The environmental impact is minor seen in a life cycle perspective.

7.5 Conclusion on markets

The markets for electricity, natural gas and liquid biofuels for transport are dominated by fossil fuels today. Table 13 below shows the production of electricity, gas and fuel for transport globally, in OECD countries and in Denmark.

Table 13. Current electricity generation, gas consumption and consumption of fuel for transportation in PJ.

	Global	OECD	Denmark
Electricity generation	62,000	33,000	124
Gas	108,000	53,000	165
Transport	90,000	47,000	208

Gasification technologies can produce electricity, heat, liquid biofuels for transport and synthetic natural gas, bioSNG and thus be a renewable alternative to the fossil fuels.

Furthermore, gasification technologies provide an excellent second leg of an energy system that integrates a large windpower capacity both seen from society and from potential investors.

In EU there is an expectation that electricity produced from biomass will double from 2010 to 2020. Gasification technology can have some benefits over other conversion technologies when sustainability is regarded.

The conclusion on the market perspectives for gasification technologies for solid biomass is very positive. The limiting factor will be the economic feasibility of the technologies which demands an efficient and reliable conversion of the biomass and the availability and supply of biomass where gasification has an advantage to other conversion technologies via the ability to convert fractions of biomass that can not be exploited for energy pursposes otherwise.

8 Biomass gasification technologies in Denmark

The annexes 1, 2 and 3 contain:

- A description of Danish based and Danish implemented gasification technologies
- A list on Danish biomass gasification plants in pilot scale, demonstration plants and commercial plants
- A list of current and recent Danish projects on biomass gasification.

The descriptions in the annexes originate directly from the suppliers and R&D institutions involved with each technology. The contents of the descriptions have not been edited, however, in cases where the technology has several representatives, inputs have been merged.

The picture drawn in the annexes is not complete. There are more technology tracks than what is documented from the suppliers. Furthermore, some suppliers have chosen not to give detailed input about their technology.

8.1 Overview of technologies

Table 14. Overview of eleven Danish biomass gasification technologies.

Name and stakeholder(s)	Technology type	Main purpose	Scale MW_{th}	Stage
Alternating Gasifier Ammongas A/S, Babcock & Wilcox Vølund A/S	Twin bed filter	Fuel (gas)	200+	Pilot
Vølund Updraft Gasifier Babcock & Wilcox Vølund A/S	Up-draft	CHP - IC engine	15-200	Commercial
The CHP system of BioSynergi BioSynergi Proces ApS	Open core down-draft	CHP - IC engine	0-15	Demonstration
Staged Down Draft Gasification Risø DTU, Weiss A/S, Dall Energy, COWI A/S	Multiple steps down-draft	CHP - IC engine	0-15	Demonstration
Pyroneer A/S DONG Energy A/S, Risø DTU, Danish Fluid Bed Technology ApS	Low temp. circulating fluid bed	CHP - cofiring Fuel (gas & liquid)	1-200	Demonstration
Close Coupled Gasification (CCG) EP Engineering ApS	Vibrating grate fluid bed	CHP - Steam engine	0-1	Pilot
Tar reforming etc. Haldor Topsøe	n.a. / "any"	Fuel (gas & liquid)	15-200+	Commercial
Catalytic low temp. pyrolysis process Organic Fuel Technology A/S	Catalytic low temperature pyrolysis	Fuel (liquid)	1-15	New/Pilot
Stirling engine with up-draft gasifier Stirling DK ApS	Up-draft	CHP - Stirling engine	0-1	Commercial
BlackCarbon Stirling DK ApS	Pyrolysis	CHP - Stirling engine	0-1	Demonstration
Biomass Gasification Gas Engine Aaen Consulting Engineers, Skive District Heating, Carbona	Circulating fluid bed	CHP - IC engine	15-200	Demonstration

Eleven biomass gasification technology tracks are covered in this work. They represent ten gasifier solutions and one supplier of downstream auxiliary equipment. The technologies are aimed at both small and large scale CHP generation as well as production of liquid or gaseous fuels. Table 14 gives an overview of the technologies.

8.1.1 Emerging gasification technologies

The existing Danish based gasification technologies are described in the annexes as mentioned above. Based on the basic knowledge and understanding of gasification processes Danish actors have produced new gasification concepts that might in the future find a place for further research and development. Emerging new technologies are not to be forgotten at a strategic level.

8.2 Screening of the biomass gasification technologies

In order to assess the potentials of the Danish biomass gasification technologies, a small group – the focusing group – has met once in Denmark. The group consists of internationally recognised gasification specialists, Bram van der Drift and Christopher Higman, and experts from FORCE Technology, Jesper Cramer and the author.

- **Bram van der Drift** (48) is a Chemical Engineer and has been working on gasification for about 15 years now at ECN in the Netherlands. This mainly involved fluidized bed processes, gas cleaning and entrained flow gasification. Since 2008, Bram is manager of the group “Syngas and SNG” in which all gasification related activities are carried out.

- **Chris Higman** is an independent consultant specializing in gasification and other syngas technologies. After eight years working in South Africa, he joined Lurgi in 1975 and worked there for over 25 years, mainly in the field of gasification. His consulting work includes gasification of coal, oil and different types of biomass. He has acted as peer reviewer for US Department of Energy Gasification R&D projects. He is co-author of the book “Gasification” and has presented papers at various conferences. He has degrees from the Universities of Oxford, UK and The Witwatersrand, South Africa.

- **Jesper Cramer** (57) is a Chemical Engineer, M.Sc. and has been working on methods for treatment of waste, solid residues and biomass incl. gasification and combustion for about 25 years now at FORCE Technology in Denmark. He has acted as project leader in several international studies on methods for treatment of waste containing heavy metals for the Danish EPA and others. He has been involved in R&D projects for gasification and combustion.

At the meeting the group has been discussing the Danish technologies in detail and the gasification industry and its perspectives in more general terms. The group has been giving valuable input both directly to the technologies via the comments and to the gasification industry at large via comments relevant for the strategic elements in this work. The basis for the discussions has been formed solely by the input from the technology suppliers and the background knowledge possessed by the group members.

8.2.1 Screening criteria

The criteria used in the assessment have been developed with basis in the project description as well as in the project proposal assessment criteria used by Energinet.dk and the Energy Development and Demonstration Programme (EUDP).

8.2.1.1 General discussion points

Given the challenges with regard to obtaining independence of fossil fuels, CO_2 mitigation and green growth (export potentials and job creation) and given a market as described in chapter 5, the group discussion focused on:

- Are the described technology tracks the right way to go seen from society?
- What is needed in terms of technical RD&D?
- Do you see any specific problems that need to be solved (news from conferences, own experience etc.)?
- Do you see any very large technical barriers for successfully reaching the goals?
- Do the technology tracks match the current and future Danish energy system?
- Do other countries have technologies readily available?

In addition, the following general issues were discussed:

- What is the general technical level in Denmark of the described gasification technologies?
- What is the standard at the R&D institutions
- What potential would the Danish based technologies have on the global market? (And is the market assessment in chapter 5 valid?)
- What is the need for cross-disciplinary actions such as
    - larger involvement between companies and research bodies
    - increased focus on basic research level (higher grants for the universities)?
    - increased focus on applied research level (increased financing for the technical service system)?

8.2.1.2 Specific technology criteria

Apart from discussing these questions at a general level, the focusing group has been screening each technology using a list of criteria.

Technical criteria

A. Technical barriers easy to overcome (if possible, division core technology and other technology)
B. Easily scalable
C. Total operational efficiency (based on the data input from the supplier)
D. High efficiency per specific cost [€/MW]

Commercial criteria

E. Market size
F. Meets a demand at a well defined customer group
G. Involves patentable technology
H. Economical growth potential

I. Job creation potential
J. Export potential
K. Current company potential

Criteria D requires further explanation:

Efficiency is an important parameter for biomass conversion technologies in order to make the investment as feasible as possible, not least within CHP technologies. However, a high efficiency should not be achieved at any cost - it should not increase the investment. Therefore, it may be useful to compare technologies on a factor that indicates the relationship between efficiency and specific investment:

$$\frac{\text{Operational efficiency } (\eta)}{\text{Investment per installed output capacity unit (€/MW)}}$$

The higher the factor, a technology can achieve, the more interesting the technology will be for the investor.

8.3 Biomass gasification technology assessment

The following paragraphs contain input from the focusing group for each technology scale. The group has been discussing each technology based on the above mentioned set of criteria.

The reader should bear in mind that this represents the view of a small group of specialists and that the assessment has been made on the input from the suppliers and the vast knowledge on gasification issues in the group. When a critical issue arises concerning a specific technology, it may be due to lack of information from the supplier. So the conclusions may be caused by lack of information. Likewise, the paragraphs should not be taken as absolute – there may very well be “empty spots”, i.e. critical issues which ought to but have not been handled by the group.

8.3.1 General view

An overview of the eleven technologies is presented in Table 15 below. Data originate from the suppliers. Although the technologies are currently at various development stages, all are quite optimistic in relation to reaching a commercial level.

In just four years more or less all technology tracks are commercially available. This is an important message to society, authorities and investors and not least to the RD&D funding schemes. The question is of course whether this is realistic for all technologies.

Table 15. Overview of the Danish biomass gasification technologies as to number of plants in operation, total number of operational hours obtained and the suppliers' expectations on when the technology will be commercially available.

	Number of plants in operation	Total hours of operation	Time to commercial (y)
Alternating Gasifier	1	50	1-2
Vølund Updraft Gasifier	4	130,000	0
The CHP system of BioSynergi	1	6,000	2-3
Staged Down Draft Gasification	2	4,000	1-2
Pyroneer A/S	4	700	>4
Close Coupled Gasification (CCG)	1	1,000	2
Tar reforming etc.	2	6,000	0
Catalytic low temp. pyrolysis process	1	300	1-2
Stirling engine with up-draft gasifier	6	12,000	0
BlackCarbon	1	2,400	2
Biomass Gasification Gas Engine (BGGE)	1	6,500	2-3

8.3.2 Technologies for small scale CHP generation

With the five technologies aimed at small scale CHP many things seem to be under control. The down draft processes produce clean gas for engine operation even though the output of char is large. Lowering the char production may be a R&D issue relevant in the scaling process.

However, scaling up a down draft gasifier is traditionally difficult and even more so if the technology applies hot moving parts. In larger scales the gas cleaning systems also might have to be enhanced. Scaling up updraft gasifiers is traditionally easier than down draft, however, work has to be done in relation to testing the fuel particle stability in order to be able to make a larger char bed. Fluidized bed type gasifiers are traditionally easier scalable.

In this size of plant it is important to operate the technology unmanned. Some of the technologies have a large amount of moving parts some of which are warm. This might make unmanned operation more difficult to obtain.

In order to handle fuel with varying water content some of the technologies will have to integrate a drying unit which is a new development that may add uncertainty to the operation. In general down-draft and up-draft gasification technologies are not very fuel flexible. They typically need a fuel that is very well described in terms of humidity and particle size. This may be an issue as the customers in Denmark and elsewhere tend to increase focus on fuel flexible systems when deciding to retrofit an existing system.

The group finds that some of the problems the technology providers face could be solved by forming partnerships applying the already successful gasifier solutions, feeding solutions, ash handling solution etc.

Some of the technologies touch on the market for biochar as fertilizer. To the group it sounds to be most viable to produce biochar from an inefficient gasification process that naturally produces char.

The group had a discussion on heat demand which is relevant for all small CHP plants. While the plant economy would benefit from 6,000 annual hours of operation, the number of operational hours might be lower as the plant might have to close down or operate at low load in summertime.

8.3.3 Technologies for medium scale and large scale CHP generation

The three technologies for medium and large scale CHP generation seem very promising and comprise fully commercially available technologies, which is also an achievement worldwide.

The market for especially technologies that produce gas for combustion in power plant steam boilers is practically unlimited, especially when the technology is fuel flexible, produces little carbon in the ash and the solution has no problem with tar and ammonia in the gas which is the case here. This is a solution that may provide high electrical efficiency and furthermore avoid loss of important nutrients such as phosphorus. The future possibility to switch between CHP and fuel production is another benefit of the technology. The only threat is if the fuel is categorized as waste and the power plant will be conceived as an incineration plant and thus has to monitor emissions etc.

Even though some of the technologies can be bought off the shelf, there is still room and a need for development. Especially for technologies with operation of gas IC engines the tar cleaning or reforming technologies need a development effort.

As for the small scale technologies, up-scaling of updraft gasifiers will require development work - the challenge being the stability of the fuel particles. Traditionally, up-scaling of fluidized bed gasifiers is less problematic.

In the process of up-scaling it might be necessary to change from IC engines to less efficient gas turbines which may influence the overall economy of a new plant. On the other hand this change may be seen as a positive development that may enlarge the market. The reason is the large emissions from IC engines. As Denmark has the least demanding emission criteria for gasification plants, plants developed to meet the Danish legislation may be ruled out by stricter emission rules in other countries.

Some of the technologies are close to the market and have been operating for many hours. With more knowledge and experience gained it is easier to pin point the challenges compared to the less mature technologies that live in "ignorance". This may make the specific technology sound more problematic than it really is and thus make RD&D programmes refrain from supporting the technology. The opposite should be the case: it is worth while to support RD&D projects on these technologies – it is safe to put money in technologies close to commercial operation.

8.3.4 Technologies for fuel generation

Four technology tracks aim at fuel generation from producer gas and represent both gasifier solutions and auxiliary equipment for gas processing. The technologies are at different development levels, hence generalization is difficult.

Some technologies may seem to be the answer to the dream of every investor and energy authority as they sound very promising and live up to any thinkable spectacular criteria. When solutions sound too good to be true it traditionally makes experienced specialists a bit suspicious. Especially so when the descriptions are coupled with expectations that the technology will be commercially available in very large size within a quite short period of time but currently has only a few hours of operation. The focusing group had this experience with some technologies.

Of course the group may be mistaken and be short of relevant process knowledge and the processes may be truly innovative. On the other hand, when an issue is raised by one specialist it could be real and it should at least be explained why it is not a problem with the current technology as it would be with just about any other technology.

In any case, there is a risk that spectacular but unrealistic technologies may appeal to investors and may obtain funding while leaving more realistic but down-to-earth technologies out and - if they fail - put the whole sector in a bad light.

This said, some of the technologies win applause by the group and harvest high scores for all criteria. Danish gasification technology and auxiliary equipment seem to be working well and have a great potential worldwide. With some development effort they actually seem to provide an answer to the dream of being able to form a system that is flexible and fits to the fluctuating nature of the other renewable energy sources. A system where choosing freely between any distribution of direct CHP generation and fuel generation.

8.4 Danish technologies - state of the art?

Danish gasification technology suppliers most naturally consider their own technology unique. Other Danish stakeholders in the industry consider the general technology level high. Is that true - do the Danes provide state of the art technology that is or will be in demand in other countries?

An indicator is the number of operational hours. International conferences usually present many interesting technologies and concepts. The solutions typically sound very promising, however, a closer look often reveals that the concept is in lab scale or presents very few operational hours. In contrast to that it is obvious that Danish technology suppliers in most cases can present pilot scale or demonstration plants with results based on thousands of operational hours - some even unmanned.

The focusing group agrees on this view and states that the Danish biomass gasification companies are in the forefront. Many interesting concepts are being developed, and the different technologies are moving forward. The stakeholders conceive creative solutions and there are less "dead-ends" than in many other industry countries. Thus the Danish companies and stakeholders are interesting cooperation partners for foreign companies. The group also finds that the 11 technology tracks are not too many. The overlap between the technologies is minimal - it may only be an issue at specific district heating plant sizes.

Only few other countries can present the same type of results even with a much larger effort. In Denmark there is a market for relatively small scale CHP in connection to the many district heating networks and thus attention and preferences from funding schemes has been on developing small scale technologies. In other countries such as Germany, the Netherlands and Finland district heating is less common and the development has taken place in connection with large industries and refineries. The view has been "the bigger the better" and small scale would be considered large scale in Denmark. For instance large sums have been invested in Germany over the past years without reaching a result as remarkable as the district heating CHP plants in Harboøre or Skive.

Also the Pyroneer technology exploited by DONG Energy that demonstrates high fuel flexibility and ash usability is a particularly good example. The perspectives of high electrical efficiency of large new and existing power plants using vast but challenging biofuels and the ability to recycle the nutrients has not been demonstrated elsewhere in the world.

On top of the special Danish market for biomass gasification technology the group mentions that the Danish way of keeping the plant size small and thus the costs low while the technology is being developed has proven successful. Scaling up on basis of a success is wise and keeps the image good as well. Furthermore, the group sees another specialty to the Danish success: successful technologies have a "godfather". The inventor or owner is a strong and dedicated personality that "lives the technology" or perceives it as his "heart and blood". There is a culture of supporting single persons or very small companies with good ideas and it apparently proves more successful than or just as successful as supporting development conducted by large teams that work eight to four in larger companies.

9 RD&D demand

From the technology descriptions from the suppliers and chapter 6.2 it is clear that technology for thermal biomass gasification is just about to reach the commercial level. Much development work is yet to be done in order to harvest the benefits from the previous development activities and thus get return on previous funding.

In (Hansen, 2010) the demand for development and demonstration efforts within CHP technology for solid biomass (covering some gasification solutions) was investigated. It became clear that development and demonstration activities were more needed than research activities.

The message was that although Danish-based cogeneration technologies for solid biofuels are advanced compared to the competitors in many areas there is a large need to continuously improve the technology by sustained development and demonstration activities. The industry currently has very strong focus on market deployment of especially technologies for cogeneration in small scale (up to 15 MW_{th}) and on the overall economy of these plants. Reference installations that display many operational hours with a reasonable economy are crucial for investors.

From the industry perspective there is still a need for development and demonstration of CHP technology below 15 MW_{th}. The development and demonstration efforts should lead to improvements in conditions such as availability, efficiency and operating and maintenance costs.

Also technologies for large plants and systems need to be improved with respect to availability and efficiency and reduced operating and maintenance costs. For all technologies, there is a need to develop the use of odd/special solid biofuels that on the one hand may have troublesome characteristics but on the other may help lower operating costs.

9.1 Results from the survey

This paragraph contains the results of the analyses of the feed back in the confidential section of the questionnaires.

The participants in the survey have been asked to reveal their view on where research, development activities and technology demonstration is needed by distributing a total of 36 votes - 12 for each category in a table containing 22 subjects per category. Please refer to Annex 5 – Questionnaire used in the survey to see the questionnaire. The respondents could choose freely how to place their votes within each category, e.g. putting all votes on one focus area or one vote on 12 areas or something in-between. Even though one respondent has chosen not to place votes in the research category, it has not been the intention to let respondents weigh the needed effort between the three categories.

An important general message is that the distribution of votes is not proportional to the amount of funding - the costs of demonstration activities are typically much larger than the costs for research and development activities on a given subject.

Another general message is that even though some technologies are close to being commercial, basic research is still needed. A better understanding of the processes for both new and existing concepts will help improve operational reliability.

Figure 6 shows the vote distribution from all 14 voting respondents. It is clear that operational reliability is the overall high score and also that this is mainly an issue to be addressed by demonstration activities. Figure 7 to Figure 9 reveal that operational reliability is mainly an issue for the suppliers of CHP technology. This is quite understandable as these plants usually need to operate more than 6,000 hours per year in order to be feasible.

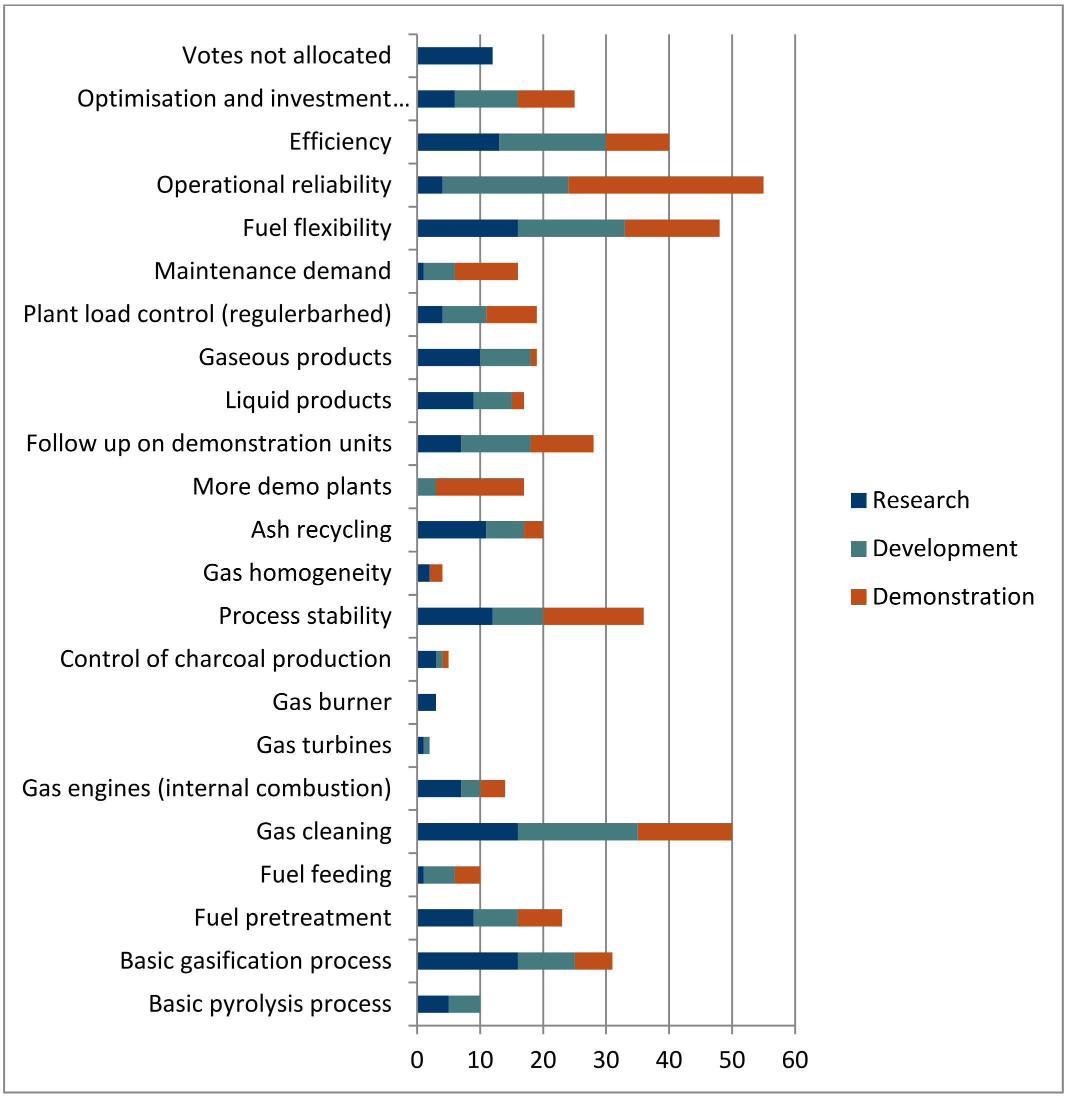


Figure 6. Vote distribution from all 14 voting respondents. One supplier has chosen not to allocate votes on research.

Operational stability involves many of the other subjects in the voting ballot. For instance some suppliers indicate that they see mechanical issues with wood chips supply system and ash discharge system. Also, stable operation on the gasifier may a challenge - controlling the temperatures and maintaining the zones in the gasifier are mentioned.

Gas cleaning has the second highest total score. The votes do not surprisingly origin from suppliers of technologies for fuel generation as is visible in Figure 10. They indicate that activities are needed at all levels – R, D and D. Also the ATG companies find gas cleaning important - Figure 12.

It may be a surprise that the suppliers of large scale CHP technology find RD&D – and especially development - within gas cleaning most important. This may, however, be explained by the fact that the technology from one supplier is aimed at both CHP and fuel generation.

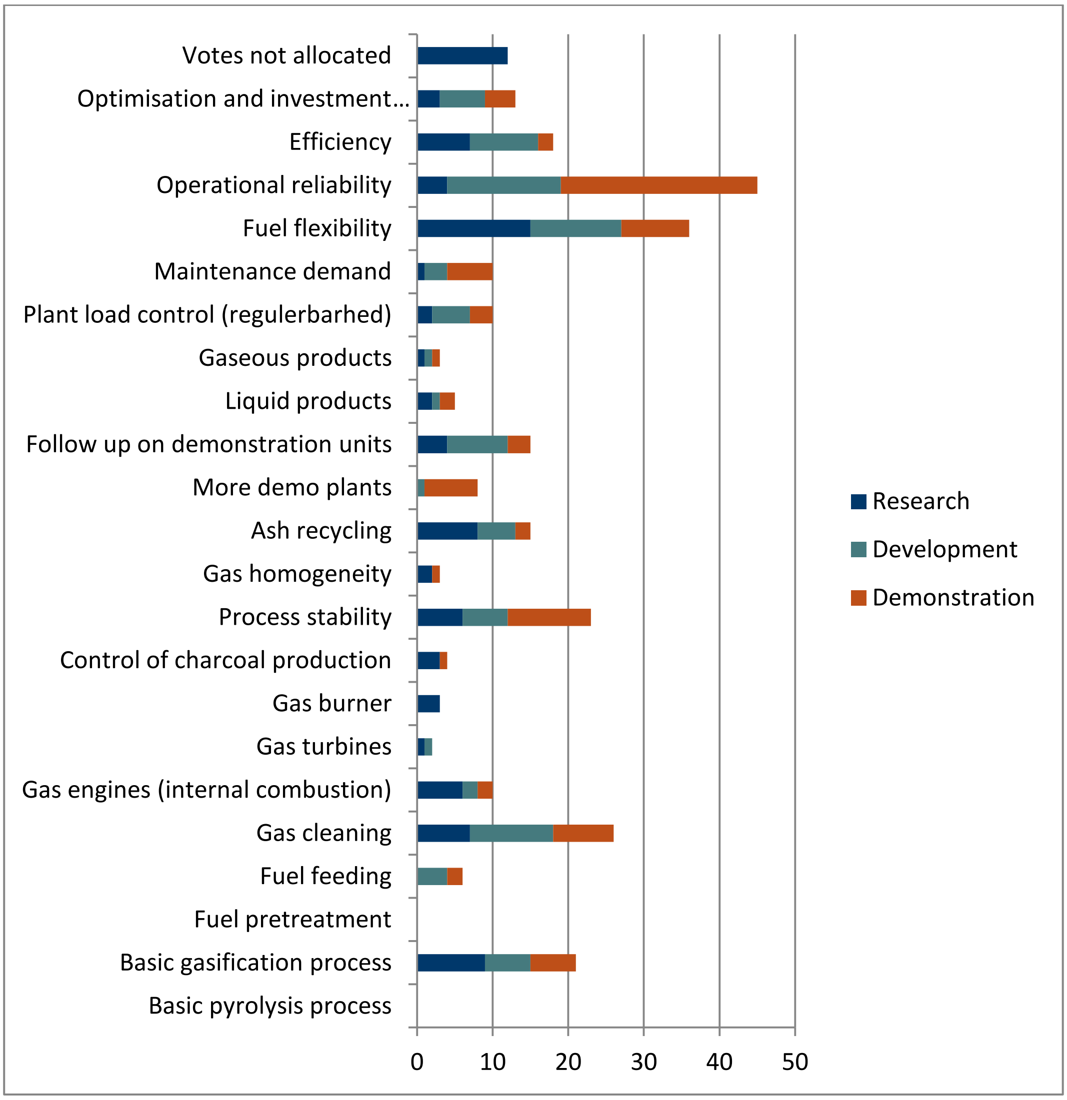


Figure 7. Vote distribution from 8 suppliers of biomass gasification technology for CHP generation. One supplier has chosen not to allocate votes on research.

Another remarkable result is the absence of interest in gas cleaning amongst the suppliers of small scale CHP technology as Figure 8 shows. This is not in line with the technology screening comments from the focusing group. They suggest that activities on gas cleaning may be necessary when up-scaling technologies. However, gas cleaning is currently economically viable only at large plants. The technology exists but is expensive.

Thus, it makes sense to suggest developing new and cheaper gas cleaning technologies that can be applied at medium sized and perhaps small sized plants.

Fuel flexibility is important for the suppliers of technology for CHP as Figure 7 shows. This can be confusing as most gasification technologies are not fuel flexible. In fact many technologies are very dependent on the fuel complying with certain requirements as to humidity and particle size. This could be the reason why the score indicates a need for research more than demonstration.

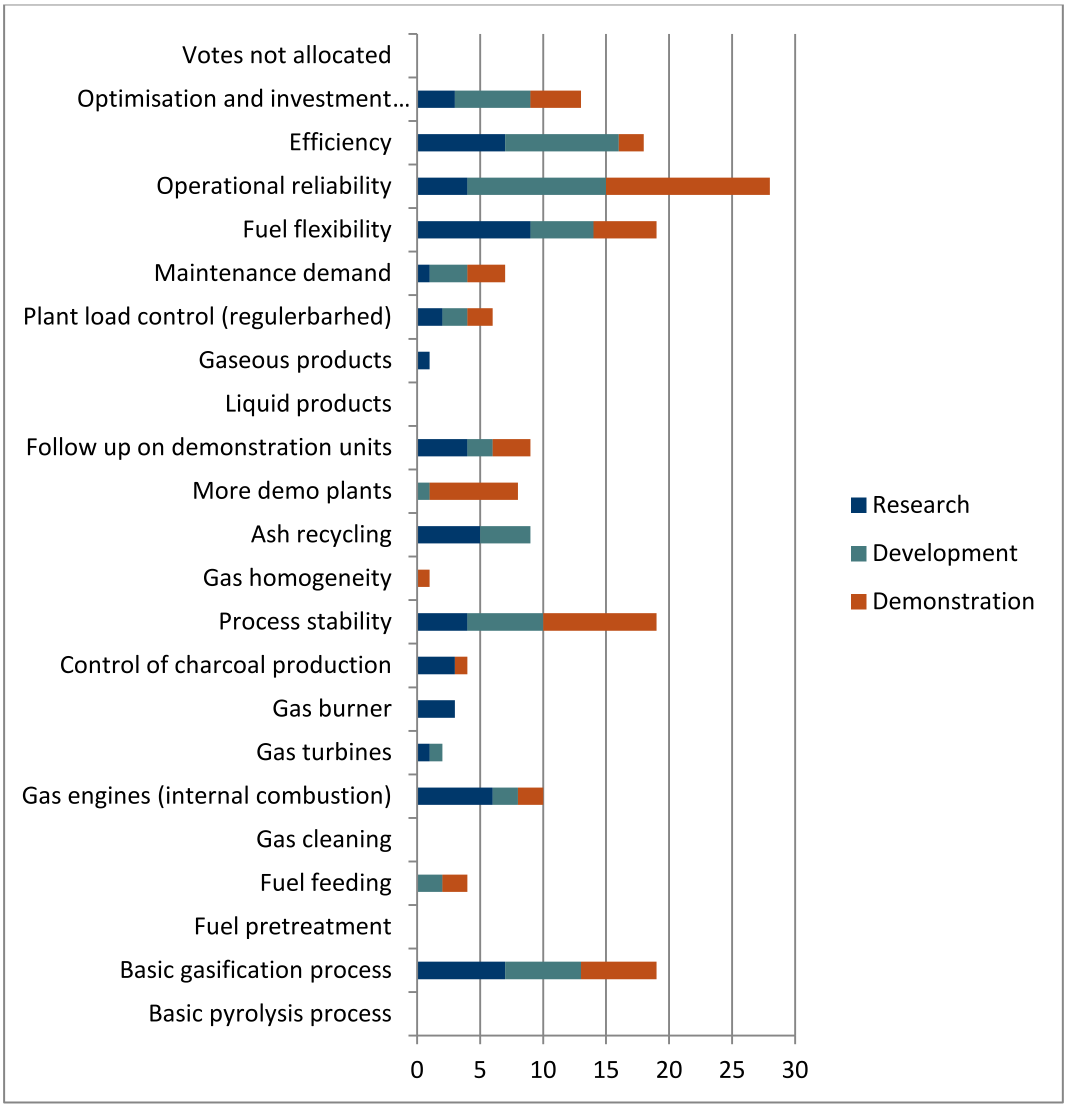


Figure 8. Vote distribution from 5 suppliers of biomass gasification technology for small scale (< 15 MWth) CHP generation.

The ATG companies have voted for fuel pretreatment (Figure 12) along with the suppliers of technology for fuel generation. Fuel pretreatment - which could mean torrefaction - may be able to uniform different fuels and thus obviate the need for the gasification technologies themselves to be fuel flexible. The suppliers vote for RD&D in fuel pretreatment but only for development and demonstration of fuel flexibility. Do they say that if the fuel is pretreated, research in fuel flexibility is no longer of great interest? In any case the preference for fuel pretreatment is not supported by the votes from the CHP technology suppliers. The focusing group has mentioned that torrefaction may be interesting for entrained flow type of gasifiers. This type is not amongst the technologies described by the suppliers in this work.

Efficiency has an important position amongst CHP suppliers and ATG companies. Along with the importance of operational stability previously mentioned this supports the view given in the introduction to this chapter.

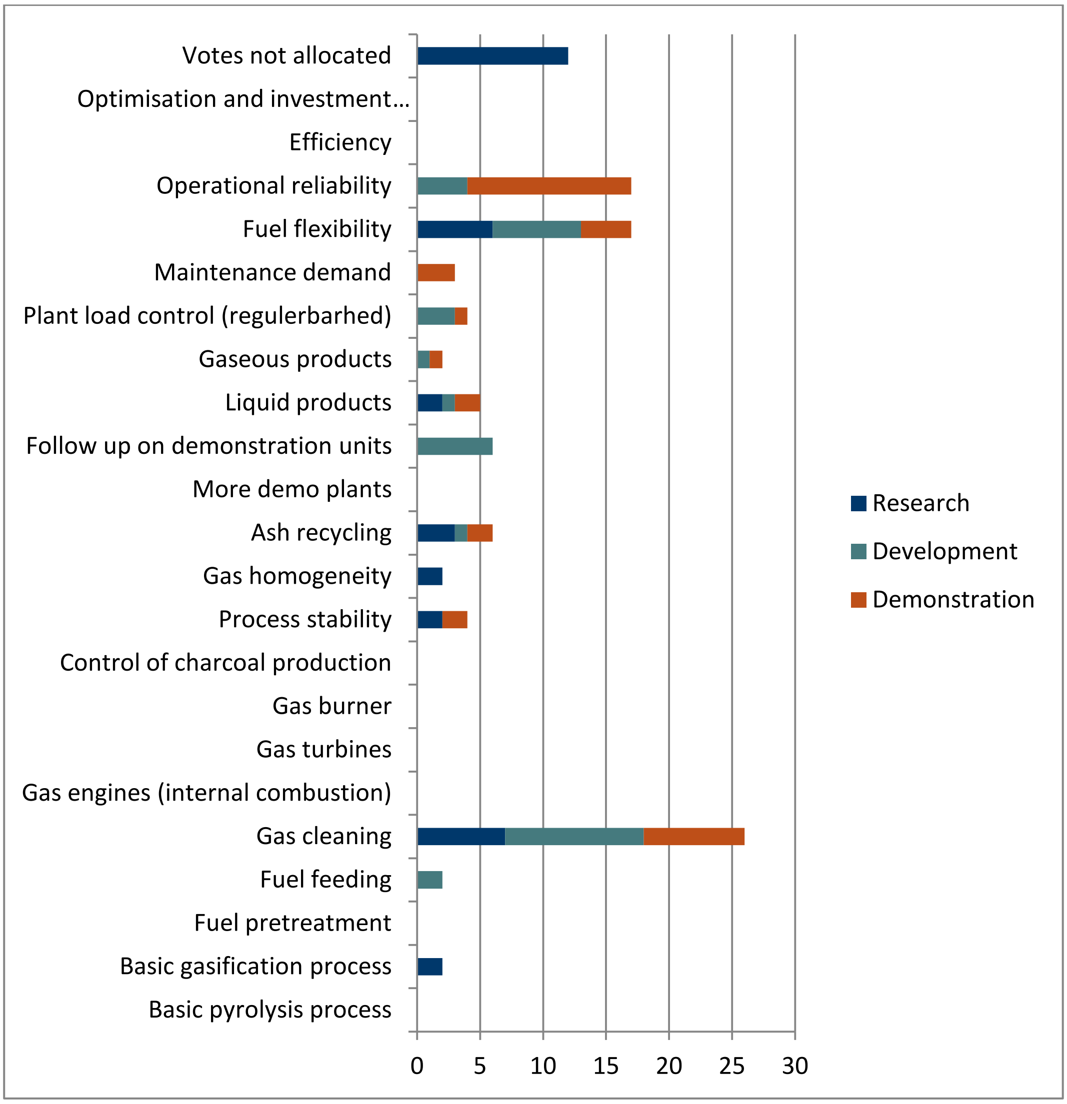


Figure 9. Vote distribution from 3 suppliers of biomass gasification technology for medium and large scale (> 15 MWth) CHP generation. One supplier has chosen not to allocate votes on research.

In Figure 12 the ATG companies prioritise optimisation and investment reduction. This is very important for investors and the priority seems natural as these companies focus on application of technologies. Also the suppliers of small scale CHP find this important and are currently working to simplify their technology and reduce production costs.

Even though it is not reflected in the votes, the suppliers of large scale CHP mention this issue in their comments too. When a technology is close to become commercially available the biggest challenge is optimization of the process and demonstration of operating experience with new components designed to simplify the concept and reduce cost.

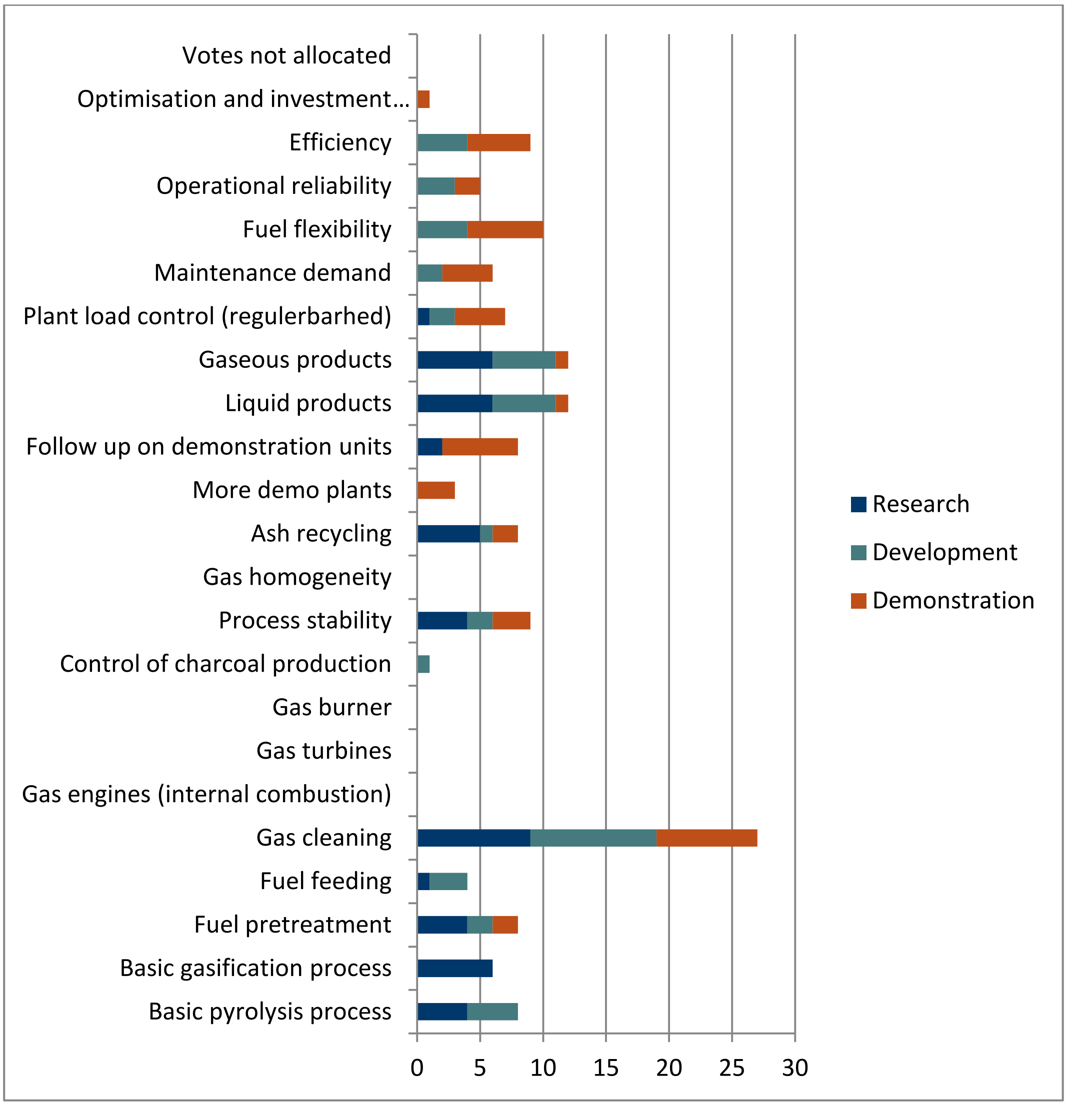


Figure 10. Vote distribution from 4 suppliers of biomass gasification technology aimed at production of fuels.

Apart from the 22 subjects in the ballot paper, suppliers also suggest that a major challenge in biomass gasification is to achieve sufficient scale of operation to get reasonable return on investment for the client.

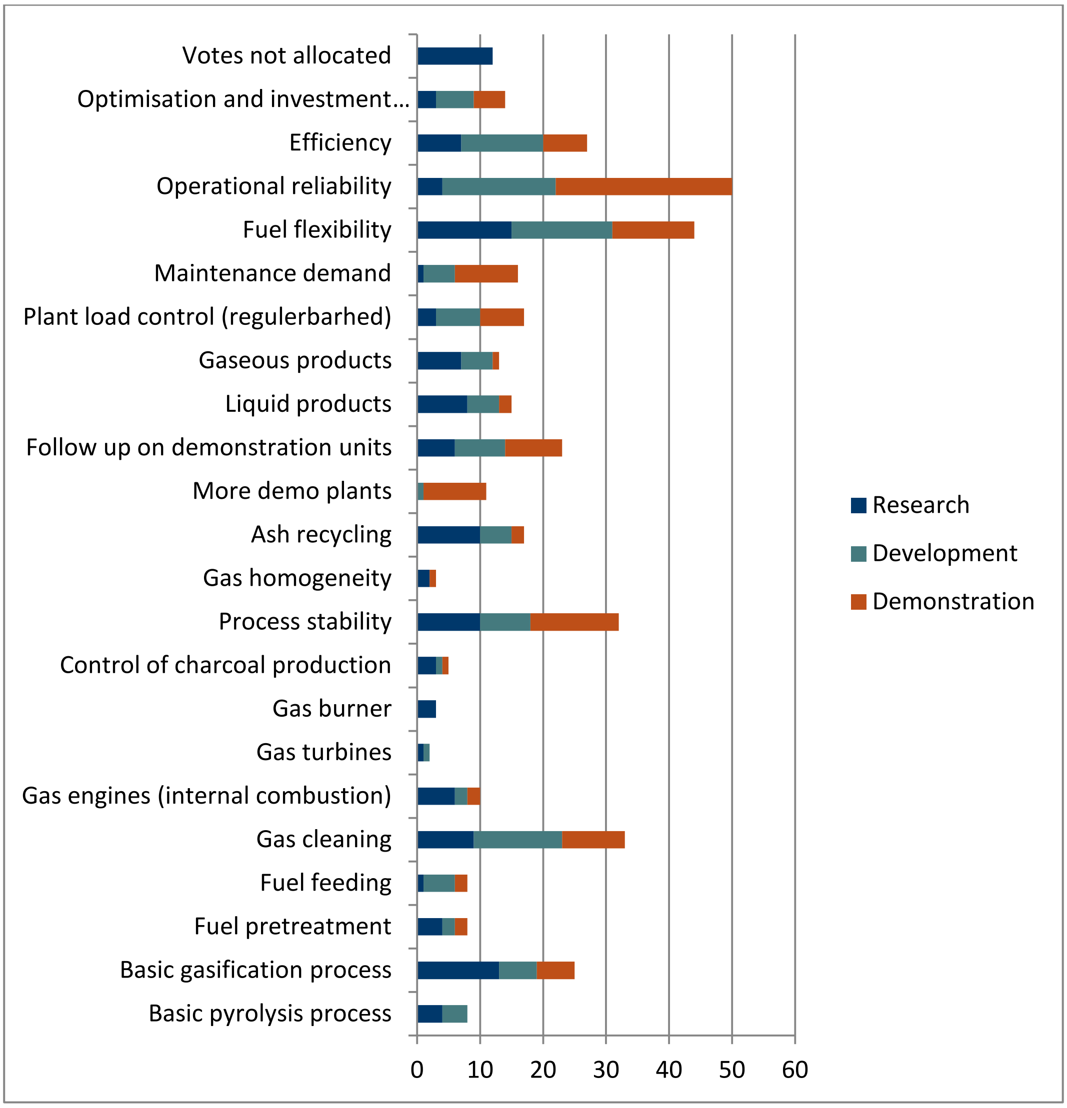


Figure 11. Vote distribution from all 11 suppliers of biomass gasification technology. One supplier has chosen not to allocate votes on research.

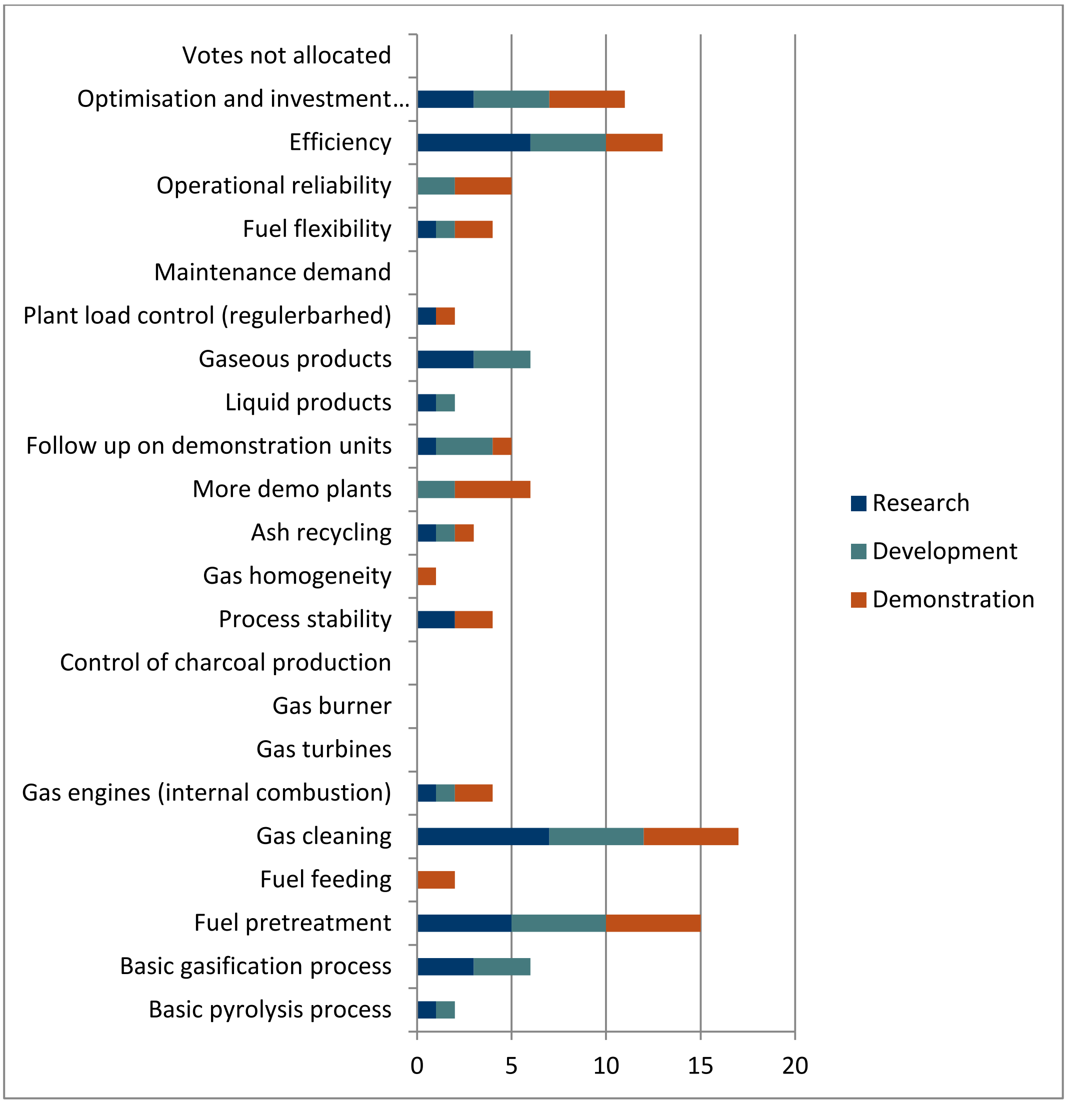


Figure 12. Vote distribution from 3 respondents from the Advanced Technology Group of companies (Danish: GTS).

Apart from the polls the questionnaires also contain qualitative feedback on the demand for R&D. At The Technical University of Denmark there is now a generally increasing focus into thermal biomass gasification. Researchers at the Institute for Chemical Engineering see a need for the following focus:

- Fundamental studies on fuel conversion and ash transformation in gasification systems
- Improved understanding of biomass ash rheology and volatilization in entrained flow gasifiers
- Improved understanding of ash behavior in the LT-CFB systems
- Improved understanding of the influence of fuel and operation conditions on fluid bed de-fluidization
- Optimization of gas cleaning and conditioning systems including removal of tar, particulates, and N and S species from syn-gas
- Improved methods for pretreatment and feeding of biomass and waste into pressurized systems

- Development of entrained flow reactor technology optimized for waste and biomass conversion
- Further development of reactors and catalysts for gas (methane) and liquid fuels production
- Development and operation optimization of advanced multi product gasification plants
- Development of gasification concepts used for CO_2 sequestration.

10 Funding demand

Inventing and developing a new technology is often closely connected with the heart and blood of the inventor. In many cases new technologies are conceived in small companies fully or partly owned by the inventor. The future for the technology and the company itself is, in many cases, dependent on public support and venture capital.

10.1 Funding demand from the survey

In order to express the necessary funding demand and needed share of public funding, the industry has been requested to indicate three funding demands for bringing their technology forward:

1. To the next step in the development ladder
2. To demonstration level
3. To a commercial level

Further some suppliers have indicated the needed level of public funding need to reach the next step in the development ladder.

The agglomerated feed back from the suppliers can be seen in the figures below. The funding demand has been arranged according to technology type. Each bar shows the number of replies in each category for the relevant technology type.

In average the respondents have stated 47% as an average demand/expectation of public funding. Six suppliers have responded to this question.

Nine suppliers have indicated their funding demand to reach the next development step. If the indications are used to accumulate the need, it amounts to a total of EUR 7 - 27 million. If the same exercise is carried out for the CHP technology suppliers, the demand is EUR 5 - 20 million. The suppliers of technology for fuel generation would need only EUR 1 - 7 million to reach the next stage.

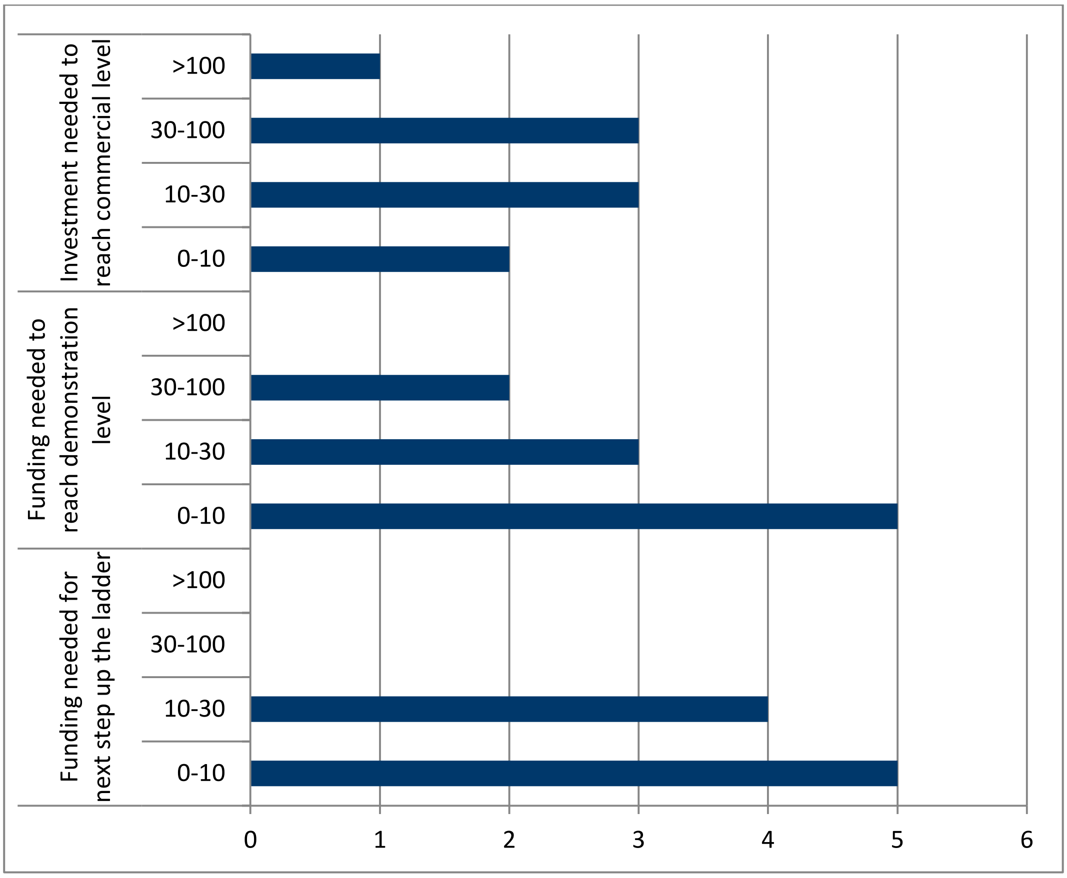


Figure 13. Funding demand at all suppliers of gasification technology.

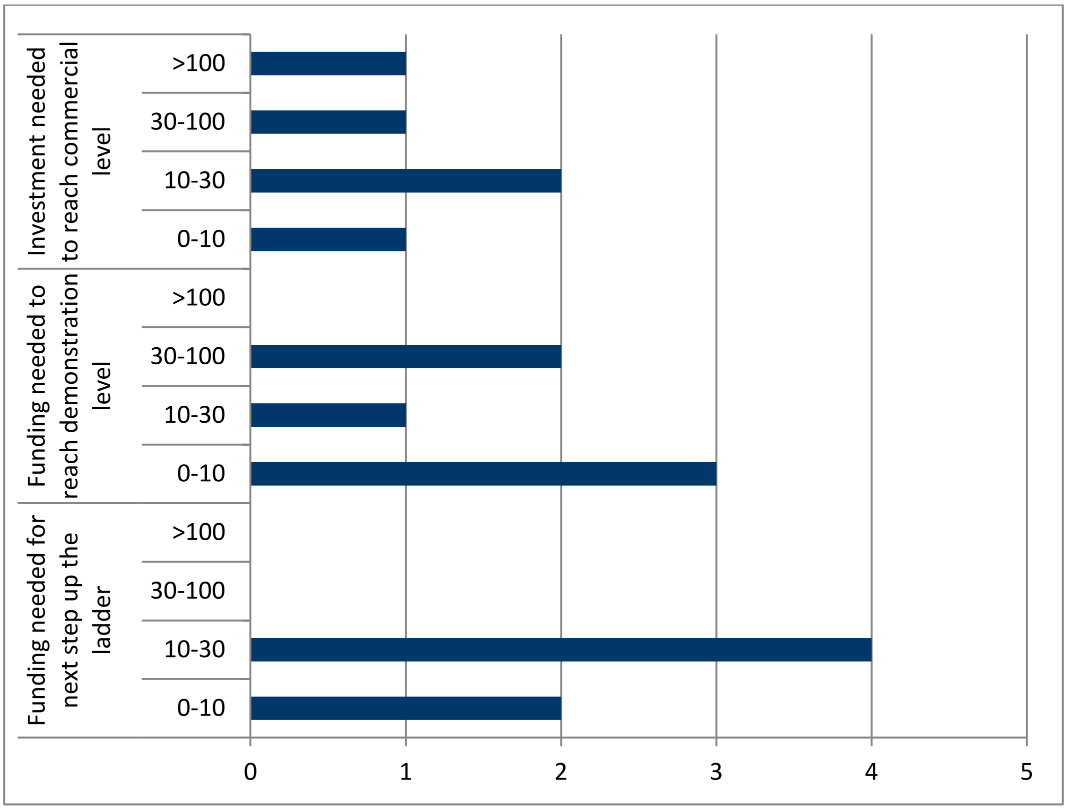


Figure 14. Funding demand at suppliers of gasification technology for CHP generation.

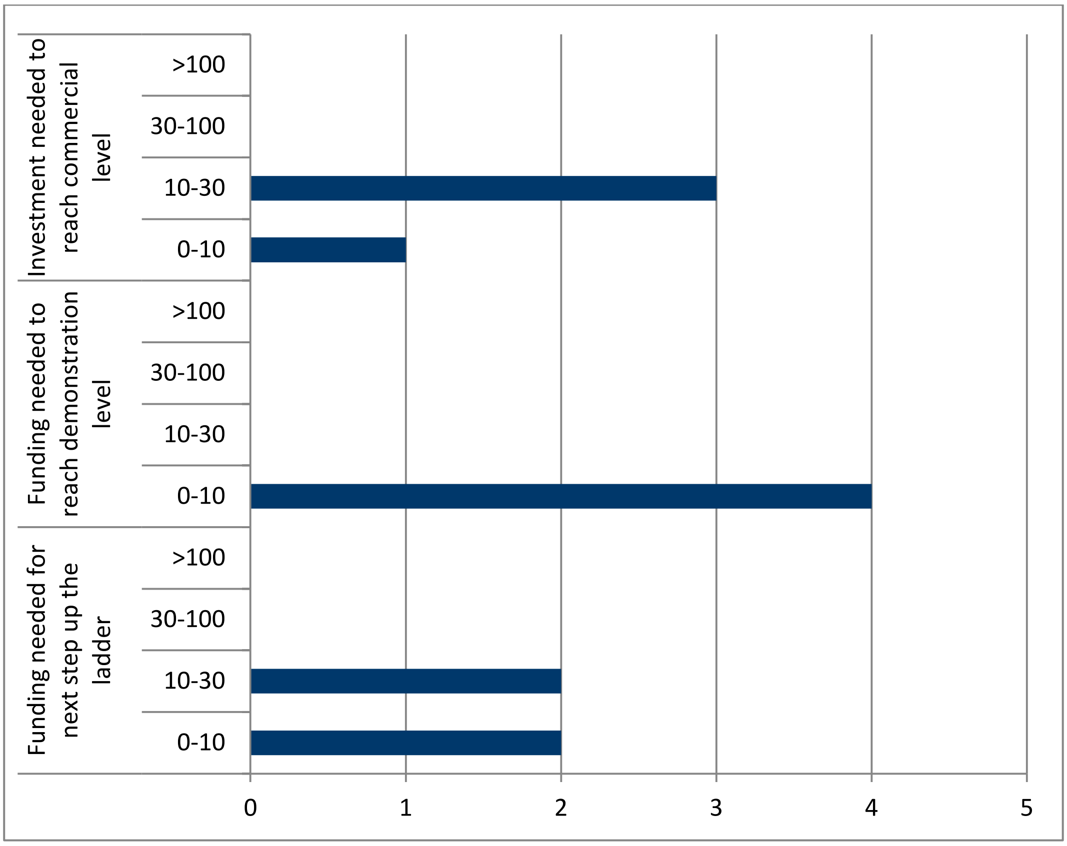


Figure 15. Funding demand at suppliers of technology for small scale CHP generation.

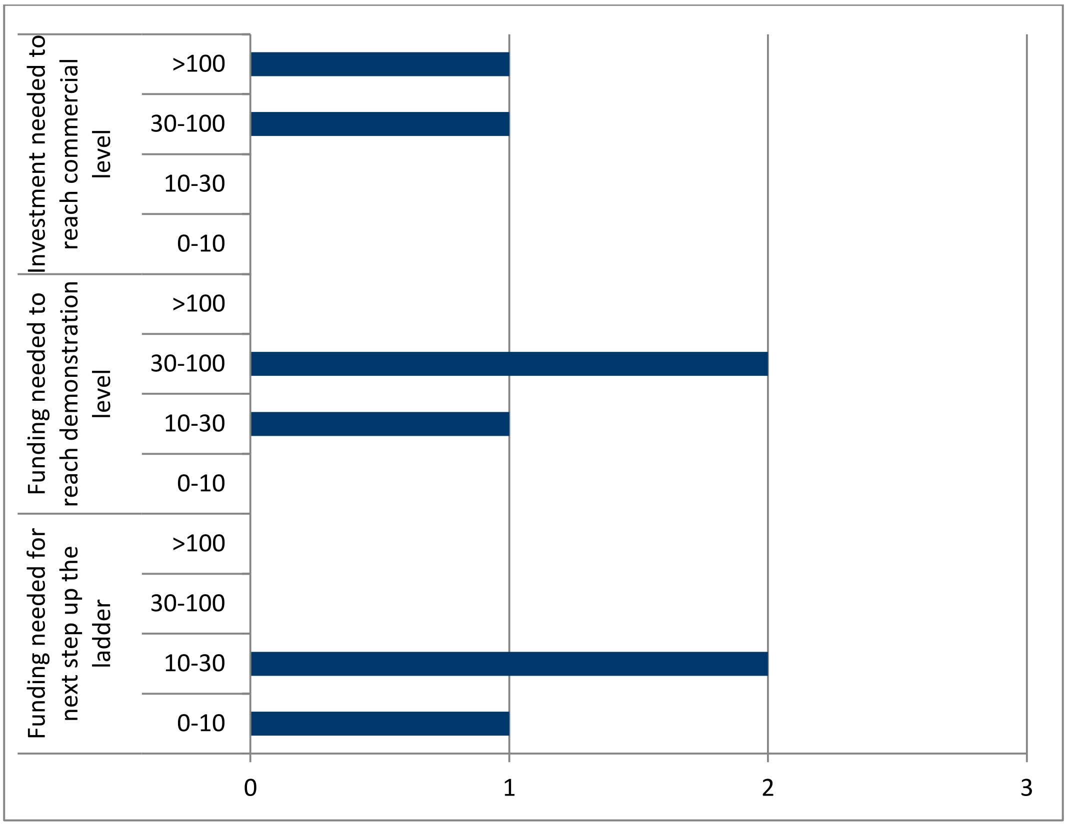


Figure 16. Funding demand at suppliers of gasification technology for large scale CHP generation.

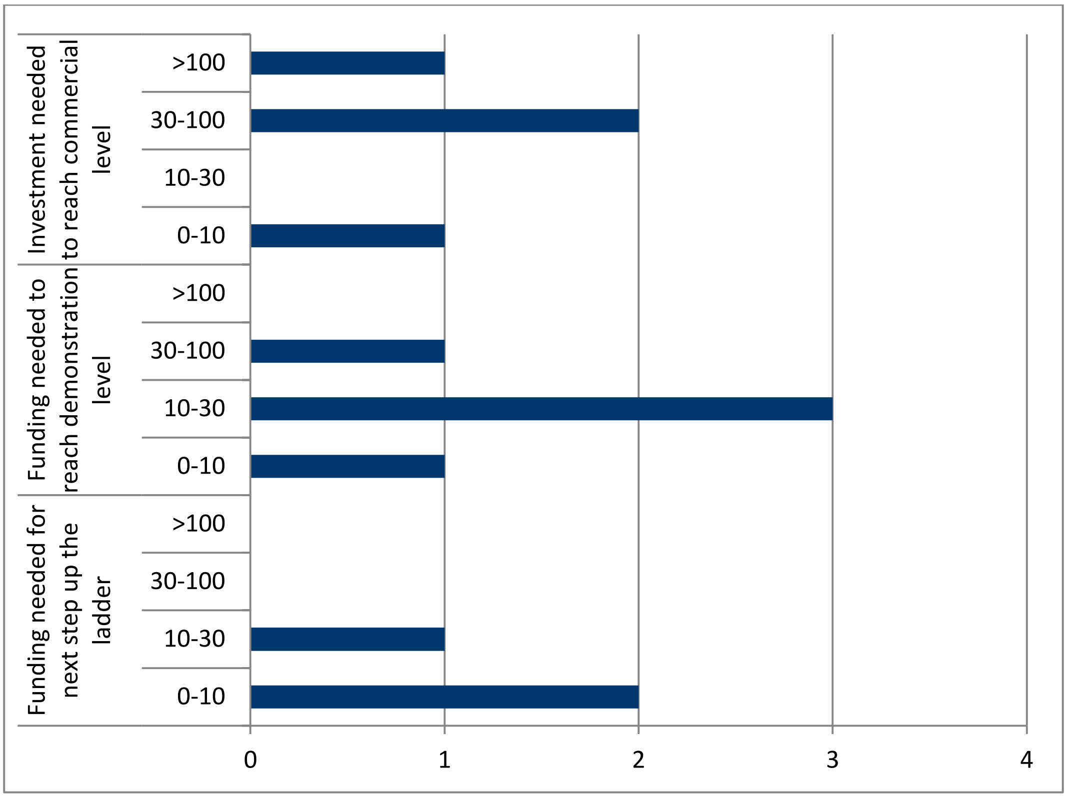


Figure 17. Funding demand mentioned by suppliers of gasification technology for fuel generation.

Looking at the graphs it draws attention to the fact that quite a number of suppliers estimate that they can demonstrate their technology for 0 - 10 million DKK. Usually, demonstration activities in full scale are somewhat more expensive. Furthermore, the graphs indicate a surprisingly modest demand for funding of demonstration plants for fuel generation.

However, some suppliers reveal in the comments that full scale demonstration of their gasification plant would amount to much more - up to 300-500 million DKK for a large scale plant - in order to have a positive business case. Lessons learnt from various biomass gasifiers indicate that the first full scale reference often suffers from being more expensive and less reliable than expected, which may ruin the business case. There are examples of bankruptcy, due to lack of money in the first years of operation. The cost of the first full scale gasifier could be 150% of the second plant, hence public support for the first full scale reference will be needed.

10.2 Estimates of funding demand for Danish technologies

In order to qualify the debate, FORCE Technology has made a rough estimate of the public funding needs for gasification RD&D over the coming years in order to successfully commercialise small scale CHP technologies and technologies for fuel generation based on gasification of solid biomass. It must be emphasized that the estimate i rough and merely suggests a level of funding. Applications such as fuel cells, hydrogen or pyrolysis for production of liquids are not included in the estimate.

In order to push the technology further ahead, there is a requirement for a substantial public funding. The funding should support demonstration projects and aim at lifting the economic risks associated with near-commercial plants.

10.2.1 Small scale CHP technologies funding need estimate

There is a strong need to demonstrate several technologies in operational periods measured in several years on more than one unit each. Only Harboøre is there today, the others are far behind.

Estimated requirement: 50% financing of 8 demonstration units each EUR 4 million equals EUR 16 million over four years plus EUR 4 million per year for follow-up operational support, monitoring, documentation and optimization activities. In total an average requirement of EUR 8 million per year.

Detailed collection of operational data and experience (and digestion of data and publication) is essential to point out future problem areas and R&D activities. An estimated average requirement for this is: 100% financing of 2 persons continuously equals EUR 0.4 million per year.

Development activities to solve problems already pointed out or found during demonstration as well as development activities aiming at making gasification technology competitive (reduce investment, improve efficiency, improve reliability, reduce O&M costs) are essential. An estimated average level of activity: Two large projects each supported with EUR 1 million initiated every year equals EUR 2 million per year.

International cooperation such as participation in network cooperation and knowledge sharing (excluding research and demonstration projects) is necessary. Estimated average level: Two persons full time equals EUR 0.4 million per year.

Research including participation in international projects is essential in order to create momentum and a solid knowhow base. Approx. 12 researchers should be full time employed on gasification in Denmark. Including equipment this requires about EUR 2.5 million per year.

The total average level of public funding required would be around EUR 13 million annually over 4 year period.

10.2.2 Large scale CHP technology funding need estimate

As a parallell to the above estimate FORCE Technology has made an estimate of the funding demand for moving a biomass gasification technology for cofiring gas into a large scale CHP generation unit from the pilot phase to a commercial level.

Estimated requirement: 50% financing of one full-scale demonstration unit would amount to EUR 20-35 million during a period of four years. Using the average, EUR 27.5 million and adding the follow-up operational support, monitoring, documentation and optimization activities that alike the small scale estimate would amount to EUR 4 million per year for a period of four years, the total average annual requirement would be around EUR 11 million per year.

Detailed collection of operational data and experience (and digestion of data and publication) is essential to point out future problem areas and R&D activities. An estimated average requirement for this is: 100% financing of 1 person continuously equals EUR 0.2 million per year.

Development activities to solve problems already pointed out or found during demonstration as well as development activities aiming at making gasification technology competitive (reduce investment, improve efficiency, improve reliability, reduce O&M costs) are essential. An estimated average level of activity: One large projects supported with EUR 1 million initiated every year.

International cooperation such as participation in network cooperation and knowledge sharing (excluding research and demonstration projects) is necessary. Estimated average level: One person full time equals EUR 0.2 million per year.

Research including participation in international projects is essential in order to create momentum and a solid knowhow base. Approx. 6 researchers should be full time employed on large scale gasification in Denmark. Including equipment this requires about EUR 1.5 million per year.

The total average level of public funding required would be around EUR 14 million annually over 4 year period.

11 Aims and focus areas

The inventory and analysis above describes the current Danish gasification industry. In the following paragraph an overall picture is drawn and a set of focus areas are listed.

Unique technology

During the last 20 years Danish based biomass gasification technology has been brought to a very high technological level seen in a worldwide perspective. This is the view of the suppliers but also of international experts that are independent from the Danish scene.

Focus has been on technology tracks aiming at applications for small and medium scale CHP to match the demand for green generation technologies in the increasingly distributed Danish electricity generation structure. Many of the technologies have great perspectives for production of fuel and lately new gasifier development tracks aimed at fuel production have been promoted by small and large companies along with technologies aimed at cleaning gas for various fuel purposes.

The assessment is that the Danish development environment has shown creative solutions and that the special Danish way of keeping it small scale until the technology is proven and that support is aimed at strong and innovative single persons that "live their technology" has proven to be successful. There are less costly dead-ends and the single technologies have a track record of far more operational hours than most competing technologies.

Large technology potential – large market potential

There seems to be no doubt that technology for gasification of solid biomass is a very important factor in future energy supply system worldwide. Technology that can balance the fluctuating renewable energy sources either directly in CHP plants or indirectly by providing possibility for energy storage and fuels.

Biomass gasification technology can be used in many types of applications in almost all thinkable sizes and with a large variety of solid fuel types. Furthermore, some gasification technologies have the advantage that they separate nutrients from the fly ash and thus enhance the possibility for recycling of the nutrients. This is an advantage to most combustion technologies and especially interesting when new fuels with high contents of ash and salts are to be utilised.

Technically, the market is very large – both in Denmark and worldwide. However, once the technologies reach a commercial level the accessible market is still limited to places with a positive interest in alternative solutions – supporting framework conditions. Biomass gasification technology requires some form of subsidy in order to be competitive with technologies for fossil solid fuels.

The markets for different gasification technologies are rather diverse. As CHP technologies focus at an existing heat and power market, the market for biomass derived transportation fuels is to a higher degree existing at the political level. Fuels to be fed into gas grids like BioSNG have not yet reached a wider political understanding.

Danish suppliers of gasification technologies for CHP and fuel generation expect to have sold more than 2,000 plants worldwide by 2020.

Strong companies

In order to be able to lay hands on the large market the suppliers need to be able to invest. Some of the Danish suppliers have the strength to enter new markets because of their size and ownership background.

The small inventors and suppliers are strong because of their drive and commitment and as such they are very important drivers of the development of Danish gasification technology at large. However, when technologies get closer to market ready and have to be up-scaled, the investment-demand increases dramatically.

In such cases it will typically be relevant for the small supplier to investigate other models such as partnerships with larger companies or sale of the technology or company. Such models have been tried with luck by some of the inventors.

Important RD&D institutions

During the past 20 year's of development of gasification technologies, Danish university environments and the Advanced Technology Group of companies have been active and played a crucial role in creating Danish success stories. Some of the institutions and their enthusiastic staff have given birth to several technology tracks that are close to commercial today.

In a future effort to bring the technologies forward, these institutions have an equally important role. The ATG companies that are aimed at applying technology R&D into society are ready to demonstrate, monitor and prove the functionality of the gasification technologies and are currently involved in doing so.

The universities have an important role to play in bringing a deeper understanding of the thermo-chemical processes in close cooperation with technology suppliers in order to find new ways and quickly solve problems that might occur in a continuous development - for instance when the suppliers are upscaling technologies. Institutes at the Technical University of Denmark are currently engaged in projects or increasing their focus on biomass gasification and thus ready for an increased R&D effort.

Large development potential - large funding demand

The technology survey has shown that the technologies are not yet fully commercially available. Only a few plants have been sold off the shelf on commercial conditions. During around 20 years the investment in the Danish biomass gasification industry has been rather large and the results are beginning to show up.

There is a large demand for taking the last step up the development ladder now in order for the companies and society to harvest the benefits of a green growth. If the step is not taken, the previous investment and possibility for green growth in the sector may be lost.

Even though the steps to be taken may not be very long, they will typically be very funding intensive as they typically involve up-scaling of the technology. There are examples that the costs for demonstrating a technology in full scale may be ten times as high as the total investment demand in the period from research, development and pilot plant to small scale demonstration plant. When a company grows from an R&D type of company to market large plants, strong back support is necessary.

Previous surveys have indicated a large demand for technology development and demonstration rather than basic research. This is important in order to prove the technology and thus attract investors. Basic research in processes can not be left out as it contributes to the understanding of operational problems.

This survey has contributed to a more detailed understanding of what topics the suppliers find it important to focus an RD&D effort on.

Within the biomass gasification technologies for CHP generation the three most important RD&D subjects are:

- Operational reliability (by far) - primarily demonstration
- Fuel flexibility - mainly research
- Gas cleaning - demonstration

Within the biomass gasification technologies for fuel generation the three most important RD&D subjects chosen by four suppliers are:

- Gas cleaning - broad RD&D effort
- Research and development within gaseous and liquid fuels
- Fuel flexibility - mainly demonstration

The Advanced Technology Group of companies in general support the view of the suppliers on gas cleaning. They add importance on energy efficiency and optimising the technologies in terms of decreasing costs for operation and maintenance as well as investment reduction.

Hence, they promote a message from investors that will ultimately help increasing the market possibilities in markets with less favourable framework conditions and strengthen the position to the fossil fuel alternatives. The ATG companies also prioritise RD&D within fuel pretreatment that may improve the operation of some gasification concepts.

The survey gives an indication of the total demand for funding when moving the technologies up the given next step the ladder. Nine of the eleven technologies would need a total of EUR 7 - 27 million to reach the next development level and the companies have stated that around half of this would have to be public funding.

A rough estimate of the funding needs for the CHP technologies to successfully go commercial suggests an annual funding demand from public sources of around EUR 13 million for small scale technologies and EUR 14 million for one large scale technology over a period of four years.

Right criteria

Distributing such a funding amount should be subject to detailed assessments using a relevant set of criteria. It is very easy to set up criteria on e.g. CO_2 performance, but as it is concluded in Swedish research, giving "priority to technologies with the lowest CO_2 abatement costs is not necessarily a very good idea.

If technologies with the lowest cost are given a high priority by introducing “technology neutral” incentives such as green certificates, it will be difficult for the immature alternatives, with a high potential in the long-term, to complete the formative phase and for an industrial capacity to develop. The alternative is to pursue a long-term industrial policy with technology-specific elements."

When funding technologies it is important not to rule out new emerging and promising technologies. There is a risk of fail when supporting new technologies, but the risk should be accepted and planned for. Applicants could be asked to describe what happens and how the results will be used if a concept does not prove to have a potential. Even if a project fails it could result in creation of e.g. a science and technology infrastructure that can be used for further experiments.

When high efficiency and proven technology is demanded it is important not to sacrifice low cost to obtain high efficiency. Introducing a new criterion taking care of the relation may support a development effort i.a. to decrease production costs as a part of demonstrating new technology - a point that is also made in an ongoing study in the IEA Bioenergy task 32 and task 33 groups.

Increased cooperation and support

In the course of the work, a number of areas have been pointed out where a future effort should be made:

- Increased cooperation between different competences at the university level - a clever combination of Danish competences on mechanical/practical design and deep chemical knowledge is expected to raise the scientific level of the successful Danish solutions and thus increase i.a. the success rate when upscaling the concepts

- Danish experts already participate in international scientific gasification networks. The effort could be even stronger and the cooperation between Danish and foreign universities increased in order to qualify the Danish effort and point the research in the right direction

- It has become the impression that the creation of Ph.D. positions for the biomass area in some cases has been somewhat complicated. There is apparently a diverse understanding of the procedures for acquiring a Ph.D. student for a given project at the the university level and at development environments. Perhaps a stronger promotion of the possibilities and increased support for cooperation activities between the universities and applied research institutions such as the institutes in the Advanced Technology Group (GTS) may help increase the scientific level in the Danish gasification projects

- Danish technology suppliers have proven great expertise in the practical and mechanical design of biomass gasification technologies. More stakeholders call for an improved cooperation between the suppliers and the scientific research level. The result would be an increased knowledge on basic parameters which may show valuable when troubleshooting concepts under development.

- Increased cooperation is needed also between the suppliers and the applied research level. Especially, the focus on maturing technologies and monitoring and documenting performance call for increased involvement of the independent competences of the institutes in the Advanced Technology Group (Danish: GTS)

- During this strategy project it has become clear that there is a demand for exchange of knowledge between the suppliers. There is an interest both to organise common promotion activities and finding a way to solve common technical problems. Previously, the CHP area in Denmark had a so-called Follow-up Programme that collected operational data on biomass CHP plants. A natural forum to lift these challenges could be a Danish Biomass Gasification Network that may be a good supplement to the existing general innovation networks. Such a network would be able to ensure independent documentation of the operation of the technologies and knowledge dissemination to the benefit of suppliers, customers, the support programmes and ultimately of the development of a green energy system. The significance of such initiatives may easily be underestimated.

Focus areas for a commercial breakthrough

Table 16. The most important focus areas for Danish biomass gasification technology

	Focus area	Aim
CHP:	Demonstration of operational reliability	Demonstrate ability to operate continously i.e. convince investors that investment is returned
CHP:	Research in fuel flexibility	Increase the applicability in a broad range of industries
CHP:	Demonstration of gas cleaning technology	Improve upscaling ability
Fuel:	RD&D on gas cleaning	Essential for fuel generation
Fuel:	R&D within gaseous & liquid fuels	Gain deeper understanding of correlation between technology and fuel quality
Fuel:	Demonstration of fuel flexibility	Proving the technology
General:	Optimisation production and O&M costs	Improve feasibility for customer
General:	Improve cooperation between suppliers and universities	Improve understanding of basic processes and enable swift problem solving
General:	Improve cooperation between suppliers and ATG companies	Improve demonstration, monitoring and proving of technologies
General:	Interchange of data & general knowledge between suppliers	Improve general problem solving on gasifier technology development

Table 16 summarises the most important focus areas for Danish technology for thermal biomass gasification which have been pointed out in the work. The focus areas are divided into three categories covering technologies for direct CHP generation, technologies for fuel generation and general issues.

Paying attention to these areas will undoubtedly increase the potential of Danish technologies for thermal gasification of biomass for CHP generation and fuel production and enable the technologies to play a key role in the future Danish energy system and worldwide.

The technologies can contribute significantly to reducing GHG emissions, to the implementation of a fossil free energy system and to create green growth. Developing the technologies will demand an advanced technology knowledge level in society and thus contribute to the vision of the knowledge society.

12 References

AEBIOM [Online]. - 2010. - http://energi.di.dk/Nyheder/Pages/DIBioenergiholdtaarsdagden6oktober2010.aspx.

Ahrenfeldt Jesper, Jørgensen Betina and Thomsen Tobias Bio-SNG potential assessment: Denmark 2020 [Report]. - [s.l.] : ForskNG-projekt nr 10299, 2010.

Bruun Sander Biochar - kan vi både få bioenergi og lagre mere kulstof i marken [Conference]. - Plantekongres : [s.n.], 2009.

BWE COWI [Online]. - 2010. - www.bwe.dk/news 2010-07-14 and www.cowi.dk nyheder.

Danish Energy Agency Energistyrelsen Årlig Energistatistik [Online]. - 24 06 2011. - http://www.ens.dk/da-DK/Info/TalOgKort/Statistik_og_noegletal/Aarsstatistik/Sider/Forside.aspx.

EC Transparency Platform [Online]. - European Commission, 2010. - http://ec.europa.eu/energy/renewables/transparency_platform/action_plan_en.htm.

Energinet.dk Energi 2050 – udviklingsspor for energisystemet [Report]. - [s.l.] : Energinet.dk, 2010.

Energy-Supply [Online]. - 2010. - http://www.energy-supply.dk/article/view.html?id=55874.

Evald Anders Biomasseressourcer. Markedsudvikling, priser, bæredygtighed og risici [Conference] // Temadag om biomasse Axelborg 13. september 2010. - [s.l.] : Dansk Energi, 2010.

Grove A. Personal communication [Interview]. - [s.l.] : Nordisk Council of Ministers, the information office in Kaliningrad, 2010.

Hansen Morten Tony Oplæg til en national handlingsplan for udvikling og demonstration indenfor kraftvarme fra fast biomasse [Rapport]. - [s.l.] : DI Bioenergi and FORCE Technology, 2010.

Hofbauer H Gasification - Technology overview [Book Section] // Thermal Biomass Conversion / book auth. Bridgwater A V, Hofbauer H and Loo S van. - [s.l.] : CPL Press on behalf of Thermal Net, 2009.

http://goteborgenergi.se/Om_oss/Var_verksamhet/Ny_energi/Biogas/GoBiGas [Online]. - May 2011.

IEA International Energy Agency Key World Energy Statistics 2010 [Online] // http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf. - 2010. - 26 05 2011.

IEA-Bioenergy Task 32 meeting. - Toronto, Ottawa, Canada : IEA Bioenergy Task 32 meeting, 2009.

Information [Article] // Information - http://www.information.dk/250847. - 2010. - 14th November 2010.

Nielsen Christian F. B. [et al.] Livscyklusvurdering Dansk El og Kraftvarme, 2008 [Online] // www.energinet.dk. - DONG Energy A/S, Vattenfall, Energinet.dk, April 2010. - 11 08 2011.

Rubæk Gitte Holton Er fosfor i aske plantetilgængeligt - Is phosphorus in ash available for plants (Danish) [Conference]. - Plantekongres : [s.n.], 2007.

Slade Raphael and Bauen Ausilio Cellulosic Ethanol: The path to market [Conference]. - Hamburg, Germany : 17th European Biomass Conference and Exhibition, 29 June - 3 July 2009, 2009.

Sterner M. Specht and M. Regeneratives Methan als Schlüsselspeichermedium in einem Künftigen Erneuerbare-Energien-System [Conference]. - Stuttgart Messe : Internationale Anvenderkonferenz für Biomassevergasung, 2011.
Vestervang Steen Personal communication. - 23/6-2011.
WPAC // BioBytes newsletter. - [s.l.] : Wood Pellet Association of Canada, 2009. - Vol. Vol. 1.
WPAC // Biobytes newsletter. - [s.l.] : Wood Pellet Association of Canada, 2009. - Vol. Vol. 1.

13 Annex 1 - Danish biomass gasification technologies

13.1 Alternating Gasifier

Ammongas A/S, Babcock & Wilcox Vølund A/S

13.1.1 General description

13.1.1.1 What is the name or working name of the concept or technology if any?

Alternating gasifier.

13.1.1.2 What is the main purpose of the gas from your technology?

[x] Internal combustion engine for generation of heat and power
[x] Liquid fuel

13.1.1.3 What is the main product from your technology?

A pure (syn) gas without nitrogen.

13.1.1.4 Which by-products are generated?

Heat.

13.1.1.5 Which residues are generated?

Ash.

13.1.1.6 Technology rationale or specialty

YES! ! ! Most remarkable is the purity and high concentration without nitrogen

13.1.1.7 What is ultimately the thermal input capacity of your technology?

[X] 200+ MW

13.1.1.8 Which market does the technology address? Which customers in which countries or regions?

Countries having bio waste and wanting electricity and liquid fuel.

13.1.1.9 How does the technology differ from other, similar technologies?

Similar do not exist (patented). But compared to other technologies able to make the same gas, our plant is much cheaper and simpler.

13.1.1.10 On which step in the development chain is the technology currently?

[x] Pilot plant

13.1.1.11 Total number of plants and total number of operating hours?

1 plant
50 operating hours

13.1.1.12 How many years will pass from now until the technology is commercially available?

1-2 years

13.1.1.13 What are the next development areas to be addressed with the technology?

More tests at the pilot plant

13.1.2 Further specifications

13.1.2.1 Gasifier principle?

[x] Other, please specify:
A twin bed filter, in which wood chips is gasified by contact with hot gas.

13.1.2.2 Fuel type(s) and moisture content?

13.1.2.3 Energy balance

Not exactly determined until now

13.1.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

Depending on the demand for the actual application

13.1.2.5 Process description - please describe the process in words

The raw material is made into gas by contact with hot gas in a twin bed patented gasifier. The resulting gas consists of 50% H_2, 30 % CO, and 20% CO_2. No tar or soot is in the gas, or produced from the plant.

13.2 Vølund Updraft Gasifier

Babcock & Wilcox Vølund A/S

13.2.1 General description

13.2.1.1 What is the name or working name of the concept or technology if any?

Vølund Updraft Gasifier

13.2.1.2 What is the main purpose of the gas from your technology?

[x] Internal combustion engine for generation of heat and power

13.2.1.3 What is the main product from your technology?

Product gas

13.2.1.4 Which by-products are generated?

Bio oil

13.2.1.5 Which residues are generated?

Ash, water, fluegas

13.2.1.6 Technology rationale or specialty

No problematic residues are produced
Electrical efficiency app. 28% (2 MWe solution with one engine)
Very low TOC in ash
Very reliable technology
High turn down ratio (10 – 100% operation range)
Storable Bio Tar increases CHP plants flexibility

13.2.1.7 What is ultimately the thermal input capacity of your technology?

[X] 15 - 200 MW

13.2.1.8 Which market does the technology address? Which customers in which countries or regions?

Primarily the market of smaller decentralized CHP plants
All countries with district heating and high feed in tariffs for green electricity and heat

13.2.1.9 How does the technology differ from other, similar technologies?

The main advantage of the Vølund Updraft Gasification technology is that the concept does not produce any problematic residues. The tar contaminated water is treated in the TarWatC system (Tar Water Cleaning system) which results in clean water that can be led to the drain

13.2.1.10 On which step in the development chain is the technology currently?

[X] Commercially available

13.2.1.11 Total number of plants and total number of operating hours?

4 plants
130.000/90.000 operating hours (Gasifier/Gas engine)

13.2.1.12 How many years will pass from now until the technology is commercially available?

The technology is all ready commercially available

13.2.1.13 What are the next development areas to be addressed with the technology?

Various optimizations and up-scaling

13.2.2 Further specifications

13.2.2.1 Gasifier principle?

[x] Updraft

13.2.2.2 Fuel type(s) and moisture content?

Wood Chips
35 - 55% moisture content

13.2.2.3 Energy balance

Input		Output	
Unit used, MW or other unit (please specify):			
Fuel input (LHV)	2,859 MW	Power	0,650 MW
Own power consumption	0,068 MW	Heat	2,043 MW
		Gases	
		Liquids	
		Other	
		Losses	0,234 MW
Total	2,927 MW	Total	2,927 MW
Please check that input = output			

Please state the basis:
Operational data
Demonstrated performance
8,474 hours
Single plant

13.2.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

No action

13.2.2.5 Process description - please describe the process in words

Process

The gasilfication process can be divided into the following stages:

- o Drying - moisture evaporation
- o Pyrolysis - releases pyrolysis gases containing hydrocarbons and tar
- o Gasification - partial oxidation/combustion, heterogeneous reaction with CO_2, H_2O and homogeneous water-gas-shift reaction and boudouard reactions
- o Combustion - oxidation/combustion of residual carbon
- o Ash layer

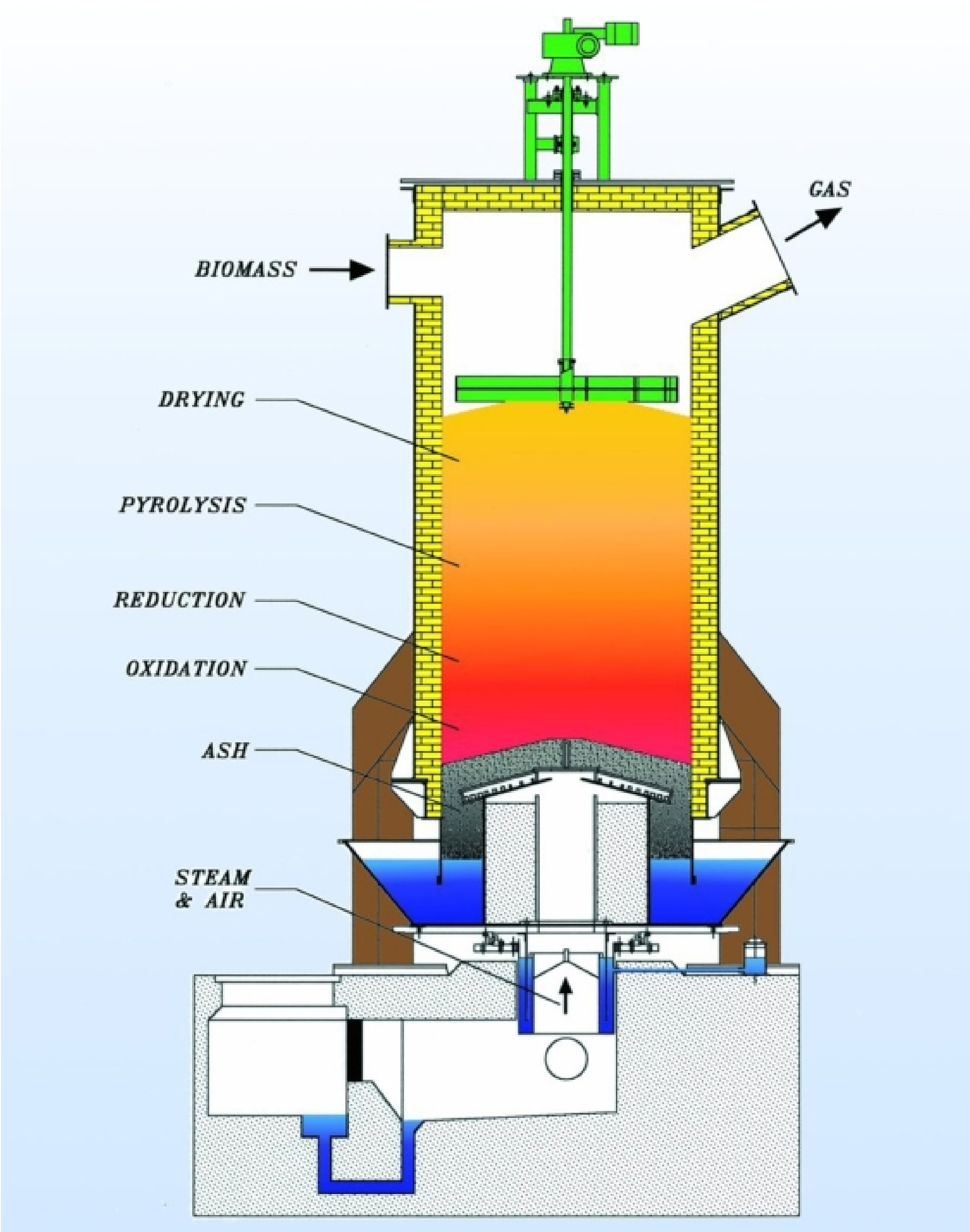
The gasifier produces a product gas with a calorific value of 6-7 MJ/Nm^3 at a low temperature (73-73°C) which makes it useful as a fuel for gas engines. The gasifier produces heavy tar with a calorific value of 29-30 MJ/kg - an excellent by-product that is stored and used as auxiliary fuel at peak load periods during the winter

Please refer to the diagram below

Gas composition

The gas composition before cooling and cleaning:

	vol % wett$_{\text{inclusiv tar}}$
CH_4	2,09
H_2	10,40
CO	16,03
O_2	0,22
CO_2	4,15
N_2	20,80
Light and heavy tar *)	1,89
w-H_2O	44,42



Technical description of gasification plant
The feeding system consists of a simple dosing silo with transport units.

The feeding of biomass by the charging conveyor is controlled to maintain a substantially constant level of the biomass in the gasifier, by having a levelling impeller at the top of the gasifier distributing the biomass over the upper surface thereof, and controlling the charging in dependence of the resistance encountered by the levelling impeller. At the bottom of the gasifier ashes are taken out and disposed of.

The gas from the reactor is taken out at the top and carried in smooth, clean pipes to the gas cleaning equipment. The gas coming out of the reactor has a temperature of approx. 75°C. The gas is cleaned and cooled to 40°C before it is carried to the engine. The exhaust gas is lead to the chimney.

The reactor is not pressurized. There is a constant low pressure which protects against leakage of gas. There is a water trap at the bottom of the reactor which acts as a gas lock.

The product gas produced in the gasifier is delivered to a gas engine driving a generator for production of electrical power. Product gas cleaning equipment in the form of a product gas cooling system and an electrostatic precipitator is located between the gasifier and the gas engine in order to provide a clean product gas for the gas engine. Furthermore, a fan increases the pressure of the product gas in order to feed the gas to the engine. During operation, the gas engine and the generator are controlled to deliver the desired electrical power.

The exhaust gas from the gas engine is led to the exhaust heat exchanger. After this, the flue gas is led to the chimney.

The product gas cooling system is connected to a heat exchanger in order to utilize the energy removed from the gas. Condensate from the product gas cooling system and the electrostatic precipitator is led to a condensate tank. The electrostatic precipitator removes particles/aerosols present in the product gas before delivery to the gas engine.

In the condensate tank, gravity is separating the condensate into bio oil at the bottom and water at the top. The bio oil is used in a separate boiler during peak heat demand. The condensate is cleaned in the TarWatC (Tar Water Cleaning) unit. The TarWatC system is for thermal treatment of condensate.

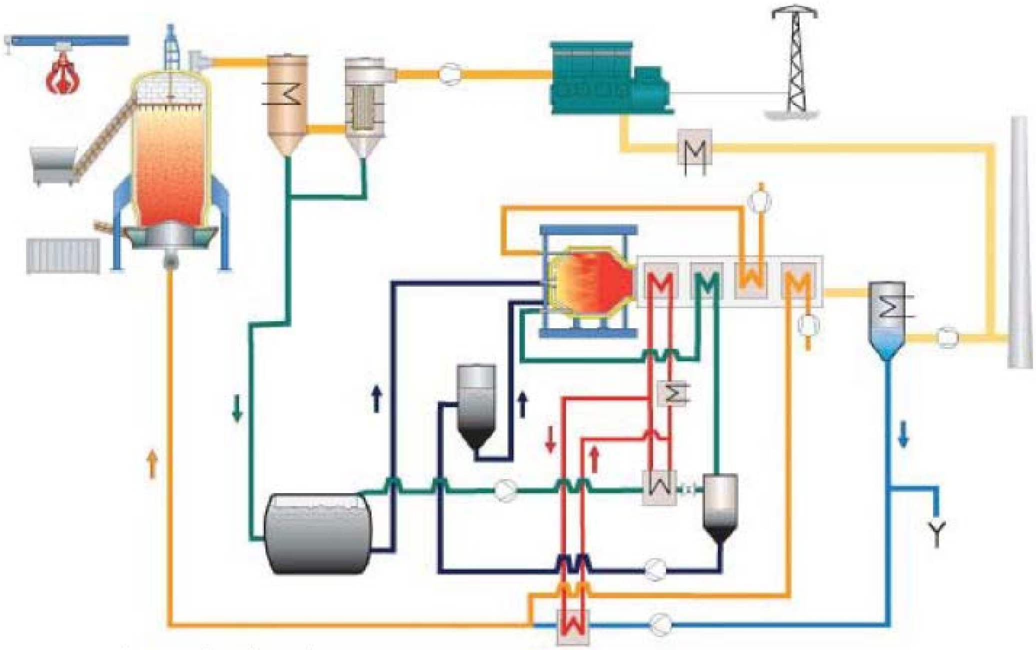
The TarWatC unit, incorporating an adiabatic combustion chamber, offers the possibility of providing a high quality burn-out of the evaporated gas condensate and the additional fuel supplied to the unit, resulting in a low content of CO and TOC (total organic carbon). Afterwards, a flue gas convection part is utilising the energy for the evaporation of the gas condensate.

The bio oil in the condensate tank has a heating value of around 30 MJ/kg and part of it is used for controlling the temperature in the TarWatC unit.

The control of the gasifier is performed by means of the fan for gasification air and is performed in such a way that the gasifier delivers product gas at the top of the gasifier at a constant pressure close to the ambient atmospheric pressure, preferably at 0-10 Pa below the ambient atmospheric pressure. The constant low pressure protects against leakage of gas. There is a water trap at the bottom of the reactor which acts as a gas lock.

During operation, the gas engine and the generator are controlled to deliver the desired electrical power, and the gas booster is controlled to deliver product gas to the gas engine at a constant pressure.

Please see the illustration below for further information concerning the principles of the technology.



Process illustration of a gasification plant

13.3 The CHP system of BioSynergi

BioSynergi Proces ApS

13.3.1 General description

13.3.1.1 What is the name or working name of the concept or technology if any?

The CHP system of BioSynergi

13.3.1.2 What is the main purpose of the gas from your technology?

[x] Internal combustion engine for generation of heat and power

13.3.1.3 What is the main product from your technology?

Heat and power

13.3.1.4 Which by-products are generated?

If not wanted - none

13.3.1.5 Which residues are generated?

Ash/charcoal
Dry fly ashes
Optionally -Wood powder- but also useable as fuel for the gasification process

13.3.1.6 Technology rationale or specialty

- Designed for a common, cheap fuel (wet forest wood chips)
- Simple and reliable
- Only one custom plant component (the gasifier) - all others components are common components
- Generates only dry residues
- High electrical and overall efficiency in particular compared to plant size

13.3.1.7 What is ultimately the thermal input capacity of your technology?

[X] 0 - 1 MW
[X] 1 - 15 MW

13.3.1.8 Which market does the technology address? Which customers in which countries or regions?

- District heating plant
- Industrial customers and public buildings with substantial demand for electricity and heat/cooling in combine

Suitable for countries/regions growing sustainable forestry products and with demand of the above mentioned energy products

13.3.1.9 How does the technology differ from other, similar technologies?

Please refer to point 11.3.1.6.

13.3.1.10 On which step in the development chain is the technology currently?

[x] Pilot plant

13.3.1.11 Total number of plants and total number of operating hours?

1 plant
6000 operating hours

13.3.1.12 How many years will pass from now until the technology is commercially available?

2-3 years depending of degree of political and market drive

13.3.1.13 What are the next development areas to be addressed with the technology?

Erection of full size demonstration plant

13.3.2 Further specifications

13.3.2.1 Gasifier principle?

[x] Open core

13.3.2.2 Fuel type(s) and moisture content?

Fresh forest and industrial non polluted wood chips of common size for grate fired wood chip heating plants. Moisture content in range of 15- 52 %, wet basis

13.3.2.3 Energy balance

Input		**Output**	
Unit used, MW or other unit (please specify):		*MW*	
Fuel input (LHV)	1,15	Power	0,3
Own power consumption	0,015	Heat	0,7
		Gases	
		Liquids	
		Other	
		Losses	0,16
Total	1,16	Total	1,15
Please check that input = output			

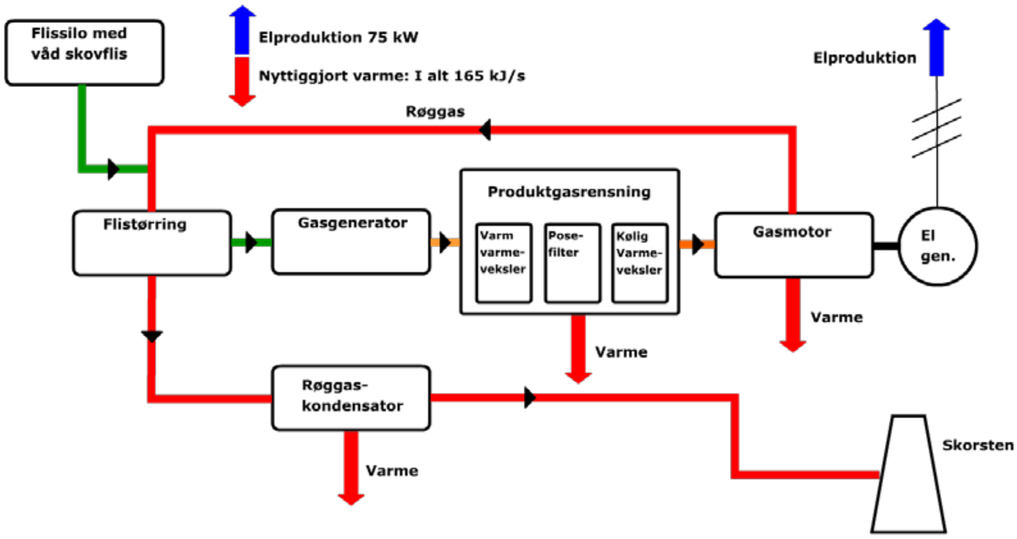
13.3.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

Not detected, not measured - not handled

13.3.2.5 Process description - please describe the process in words

System description

The central process in the combined heat and power system, which converts wood chips into a combustible producer gas, takes place in a air-staged Open Core downdraft gasifier. The producer gas is used as a fuel for a combustion engine, which generates electricity and heat. The plant is designed for automatic unmanned operation.



The principal processes in BioSynergi s combined heat and power system

The system is designed to use ordinary wood chips from forestry operations. Wood chips are produced from surplus of small trees from forestry maintenance operations, which are too small to be sold for other purposes. When the foresters remove some of the small trees, the growing conditions for the remaining trees in the plantation are improved, which in turn improves their quality.

At arrival the fresh wood chips typically have a water content of 40-55%, wet basis. After unloading in the fuel transport system, the wet wood chips are conveyed for drying in a rotating drier. It is heated by the exhaust gas from the gas engine. After drying, the wood chips have a water content of 15-20%, wet basis and are by the mechanical transport system carried along for inlet at the top of the gasifier.

The air-staged Open Core gasifier can virtually be in operation with free air access to the top of the fuel layer at its centre. However, during normal operation, the top is kept closed, enabling preheated air to be supplied for the gasification process. As at true downdraft process, fuel, air and producer gas move in the same direction down through the gasifier.

The internal part of the gasifier is made from fire-resistant ceramic materials and is at the bottom equipped with a movable grate.

Ash from the gasification process is extracted through a water seal at the bottom of the gasifier. From the very beginning of the design phase, the aim has been to ensure that wearing components are easy to replace and for the main sections of the structure to be easy to separate and assemble on-site.

The air flow to the gasification process can be adjusted for distribution between three separate sections within the gasifier. Some of the air is added to the gas flow in the middle of the gasifier and enhance the internal conversion process which converts most of the tar substances from the pyrolysis process.

The temperature of the producer gas is approximately 550°C when it leaves the gasifier. It is cooled immediately as it passes through a heat exchanger, which heats the air for the gasification process.

The producer gas continues to a water-cooled heat exchanger, which cools the gas to approximately 120°C. The producer gas is then cleaned of particles and tars in a bag house filter. The residual product from the bag filter is dry fly ash.

After the bag house filter, the producer gas is cooled once more, and turns out with an appropriate low temperature of approximately 60°C before it is fed to the gas engine. On its way to the gas engine, the producer gas passes a gas suction fan, which maintains under-pressure condition in the gasifier and gas cleaning section.

During the start-up and preheating of the plant, the producer gas is fed through a bypass pipe which circumvents the bag filter. It is then sent by the blower for combustion in an outdoor gas flare.

When preheating of the plant has been completed, the producer gas is fed to the gas engine, where it is combusted after being mixed with air in the engine's intake system. The gas engine is coupled to an electricity generator, which in turn is connected to the national grid.

The heat from the gas engine s cooling water and engine oil is used for heat production, while the exhaust heat is (as mentioned previously) used in the first instance to dry the wood chips. After drying, the energy in the moist exhaust gases is recovered in a condensing exhaust gas cooler.

The condensing exhaust gas cooler also separates water and dust particles from the exhaust gas. The dust comes from the drying of the fresh wood chips. It is filtered out before the surplus water is discharged into the sewer. At the end of the process, the exhaust gas has a temperature of approximately 60-65 °C and is saturated with water vapour when it is led out through the chimney.

Composition of the producer gas

Technical University of Denmark (DTU) has in December 2006, analysed the producer gas from BioSynergi s demonstration plant. The results of these analyses indicated the following typical producer gas composition:

Gas component	Volume % (dry basis)
H_2	18.5
CO	15.8
CO_2	14.1
CH_4	1.6
N_2 (estimated)	50.0

During the measurements, the interval for the lower calorific value of the producer gas was determined to be: 4.6 - 5.4 MJ/mn^3 (mn^3: normal cubic metres). The future 300 kW_{el} plant produces a gas quality which is equivalent or above the values indicated by the measurements done at the smaller demonstration plant.

Energy utilisation and principal data

Of the energy that is added in the form of wet forest woodchips, approximately 26% is converted to electricity and 58% is converted to heat. That estimation is based on the small demonstration plant referred above. Due to scale benefits, higher efficiencies are anticipated for a plant of approximately 300 kWel. Based at results from a mathematical simulation model, the anticipated key values for the future 300 kWel CHP plant is presented in the table.

300 kW_{el} BioSynergi combined heat and power system				
Electricity output	Heat output	Infeed thermal capacity	Gas production	Annual wood chip consumption (45% water content)
[kW]	[kJ/s]	[kW]	[m_n^3/h] (Normal cubic metres/hour)	[Tonnes/year]
300 (26%)	667 (58 %)	1,150 (100 %)	800	2,700

Atmospheric emissions

In December 2006, the Danish Technological Institute carried out authorized measurements on the exhaust gas from the plant s gas engine. The exhaust gases from the engine are the only atmospheric emissions that the plant produces during normal operation. The measurements were taken in the chimney after the drying process.

Measurement results from the demonstration plant, December 2006
Particles <4 mg/m_n^3
CO <1600 mg/ m_n^3
NOx <650 mg/ m_n^3
UHC<100 mg/ m_n^3
[mg/ m_n^3]: milligrams per normal cubic metre. Reference oxygen percentage in exhaust gas: 5% O_2

Residual products and other discharges

The residual products from the gasification process consist of fine charcoal and ash. These residual products are extracted in wet form and can be disposed of at a landfill site.

As mentioned previously, a dry process is used to clean the producer gas for dust and tar. The residual product from the gas cleaning is dry flue ash. Optionally, the residues from the dry process can be extracted in wet form for disposal together with the ash from the gasification process.

The exhaust gas from the wood chip drying is cleaned for wood particles and generates small quantities of wood dust in dry form and wood dust in wet form. This dust product can be disposed of at a landfill site. Condensate from the wood drying exhaust gas is produced from the energy recovery process. This condensate is neutral with respect to pH and can be discharged into a sewer.

Operating tasks and time usage

Typical daily operating tasks consist of supervising the operation of the plant and tasks relating to the reception of wood chips and the disposal of ash and wood dust. It is normally assumed for budget calculation that one man will spend an average of three -four hours per day on the above mentioned operating and servicing tasks.

13.4 Staged Down Draft Gasification

Risø DTU, Weiss A/S, Dall Energy, COWI A/S

13.4.1 General description

13.4.1.1 What is the name or working name of the concept or technology if any?

Staged Down Draft Gasification

13.4.1.2 What is the main purpose of the gas from your technology?

[x] Internal combustion engine for generation of heat and power

13.4.1.3 What is the main product from your technology?

Heat and power

13.4.1.4 Which by-products are generated?

Ash

13.4.1.5 Which residues are generated?

Condensate from cooling product gas before engine and flue gas if possible.

13.4.1.6 Technology rationale or specialty

The technology is distinguished by a high electrical efficiency. It is possible to use commercial wood for CO_2 neutral electricity generation.

13.4.1.7 What is ultimately the thermal input capacity of your technology?

[x] 0 - 1 MW
[x] 1 - 15 MW

13.4.1.8 Which market does the technology address? Which customers in which countries or regions?

At present, the market will exist when electricity transfer price is high enough. There will be many uses, including in areas where infrastructure is not well developed, and where fuel is available locally.

The market is politically determined, so the potential to become very large as the desire for a greener profile.

13.4.1.9 How does the technology differ from other, similar technologies?

High cold gas efficiency and low tar content in gas

13.4.1.10 On which step in the development chain is the technology currently?

[x] Demonstration plant

13.4.1.11 Total number of plants and total number of operating hours?

2 plants - Viking at DTU & plant at Weiss A/S in Hadsund
4000 operating hours

13.4.1.12 How many years will pass from now until the technology is commercially available?

GOOD QUESTION!
Hillerød : 2011-12
Next generation demonstration: 2012-2013
Next generation commercial: 2014 ->

13.4.1.13 What are the next development areas to be addressed with the technology?

Demonstration plant

13.4.2 Further specifications

13.4.2.1 Gasifier principle?

[x] Downdraft
[x] Multiple steps

13.4.2.2 Fuel type(s) and moisture content?

Wood chips - moisture content 30-50%

13.4.2.3 Energy balance

Input		**Output**	
Unit used, MW or other unit (please specify):			
Fuel input (LHV)	1500	Power	500
Own power consumption		Heat	900
		Gases	
		Liquids	
		Other	
		Losses	200
Total		Total	
Please check that input = output			

Please state the basis:
Theoretical performance

13.4.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

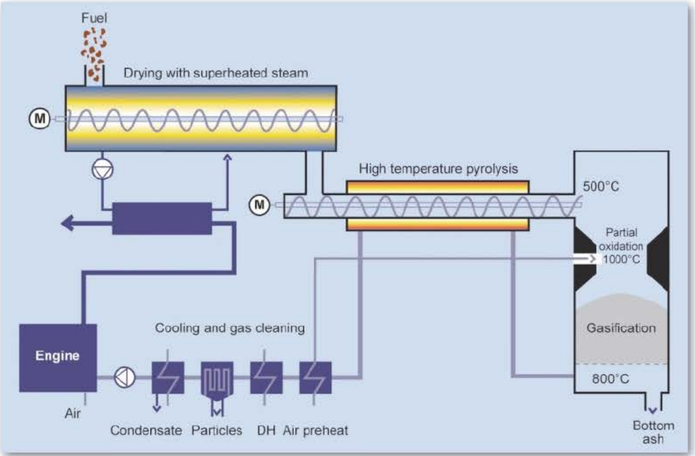
So fare no problems with these components.

13.4.2.5 Process description - please describe the process in words

Basic process steps are: Steam drying of fuel, externally heated pyrolysis, partial oxidation, gasification, gas cooling, bag house filtration, cooling, gas engine.

The new solutions for the next generation two-stage gasification system are confidential. Below is a brochure about the existing technology.

Upscale of the two stage gasifier



The two-stage gasification process is a very stable process.

The cold gas efficiency is very high, and the tar content in the gas is extremely low.

In order to scale up to a commercial attractive size of 1-3MWe, the well-known fixed bed design of the two-stage gasifier was modified

Principle layout of two stage gasifier, where the fuel is dried with superheated steam before the high temperature pyrolysis.

A 500 kW thermal two stage gasification plant for gasification of wood chips with a steam dryer was designed, built and tested.

The pilot plant demonstrated:

- Long term stable operation
- Easy to operate
- High cold gas efficiency

Based on the positive results of the pilot plant a full scale plant is now being prepared in Denmark.

Acknowledgement:
The upscale of the two stage gasifier is supported by Energinet.dk

Bjarne Skyum, Weiss A/S at the 500 kW plant.

Project partners:

WEISS COWI Risø DTU National Laboratory for Sustainable Energy DTU Dall Energy New biomass technologies

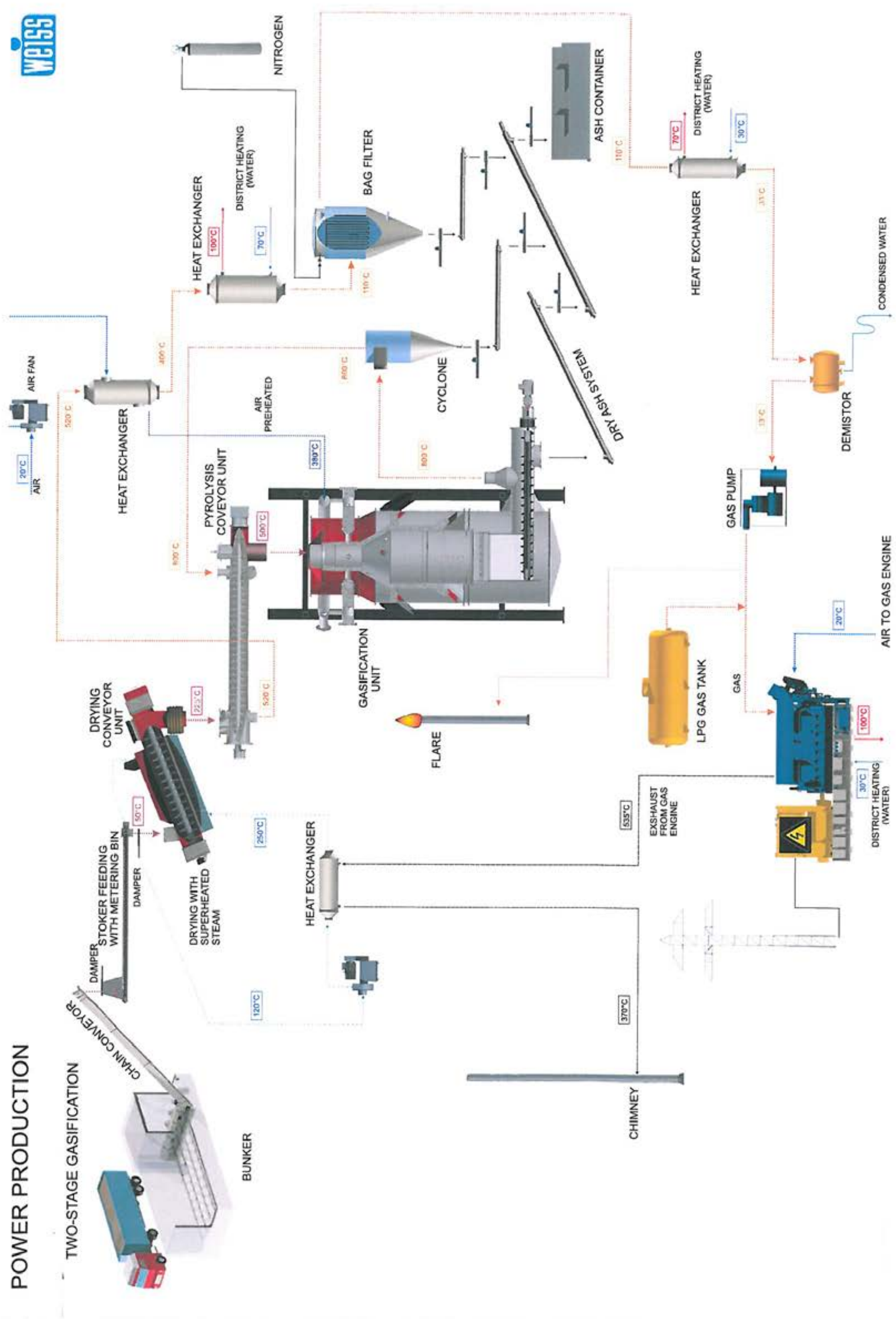
Contacts:

Bjarne Skyum
bjs@weiss-as.dk

Reto M. Hummelshøj
rmh@cowi.dk

Ulrik Henriksen
ubhe@risoe.dtu.dk
Jesper Ahrenfeldt
jeah@risoe.dtu.dk

Jens Dall Bentzen
jdb@dallenergy.com


POWER PRODUCTION
TWO-STAGE GASIFICATION
BUNKER
CHAIN CONVEYOR
DAMPER
STOKER FEEDING WITH METERING BIN
DAMPER
DRYING WITH SUPERHEATED STEAM
DRYING CONVEYOR UNIT
PYROLYSIS COVEYOR UNIT
GASIFICATION UNIT
HEAT EXCHANGER
AIR FAN
AIR
AIR PREHEATED
CYCLONE
HEAT EXCHANGER
DISTRICT HEATING (WATER)
BAG FILTER
NITROGEN
DRY ASH SYSTEM
ASH CONTAINER
HEAT EXCHANGER
DISTRICT HEATING (WATER)
DEMISTOR
CONDENSED WATER
GAS PUMP
FLARE
LPG GAS TANK
GAS
AIR TO GAS ENGINE
DISTRICT HEATING (WATER)
EXSHAUST FROM GAS ENGINE
HEAT EXCHANGER
CHIMNEY

13.5 Pyroneer A/S

DONG Energy A/S, Risø DTU and Danish Fluid Bed Technology ApS

13.5.1 General description

13.5.1.1 What is the name or working name of the concept or technology if any?

The concept is a low temperature circulation fluidised bed gasifier (LT-CFB), formely known as the Stoholm gasifier developed by DFBT. DONG Energy however procured the technology and rights in 2009, with the intention of up-scaling and commercialising the technology. In general the gasifier will be called the low temperature gasifier, and it will be marketed by the DONG Energy subsidiary company Pyroneer A/S, which at present is being established.

13.5.1.2 What is the main purpose of the gas from your technology?

[x] Combustion for generation of heat and power
[x] Gaseous fuel
[x] Liquid fuel

The main commercial purpose the next 5-10 years will be to use the gas for co-firing dust tolerant boilers. When the tar reforming and gas cleaning technology has been developed and proven, the gas can be used in synthesis of methanol, DME, gasoline and SNG, and thus be a integrated part of a bio-refinery.

13.5.1.3 What is the main product from your technology?

The low temperature gasification technology converts all kind of feedstock into a combustible gas, that can be combusted in high efficient supercritical boilers. First generation of gasifiers will only be equipped with a cyclone for dust removal. The intention is also to develop a second generation with more advance gas cleaning.

13.5.1.4 Which by-products are generated?

A mixture of sand and ash (mainly ash), that can be spread on farmland as a fertiliser. Due to the low temperature in the process (750°C) fertilising species as K and P are maintained in a solid state, and are not evaporated, hence these can by a cyclone be separated from the produced gas by a cyclone. Depending on the fuel, the ash will be rich in specially potassium (K) and phosphor (P), which are valuable as fertilisers.

13.5.1.5 Which residues are generated?

No residues are generated

13.5.1.6 Technology rationale or specialty

The low temperature gasification technology enables utilisation of high-alkali fuels such as straw, mischanthus, willow in state of the art power generation technologies, such as ultra supercritical steam boilers operating with electrical efficiencies in the range of +47%.

Normally the combustion of biomass as straw is associated with corrosion problems due to alkaline species as KCl, and hence power plants operates with reduced steam temperature and thus reduced efficiency, compared to what can be obtained when operating on coal. Other kinds of waste fractions such as manure fibres are that troublesome that we with present technologies cannot convert them at all. If biomass and waste is, however, gasified, at a suitable low temperature, the troublesome alkaline species can be maintained in a solid state. By a cyclone, it can then be separated from the created gas, and instead of causing corrosion in the boiler, it can be reused as a fertiliser product.

13.5.1.7 What is ultimately the thermal input capacity of your technology?

[(X)] 1 - 15 MW
[X] 15 - 200 MW

13.5.1.8 Which market does the technology address? Which customers in which countries or regions?

The low temperature gasification technology will firstly be applied in the combustion of the produced gas in dust tolerant boilers. The technology allows agricultural residues and energy crops such as straw, miscanthus and willow to be co-fired in high-efficient coal-fired boilers, and thus replace coal.

The technology is over time expected to be marketed worldwide, however, the starting point will be northern Europe. We expect clients to come from the utility and industrial sector.

It is, however, also the intention to develop a more advanced gas cleaning, which will allow the gas to be used in non-dust tolerant applications within the petrochemical industry and for replacing natural gas in the power industry.

13.5.1.9 How does the technology differ from other, similar technologies?

Traditional biomass CFB gasifiers are not able to use troublesome high-alkali fuels such as straw, mischanthus, willow, etc due to bed agglomeration caused by melting alkali species. However, the present gasification technology operates below the ash melting temperature, and hence alkali species are maintained in a solid state, and can be separated from the produced gas by mechanical methods as cyclones and filters. The low temperature gasifier is a fluidised bed gasifier producing a 650°C hot syngas containing tar and dust. The only gas cleaning will be a refractory lined cyclone removing dust. It is expected that the combination of a low-temperature gasifier and a cyclone makes it possible to remove around 90-95% of the alkali, mainly sodium (Na) and potassium (K). The gasifier efficiency is expected to be 95%, based on the amount of energy from the straw that enters the boiler. Compared to other gasifiers, this gasifier is very fuel flexible.

13.5.1.10 On which step in the development chain is the technology currently?

[x] Pilot plant
[x] Demonstration plant

13.5.1.11 Total number of plants and total number of operating hours?

4 plants
>450 operating hours, expected to increase significantly during 2011-2012

The low temperature circulation fluid bed (LT-CFB) gasification technology was invented in 1997 where the first patent application was filed. A first proof and optimisation of the concept was achieved by building and testing a small 50kW$_{th}$ test plant at The Technical University of Denmark, DTU. Several 50kW$_{th}$ tests and optimisation work were performed within, first small projects supported by the Danish Energy Agency, and thereafter in a first ForskEl project (Eltra PSO no. 3106) which also comprised the design, erection and first start-up of a 500kW$_{th}$ plant also located at DTU. The intention was to test the scalability, more realistic refractory lined construction and basic automation. Since then a new 100KW$_{th}$ has been constructed, in order to perform more detailed test on various fuels. At present the scalability is again being tested in the 6MW$_{th}$ version, able of converting 1.5 tonnes of straw per hour. This plant is located at the Asnæs Power Station, where unit 2 will co-fire the produced gas. This plant will be commissioned during spring 2011, and will provide the needed information required for scaling up the technology to 50MW$_{th}$.

Pilot and demo plant references

a) 50kW pilot test plant

The 50kWth test plant was built at DTU in 1999 based on funding from the Danish Energy Agency. This was the first plant, which purpose was to show that the basic ideas behind the process could work. From 1999 to 2004, several tests were performed with a total of more than 100 hours of operation. The optimal operation window regarding mainly temperatures and flows was identified using several types of fuel (difficult straw, pig manure, hen manure and wood). The process was originally designed for straw, but turned out to be very suitable for gasification of manure fibres too.

The plant worked very well from the beginning, with few technical difficulties and proved the concept: It was possible to gasify difficult biofuels at low temperature and to keep nearly all of the problematic ash components separate from the product gas. The process was also optimised mainly by reducing the char loss, and eventually high efficiency was obtained.

b) 500kW pilot test plant

Based on the good experiences from the 50kWth plant, the 500kWth plant was designed and built at DTU and commissioned in 2004 funded by ELTRA PSO project no. 3106.

The plant was built and later some features were added so that the design was similar to how plants in the MW-class would be made eg with fully ceramic lining, continuous fuel feed and ash extraction. Automation was based on a modern PLC system.

From 2004 to 2006, a total of 186 hours of operation were performed, divided on the commissioning and four subsequent tests within the PSO project no. 4833. Some of the most important test data are included in the table below.

Fuel/Month	Ash % dry	HHV raw MJ/kg	Fuel input kW, HHV	Operation hours at >700°C
Straw Dec. 04+Feb.05	12	15.8	520/485	10+25 h
Pig manure May 05	28	15.2	420/486/552	42 h
Biogas residue Sep. 05	43	9.6	646 (/352)	59 h
Biogas residue Sep. 06	37.5	11.3	531	39 h

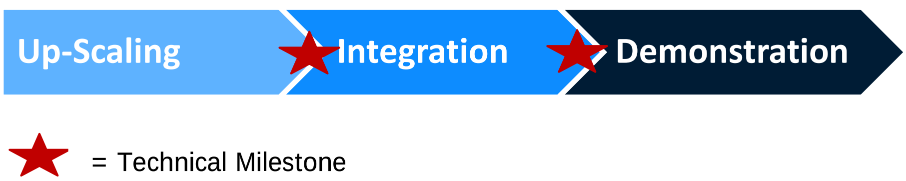
During the tests, different process parameters such as temperatures and fuel input were varied to learn more about the process and effect of the parameters. The process handled the high ash content and low heating value of especially the two different types of biogas residue very well. The process was very stable and easy to control. During the last test, the temperature of the char bed was automatically controlled extremely precisely, which is important when operating close to the bed agglomeration temperature limit.

c) 100kW pilot test plant

The former 50KW plant was replaced with a new, and more automated 100kWth plant which also reflects the experiences achieved with the 500kWth plant. The new 100kWth plant is also used for tests at Risø-DTU with the aim of evaluating various new fuels and options for further cleaning the gas in order to make it usable for more demanding applications. These activities were funded by PSO-Eranet project no. 10111.

d) 6MW demonstration plant

A low-temperature gasifier has recently been constructed in Kalundborg at the Asnæs Power Station. The intention is to verify that the technology can be up-scaled, and to demonstrate a large number of operating hours. The project started mid-2010, and has a duration of four years, with a total budget of DKK 90 million, of which DKK 35 million has been given as support from Energinet.dk through PSO. The project is divided into three phases.



1) **Up-scaling**: Focus will be on engineering and construction of the gasifier. The gasifier will not be integrated with the power plant, and it will only be equipped with the most necessary control and instrumentation equipment needed for safe operation. The purpose is to demonstrate that the gasifier also works in an up-scaled version.

   - 200 hours of testing with 300 tones of straw

2) **Integration**: When the gasifier has been successfully commissioned, it will be integrated with the power station, and focus will be on optimised char conversion, separation of ash, gas transport, burner design, etc. The control and instrumentation system will be improved and connected to the power station. From this period on the product gas will be used for producing power to the grid.

   - 1000 hours of testing with 1400 tonnes of biomass

3) **Demonstration**: The purpose of this period is to equip the gasifier with the needed instrumentation and logic to demonstrate safe and reliable automatic operation during a longer period. The purpose is to demonstrate reliability and to test wear and tear. Furthermore, the plant and the test results will be the reference for future full-scale plants.

   - 2000 hours of testing with 3400 tonnes of biomass

Timeline

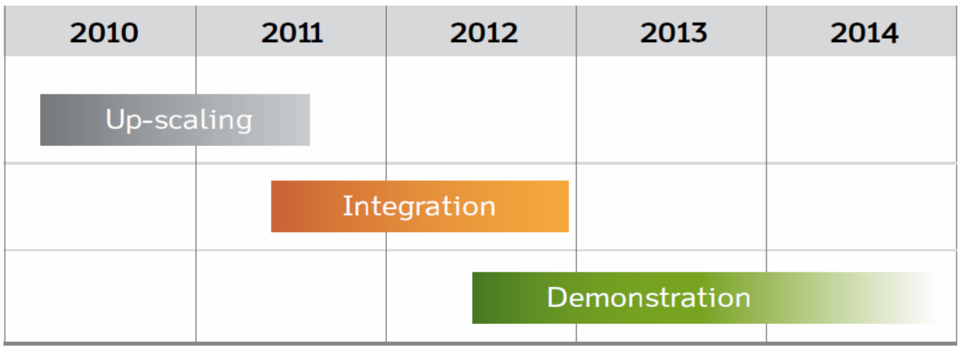


Figure 18: 100KW gasification pilot at DTU

Figure 19: 500KW gasification pilot at DTU

Figure 20: 6MW gasification demo in Kalundborg

13.5.1.12 How many years will pass from now until the technology is commercially available?

The low temperature gasification technology, which has already been tested and verified during three different pilot plants at a size of up to 0.5MW, will be tested in a 6MW demonstration plant from the beginning of 2011, which will provide sufficient learning to further scale up the technology to a commercial size of approx 50-100MW, ready for commissioning in 2015.

An industrial market segment in the scale of 5-20MW_{th}, could, however, be commercially ready already from 2013.

The second generation gasification technology with more advanced gas cleaning could be commercially available from 2018.

13.5.1.13 What are the next development areas to be addressed with the technology?

The next development areas (second generation gasification technology) will be to increase the possibilities for using the generated gas in other applications than dust tolerant boilers. Hence development focus will be gas cleaning.

Due to the low temperature, the total content of tars in the gas will be relatively high, but the specific tar components may be easier to convert than those tars generated in gasifiers operating at higher temperatures. Developing the tar reforming technology will significantly expand the application areas of the technology. The tar reforming technology most likely needs a rather dust free gas, and hence the development and demonstration of a hot gas dust filter is important.

13.5.2 Further specifications

13.5.2.1 Gasifier principle?

[x] Circulating fluid bed

13.5.2.2 Fuel type(s) and moisture content?

The strength of the gasifier is the opportunity to utilise high ash and high alkaline biomass and waste fractions. If the feedstock is wet, it will due to the thermal efficiency most likely be beneficial to pre-dry the feedstock to around 20% moisture.

So-far the following feedstock has been gasified with success:

- Straw
- Pig manure
- Biogas residue
- Chicken litter
- Leftover from Pectin production
- Other organic biomass waste fraction.

Other suitable fuels are:
- Miscanthus
- Willow
- Wood residues
- Sewage sludge.

The below energy balance is based on Danish wheat straw with 16% moisture and 4.5% ash, which results in a lower heating value of 14.6MJ/kg.

13.5.2.3 Energy balance

Input		**Output**	
Unit used, MW or other unit (please specify):			
Fuel input (LHV)	50.00MW	Power	
Own power consumption	0.75MW	Heat	
		Gases	47.80MW
		Liquids	
		Other	
		Losses	2.95MW
Total	50.75MW	Total	50.75MW
Please check that input = output			

The gas can afterwards be converted in supercritical boilers with an electrical effect of +47%. The Energy balance is based on an up-scaled version of the design used in the three previous pilot plants, and based on experimental results obtained in those plants. Hopefully the figures will be confirmed in the $6MW_{th}$ demonstration plant that will go into operation during spring 2011.

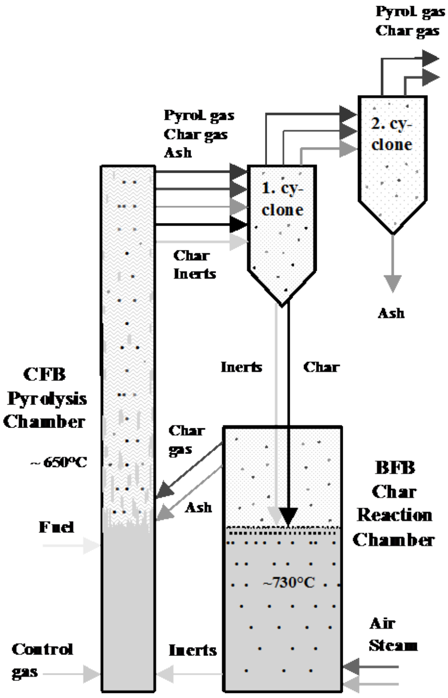
13.5.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

Nitrogen containing species present in the gas is a source for generation of fuel NO_x in the boiler. In Denmark there is a NO_x tax of around 10DKK/kg of NO_x emitted from the stack, and hence various means of reducing the NO_x generation in the boiler are installed, such as stage air combustion. Furthermore, all the larger central power stations are equipped with a NO_x removal unit, called a $DeNO_x$. Normally ammonia is used to reduce NO_x to nitrogen.

13.5.2.5 Process description - please describe the process in words

Small fuel particles enter the pyrolysis chamber and are rapidly pyrolysed at eg ~650°C due to good thermal contact with mainly re-circulated sand and ash particles. Due to the low temperature and retention time in the pyrolysis chamber, essentially only light tars and the least problematic PAHs are formed.

The residual char, pyrolysis gasses and inert particles are blown upwards to the primary cyclone, which separates char and inert particles to a bubbling bed char reactor. Here the char is gasified at typically around 730°C using mainly air. Some steam or water may also be added in order to improve the conversion of char. Due to the low and very stable temperature, only little ash melting takes place, and therefore agglomeration problems can be avoided without using additives.



The produced char gas and fine ash particles leave the top of the char reactor and enter the pyrolysis chamber, where the char gas contributes to the high gas velocity in the upper part. Heavier inert particles re-circulate to the pyrolysis chamber from the bottom of the char reaction chamber while serving as a heat carrier.

The heat release due to the mainly exothermic reactions in the char reactor is consumed by the mainly endothermic processes in the pyrolysis chamber. Therefore, the exit stream out of the pyrolysis chamber has a lower temperature compared to the temperature in the char reactor. Consequently, nearly all alkali and similar ash components are retained in the solid state and can therefore be separated as efficiently as the ash particles entering the cyclones.

No heating or heat absorption surfaces are needed anywhere in the process and all complications and potential problems related to such surfaces are therefore avoided.

Ash particles may re-circulate several times, but eventually the main part will typically escape through the primary cyclone and be separated by the more efficient secondary cyclone. A further coarser ash stream may be drained from the bottom of the gasifier, and in these two ways, typically around 95% of the ash can be retained. The residual eg 5% of the ash will enter the combustion chamber of the coal-fired power station as entrained in the produced, hot combustible product gas.

Based on gasification of 12.4 tonnes straw per hour, the following product gas is expected:

Gas production, wet:	24.5 tonnes/hr - 19,000 Nm^3/hr
Gas LHV, wet:	5.9 MJ/kg - 7.6 MJ/Nm^3
Gas pressure at battery limit:	1.3 bar a
Gas temperature at battery limit:	650 ^{o}C

If the gas is co-combusted in a coal boiler operating with an electrical efficiency of 45%, one could generate 21.5MWh electricity from 12.4 tonnes of straw.

13.6 Close Coupled Gasification (CCG)

EP Engineering ApS

13.6.1 General description

13.6.1.1 What is the name or working name of the concept or technology if any?

Close Coupled Gasification (CCG)

13.6.1.2 What is the main purpose of the gas from your technology?

[x] Combustion for generation of heat and power

13.6.1.3 What is the main product from your technology?

Heat and power, biochar/fertilizer

13.6.1.4 Which by-products are generated?

13.6.1.5 Which residues are generated?

Ash

13.6.1.6 Technology rationale or specialty

Accepts a wide range of biomass/residues and sewage sludge. Highly efficient combustion of gasses. Low NOx design, low CO and particulate emission. High efficiency at low load.

13.6.1.7 What is ultimately the thermal input capacity of your technology?

[x] 0 - 1 MW

13.6.1.8 Which market does the technology address? Which customers in which countries or regions?

Institutional and public buildings. Agro and forestry industry. Light industry – especially wood working. Remote and rural areas of the world.

13.6.1.9 How does the technology differ from other, similar technologies?

High efficient low temperature CCG technology and clean combustion ensures clean boiler operation with low corrosion rate of superheater surfaces on high pressure steam boiler (100 bar, 500°C) Steam generates electricity in advanced oil free, cam less drive steam engine.

13.6.1.10 On which step in the development chain is the technology currently?

[x] Pilot plant

13.6.1.11 Total number of plants and total number of operating hours?

1½ plant
1000 operating hours

13.6.1.12 How many years will pass from now until the technology is commercially available?

2 years

13.6.1.13 What are the next development areas to be addressed with the technology?

Production of fertilizer.

13.6.2 Further specifications

13.6.2.1 Gasifier principle?

[x] Other, please specify: Vibrating grate fluidized bed.

13.6.2.2 Fuel type(s) and moisture content?

Multible - positive test runs with more than 60% moisture.

13.6.2.3 Energy balance

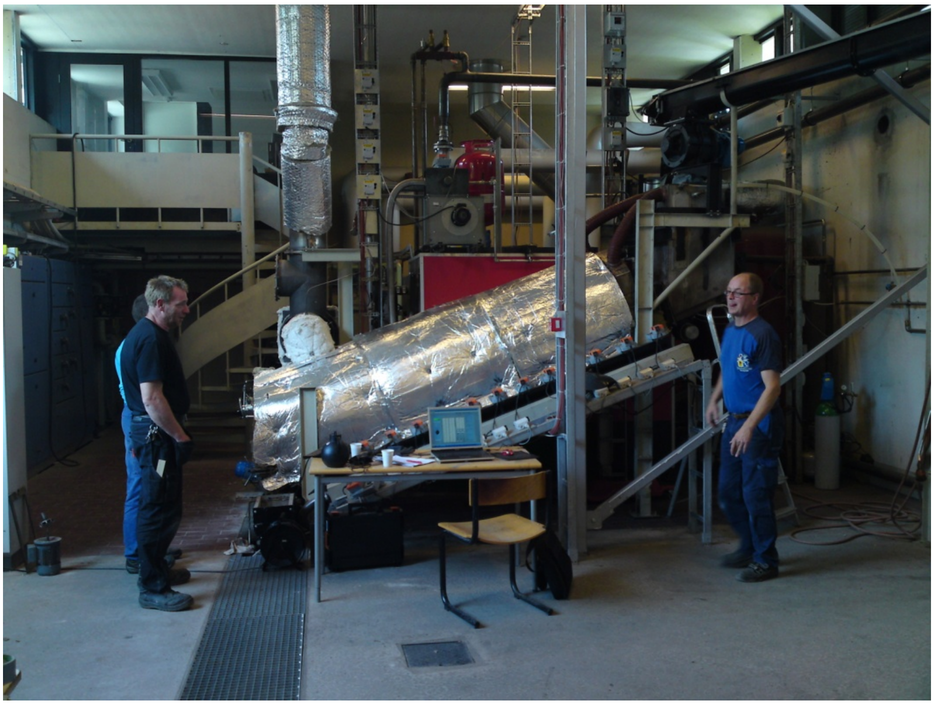
13.6.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

Low NOx design at substoichiometric conditions and following staged combustion of the gas.

13.6.2.5 Process description - please describe the process in words

The unit is fed through a cutting cell sluice on to a vibrating feeder/hopper. It is introduced to the inclined vibrating low temperature gasification grate featuring advanced controlled air and steam gasifying agent. The very long gasifier grate secures possibility of full reduction of fuel to bottom ash if this is desired. Products like biochar, char and activated carbon do not call for the long grate and can be produced at temperatures up to 500°C. Full burn out requires gasification temperatures of up to 700°C

The off gas is primarily burned in a cyclone burner at high temperature (Up to 1250°C) securing low CO, still low NO_x and possible vitrification/melting of gas carried over particles. The vitrified ash can be used anywhere. The off gas boiler or steam boiler produces warm water or high pressure/temperature steam.



CCG phase A hot water boiler

CCG phase B 100 bar 500°C superheated steam boiler

13.7 Tar reforming, gas cleaning, liquid product synthesis, SNG: technology and catalyst

Haldor Topsøe

13.7.1 General description

13.7.1.1 What is the name or working name of the concept or technology if any?

Tar reforming, gas cleaning, liquid product synthesis, SNG: technology and catalyst

13.7.1.2 What is the main purpose of the gas from your technology?

[x] Gaseous fuel
[x] Liquid fuel
[x] Other, please specify: Chemicals

13.7.1.3 What is the main product from your technology?

See above.

13.7.1.4 Which by-products are generated?

13.7.1.5 Which residues are generated?

13.7.1.6 Technology rationale or specialty

Our technologies are applicable downstream biomass gasification.

13.7.1.7 What is ultimately the thermal input capacity of your technology?

[x] 15 - 200 MW
[x] 200+ MW

13.7.1.8 Which market does the technology address? Which customers in which countries or regions?

Global.

13.7.1.9 How does the technology differ from other, similar technologies?

13.7.1.10 On which step in the development chain is the technology currently?

[x] New concept
[x] Pilot plant
[x] Demonstration plant
[x] Market ready
[x] Commercially available

13.7.1.11 Total number of plants and total number of operating hours?

2 plants
6000 operating hours on Tar reforming

13.7.1.12 How many years will pass from now until the technology is commercially available?

13.7.1.13 What are the next development areas to be addressed with the technology?

For biomass: gasoline production and Bio-SNG production

13.7.2 Further specifications

13.7.2.1 Gasifier principle?

13.7.2.2 Fuel type(s) and moisture content?

13.7.2.3 Energy balance

13.7.2.4 How are nitrogenous compounds / emissions - such as NH_3 and HCN - handled?

Catalytic cracking.

13.7.2.5 Process description - please describe the process in words

13.8 Catalytic low temperature pyrolysis process

Organic Fuel Technology A/S

13.8.1 General description

13.8.1.1 What is the name or working name of the concept or technology if any?

Catalytic low temperature pyrolysis process.

13.8.1.2 What is the main purpose of the gas from your technology?

[x] Combustion for generation of heat and power
[x] Liquid fuel

13.8.1.3 What is the main product from your technology?

29% oil and 20% gas

13.8.1.4 Which by-products are generated?

Water

13.8.1.5 Which residues are generated?

20% residues with approx. 60% carbon and fertilizer product (from the raw material - straw)

13.8.1.6 Technology rationale or specialty

Easy to operate, due to simplicity of the plant. Low capital cost due to simplicity of the plant.

13.8.1.7 What is ultimately the thermal input capacity of your technology?

[x] 1 - 15 MW

13.8.1.8 Which market does the technology address? Which customers in which countries or regions?

End users by direct sale or by agents. Gas to be used for power generation, oil to be used in ships and airplanes (refined) & domestic power generation.

13.8.1.9 How does the technology differ from other, similar technologies?

Low demand of input energy and possibility for high efficiency in the process (conversion from solid raw material to oil/gas).

13.8.1.10 On which step in the development chain is the technology currently?

[x] New concept
[x] Pilot plant

13.8.1.11 Total number of plants and total number of operating hours?

1 plant and a new plant from June 2011

300 operating hours

13.8.1.12 How many years will pass from now until the technology is commercially available?

1-2 years

13.8.1.13 What are the next development areas to be addressed with the technology?

Second generation of test plant and after that a full-scale demo plant. Full scale is 1000 kg oil and 700 kg gas per hour.

13.8.2 Further specifications

13.8.2.1 Gasifier principle?

[x] Other, please specify: Catalytic low temperature pyrolysis process.

13.8.2.2 Fuel type(s) and moisture content?

All materials containing carbon and hydrogen. (Bio products such as straw, wood, refuse from households.) Moisture content 10-15 %, if higher pre drying is needed.

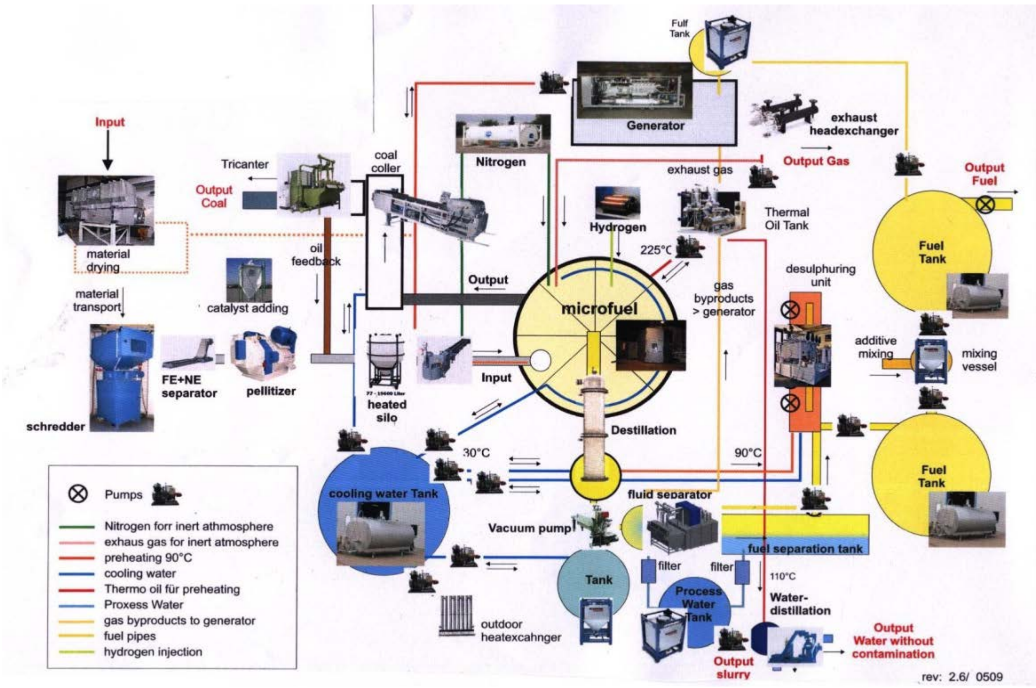
13.8.2.3 Energy balance

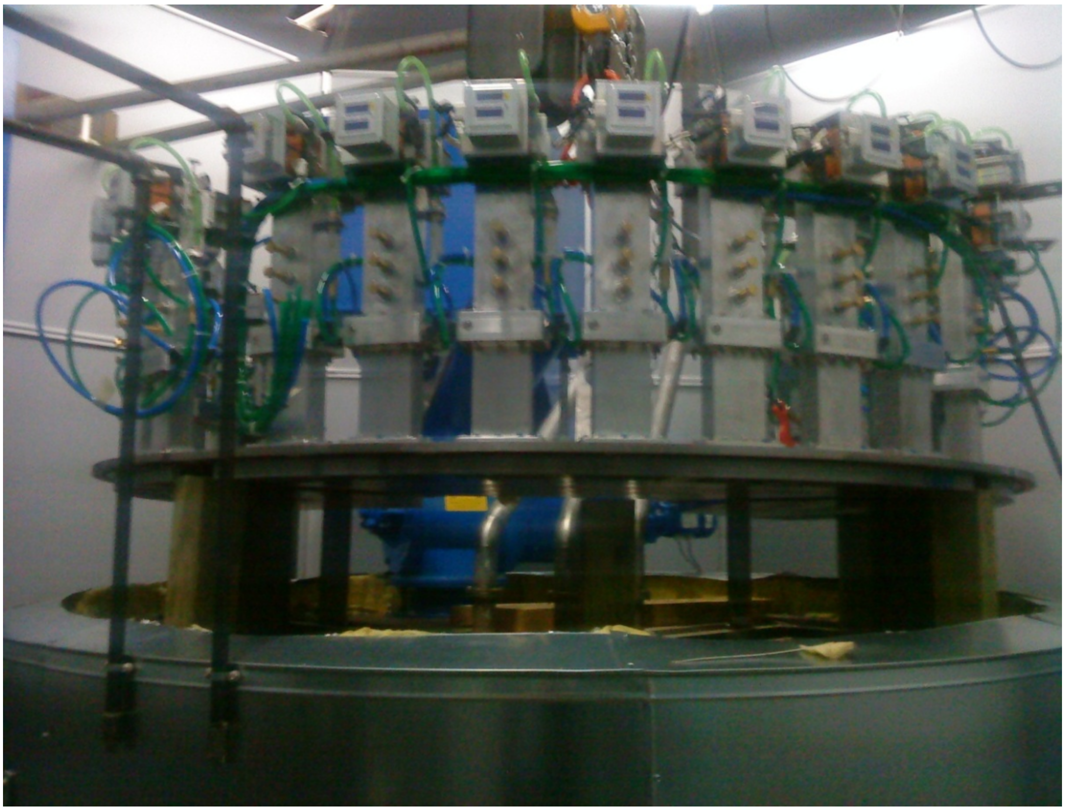
Not yet fully determined, testing is ongoing.

13.8.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

As the process takes place in a reactor in inert atmosphere with low temperature, we don't expect any nitrogenous emissions.

13.8.2.5 Process description - please describe the process in words


Fulf Tank
Generator
exhaust headexchanger
Input
Tricanter
Output Coal
coal coller
Nitrogen
exhaust gas
Output Gas
Output Fuel
Thermal Oil Tank
Hydrogen
225°C
material drying
oil feedback
Output
Fuel Tank
desulphuring unit
material transport
catalyst adding
gas byproducts > generator
microfuel
additive mixing
mixing vessel
FE+NE separator
pellitizer
heated silo
Input
schredder
Destillation
Fuel Tank
30°C
90°C
Pumps
cooling water Tank
fluid separator
Nitrogen forr inert athmosphere
exhaus gas for inert atmosphere
preheating 90°C
cooling water
Thermo oil für preheating
Proxess Water
gas byproducts to generator
fuel pipes
hydrogen injection
Vacuum pump
fuel separation tank
filter
filter
110°C
Tank
Process Water Tank
Water-distillation
outdoor heatexcahnger
Output Water without contamination
Output slurry
rev: 2.6/ 0509



13.9 Stirling engine with up-draft gasifier

Stirling DK ApS

13.9.1 General description

13.9.1.1 What is the name or working name of the concept or technology if any?

Stirling engine with up-draft gasifier

13.9.1.2 What is the main purpose of the gas from your technology?

[x] Combustion for generation of heat and power

13.9.1.3 What is the main product from your technology?

Heat and power

13.9.1.4 Which by-products are generated?

None

13.9.1.5 Which residues are generated?

Ash

13.9.1.6 Technology rationale or specialty

The technology transfers low value biomass in high value CO_2 neutral heat and power. Unique on the Stirling technology is that it was specifically developed for small-scale applications. The Stirling engine based biomass CHP fills a significant technology gap for small scale applications, covering base load heat and power production with low-cost fuels such as biomass. A single unit produces 35 kWe and 150 kWth from 200 kW fuel input. Plants are built by modular units and can consist of up to four engines (140 kWe output) per gasifier.

The advantage in using a Stirling engine over an internal combustion engines is that the heat is transferred to the engine by a heat exchanger. Consequently, the combustion can be seen as a from the Stirling engine separate process. Due to this the combustion can be optimised by establishing adequate high temperatures and residential times in the combustion chamber, in order to achieve low emissions without influencing the electricity production from the Stirling engine. By using the updraft gasifier an almost particle free product gas is generated. The generated tar is not a problem for our application due to the fact that the combustion process takes place out of the Stirling engine. Consequently, there is no need for product gas cleaning. Finally, with the optimised combustion the overall emissions of the plant in terms of CO, NO_x and particles are very low.

Un-manned operation and remote control via internet connection.

13.9.1.7 What is ultimately the thermal input capacity of your technology?

[X] 0 - 1 MW

13.9.1.8 Which market does the technology address? Which customers in which countries or regions?

- o Extreme potential in two separate markets:
- o The industrialized world: Majority of large buildings, industrial facilities, or small societies with a heat demand
- o Remote regions: Substitute technology for diesel generators
- o Total markets potential larger than the global wind turbine market

13.9.1.9 How does the technology differ from other, similar technologies?

There are no other similar technologies in the power output range (35-140 kWe). As the Stirling engine has an external combustion no gas cleaning is needed.

13.9.1.10 On which step in the development chain is the technology currently?

[x] Commercially available

13.9.1.11 Total number of plants and total number of operating hours?

6 plants
12,000 operating hours

13.9.1.12 How many years will pass from now until the technology is commercially available?

13.9.1.13 What are the next development areas to be addressed with the technology?

New combustion technology - flameless oxidation combustion
New engine design

13.9.2 Further specifications

13.9.2.1 Gasifier principle?

[x] Updraft

13.9.2.2 Fuel type(s) and moisture content?

Wood chips, moisture content 35-55%

13.9.2.3 Energy balance

Input		Output	
Unit used, MW or other unit (please specify): kW			
Fuel input (LHV)	200	Power	35
Own power consumption	3	Heat	140
		Gases	-
		Liquids	-
		Other	-
		Losses	28
Total	203	Total	203
Please check that input = output			

Please state the basis:
Seen on different plants (at least 4)

13.9.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

Not relevant

13.9.2.5 Process description - please describe the process in words

The updraft gasifier is fed with wood chips via screw conveyors. Moisture content of the wood chips shall be between 35 and 55 %.

The updraft gasifier delivers product gas at a temperature of around 70° C (LHV ≈ 3.5 - 4.5 MJ/Nm3) to one or more combustion chambers, each situated above a Stirling engine. In contrast to gasifier plants with internal combustion engines, in our process, the tar-filled product gas can be directly combusted with no need for cleaning. The ash from the gasifier is discharged through screw conveyors in the bottom of the gasifier.

The product gas is ignited in the combustion chambers, whereby the top part of the Stirling engines is heated by the flue gasses. The bottom part of the engines is simultaneously cooled by water and the temperature difference between the hot and the cold sides thus drives the Stirling process. This process in turn drives a generator, whereby electricity is generated.

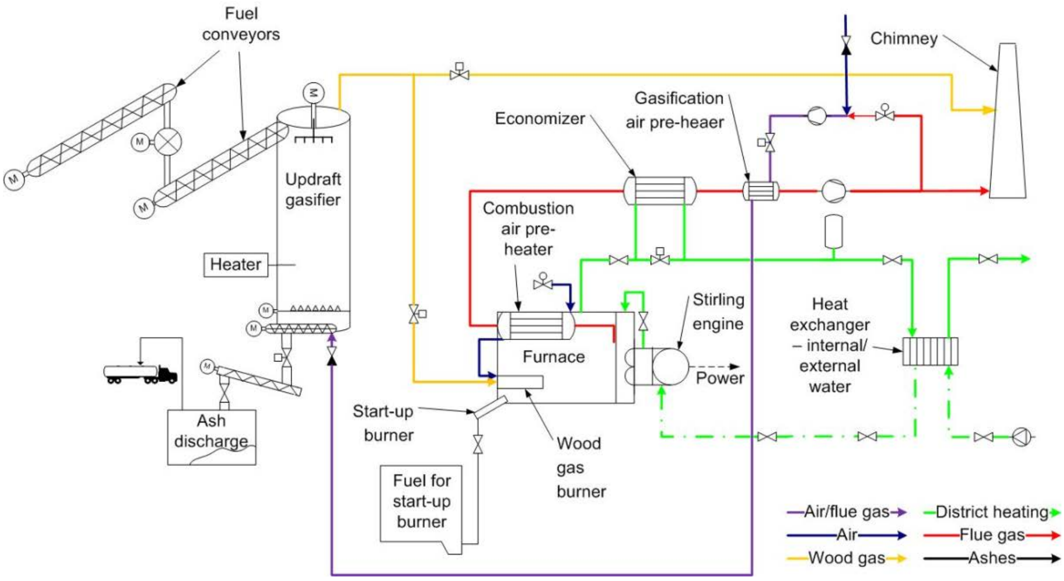
In order to raise the combustion temperature, the intake air is pre-heated by a system of air pre-heaters. The remaining energy in the flue gasses is used to heat the cooling water up to 85 degrees C via an economizer.

The plant is fully automated and is controlled by a PLC with data collection.

A two engine plant fed by 400 kW wood chips, will generate around 70 kWe power and 280 kW heat. Stirling DK offers standard solution with 1-4 engines with an electric output ranging from 35 kWe to 140 kWe.

Data for one engine plant:

Specification	Description
Fuel Type	Wood chips
No. Stirling Engines	1 pcs 35 kWe SD4-E4 engine
Combustion System	Updraft gasification
Operating hours	Expected 6,000 per year
Energy Input	200 kW (~ 70 kg/wood chips (moisture content ~42 %) per hour ~ 420 tonnes/year)
Energy Output	35 kWe electric output ~ 210 MWh/year. 140 kWth thermal output ~ 840 MWh/year



s

P&I diagram (principle) of Stirling gasification CHP plant with one Stirling engine.

Stirling gasification plant at DTU, Lyngby

13.10 BlackCarbon

Stirling DK ApS

13.10.1 General description

13.10.1.1 What is the name or working name of the concept or technology if any?

BlackCarbon

13.10.1.2 What is the main purpose of the gas from your technology?

[x] Combustion for generation of heat and power

13.10.1.3 What is the main product from your technology?

Heat and power

13.10.1.4 Which by-products are generated?

Biochar

13.10.1.5 Which residues are generated?

None

13.10.1.6 Technology rationale or specialty

The production of biochar for use as fertilizer. The technology converts untreated wood to heat, power and biochar.

Efficient small-scale base load power production (one unit plant produces 35 kWe) for solid fuels.

Emissions from the combustion of the product gas in the combustion chamber are very low.

Relatively simple technology – no gas cleaning.

Un-manned operation and remote control via internet connection.

13.10.1.7 What is ultimately the thermal input capacity of your technology?

[X] 0 - 1 MW

13.10.1.8 Which market does the technology address? Which customers in which countries or regions?

Retail through agents in Denmark, Germany, Austria, Italy and UK.

End-customers could be in the agricultural or forestry sector.

13.10.1.9 How does the technology differ from other, similar technologies?

By the production of biochar.

As the Stirling engine has an external combustion no gas cleaning is needed. Further, it is a very compact plant.

13.10.1.10 On which step in the development chain is the technology currently?

[x] Demonstration plant

13.10.1.11 Total number of plants and total number of operating hours?

1 plant
2,400 operating hours

13.10.1.12 How many years will pass from now until the technology is commercially available?

2 years

13.10.1.13 What are the next development areas to be addressed with the technology?

The mechanical design has to be improved in order to address lifetime issues
New combustion technology - flameless oxidation combustion
New engine design

13.10.2 Further specifications

13.10.2.1 Gasifier principle?

[x] Other, please specify: Pyrolysis process in a conveyor

13.10.2.2 Fuel type(s) and moisture content?

Un-treated wood, moisture content < 20 %

13.10.2.3 Energy balance

Input		Output	
Unit used, MW or other unit (please specify): kW			
Fuel input (LHV)	300	Power	35
Own power consumption	3	Heat	110
		Gases	-
		Liquids	-
		Other	110
		Losses	48
Total	303	Total	303
Please check that input = output			

Please state the basis:
Nominal data demonstrated by operating a single plant for 2,400 hours.

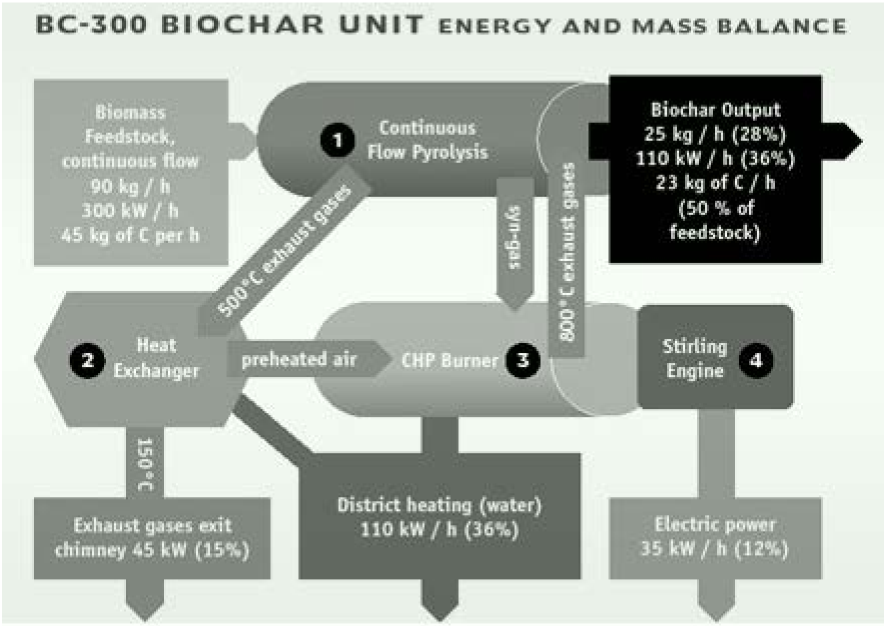
13.10.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

Not relevant

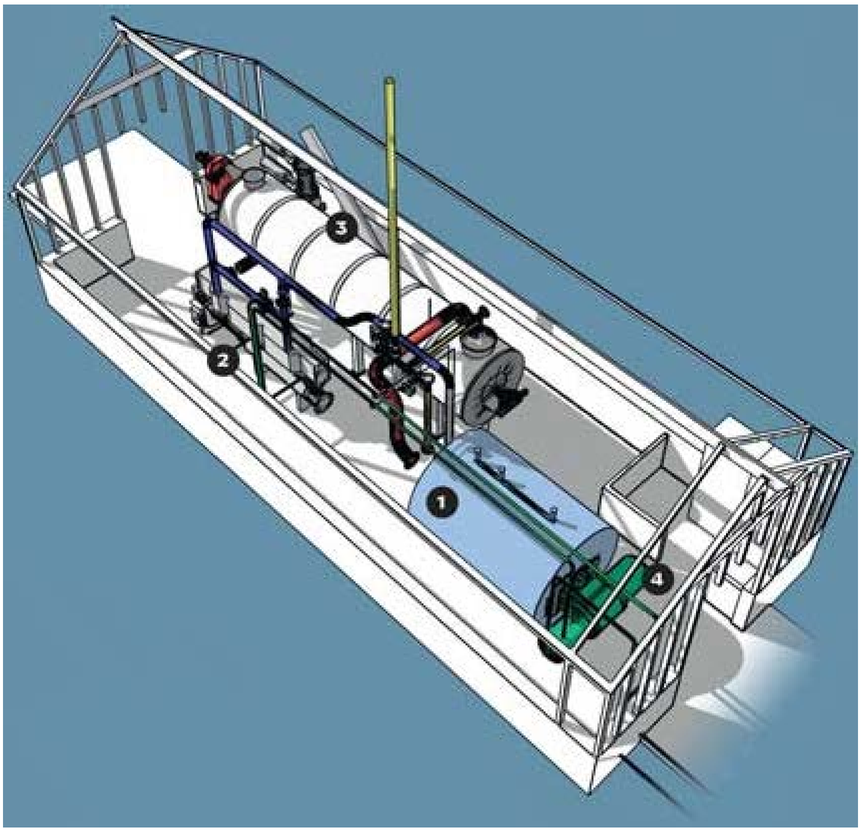
13.10.2.5 Process description - please describe the process in words

Based on the Stirling engine, the plant is fuelled with wood chips which are heated to 600°C without the presence of oxygen. This process creates a pyrolysis gas which is ignited. The heat from the combustion process drives the Stirling engine, generating power.

The plant consists of a 400 kW pyrolysis unit (normally operated at 300 kW), a combustion chamber, and one (1) 35 kWe Stirling engine.



Process diagram for pyrolysis plant.



Plant outline – pyrolysis plant.

13.11 Biomass Gasification Gas Engine (BGGE)

Aaen Consulting Engineers, Skive District Heating, Carbona

13.11.1 General description

13.11.1.1 What is the name or working name of the concept or technology if any?

Biomass Gasification Gas Engine (BGGE)

13.11.1.2 What is the main purpose of the gas from your technology?

[x] Combustion for generation of heat and power

13.11.1.3 What is the main product from your technology?

Product gas for combustion in gas engines, alternatively in gas boilers

13.11.1.4 Which by-products are generated?

In principle no by-products are generated. However the fly ash shows up to contain approximately 70 % of carbon, which of course is utilizable.

13.11.1.5 Which residues are generated?

- Fly ash containing non gasfied carbon
- Wastewater containing hydrocarbons and ammonium in acceptable amounts
- Used carbon from the active carbon filter for the scrubber water
- Used bed material

13.11.1.6 Technology rationale or specialty

The technology offers the possibility for establishment of small size (15 – 50 MW) very efficient CHP plants based on biomass compared to small steam turbine CHP plants.

The technology constitutes a very important step in the development of converting biomass into liquid fuel for transportation

The reformer technology solves when fully developed the tar and ammonium problem in the product gas derived from biomass

13.11.1.7 What is ultimately the thermal input capacity of your technology?

[x] 15 - 200 MW

13.11.1.8 Which market does the technology address? Which customers in which countries or regions?

- Industrial plants with need of electricity, heat and/or cooling
- The market for transportation fuels
- Central and de-central CHP plants

As a utility our only market interest is the purchaser of electricity and the receivers of heat (stakeholders), in both cases via the connected grids.

However I/S Skive Fjernvarme has through an agreement with the technology developer, Carbona, an economical interest in this company's marketing success.

13.11.1.9 How does the technology differ from other, similar technologies?

The pressurized fluidized bed technology offers stable operation conditions due to the heat capacity of the bed material in the range of 15 – 200 MW.

The electricity efficiency is higher than for a corresponding steam turbine plant.

13.11.1.10 On which step in the development chain is the technology currently?

[x] Demonstration plant

13.11.1.11 Total number of plants and total number of operating hours?

1 plant
6,500 operating hours

13.11.1.12 How many years will pass from now until the technology is commercially available?

It is estimated, that the plant is fully developed in 2 – 3 years.

13.11.1.13 What are the next development areas to be addressed with the technology?

- Optimizing of the plant process control, to optimize and stabilize the plant performance.
- Optimizing of the reformer performance.
- Optimizing of the gas filter capacity.

13.11.2 Further specifications

13.11.2.1 Gasifier principle?

[x] Circulating fluid bed

13.11.2.2 Fuel type(s) and moisture content?

Wood pellets, 8 – 10 % humidity.
Other dry biomass fuels possible.

13.11.2.3 Energy balance

Input		**Output**	
Unit used, MW or other unit (please specify): MW			
Fuel input (LHV)	14,5	Power	3,0
Own power consumption	0,5	Heat	8,9
		Gases	
		Liquids	

		Other	
		Losses	3,1
Total	15,0	Total	15,0
Please check that input = output			

13.11.2.4 How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

The amount of nitrogenous compounds in the product gas is reduced in the reformer and the following scrubber system. However the NO_x concentration in the exhaust gasses exceeds the limits stated by the environmental authorities in the plant's environmental approval, but the plant has received a temporary dispensation from the demands.

After the reformer the product gas is washed in the scrubber. This leads to a high concentration of ammonium in the wastewater from the scrubber. However, even though the ammonium concentration has exceeded the limit, a permission to discharge the scrubber water to the sewer is obtained.

13.11.2.5 Process description - please describe the process in words

Gasification Plant

The Gasification Plant includes fuel feeding, gasification and gas treatment (gas cooling, cleaning and distribution).

Fuel is supplied from an indoor wood pellet storage next to the Gasification Plant. The fuel storage at the gasification plant is filled up through an underground conveyor, elevator and elevated belt conveyor. Fuel is moved by grab crane from the storage to the chute of the fuel elevator feeding the gasification plant. The fuel elevator forwards the fuel to the gasifier feeding lines through a distributor conveyor screw.

The feeding system includes two feeding lines containing weigh hopper, lock hopper and surge hopper. Fuel is fed by feeding screws into the gasifier, to the lower section of the fluidized bed. Air and steam are used as gasification mediums. The product gas generated in the gasifier contains carbon monoxide (CO), hydrogen (H_2) and methane (CH_4) as main combustible components. The inert gas components are nitrogen (N_2), carbon dioxide (CO_2) and water vapor (H_2O). The gasifier bed material is limestone or dolomite, which is fed through a separate feeding line. The bed material and ash removal occurs through the grid/bottom of the gasifier. The fine ash elutriated from the fluidized bed is partly separated from the product gas in a cyclone, which returns the solid material into the fluidized bed.

The gas contains some tar components (light and heavy hydrocarbons) as well. Tars will be destructed in the tar cracker (the reformer) unit following the cyclone of the gasifier. The tar cracker contains catalyst material, which decomposes hydrocarbons to hydrogen (H_2) and carbon monoxide (CO). The catalyst decomposes also ammonia to nitrogen and hydrogen.

Gas engine requires product gas of 80% relative humidity at 40 °C gas temperature, therefore the gas is conditioned to this condition. The clean and conditioned product gas is fed to a gas buffer tank, which supplies the gas engines or the gas boilers. The gas buffer tank is connected to the flare for transient operation.

Power Plant

The CHP plant is based on three (3) gas engines of JMS620GS (Jenbacher AG, Austria) type. The gas engines are four-stroke, air/gas mixture turbocharged, after cooled engines with high performance ignition system and electronically controlled air/gas mixture system. The engines are equipped with the advanced LEANOX lean-burn combustion system developed by Jenbacher AG to control NOx emissions. The exhaust system of the gas engines is equipped with CO catalyst to reduce CO emissions. The CO catalyst is an oxidizing catalyst of Pt-Rh type operated at 420-450 °C. The gas engines are equipped with exhaust silencers.

The heat of gas engine cooling (lubrication oil, jacket cooling and first stage inter cooler) and the gas engine exhaust gas is recovered producing district heat in separate heat exchangers. The CHP plant is equipped with a common stack accommodating the separate exhaust pipes of the gas engines and the gas boilers.

Heating plant

The gasification plant is also connected to a 2*10 MW gas boiler plant for utilization of the product gas, when the gas engines are out of operation.

Auxiliary Systems

The CHP plant operation is supported by several auxiliary systems.

Nitrogen is used for inertization, purging and pressurization in the gasification process. A membrane type nitrogen generation unit will be applied.

Instrumentation air will be supplied by a separate instrumentation air system.

Demineralized water is used as makeup water for the closed cooling circuit scrubbers, equipment cooling system and district heat water system. Demineralized water is supplied by the existing water preparation plant. The makeup water (boiler water quality) for the gas cooler is prepared in a polishing step utilizing demineralized water from the existing water preparation plant.

Process condensate removed from the gas scrubbers is filtered and pH is adjusted in the process condensate treatment system.

Light fuel oil system will be installed to supply fuel for gasifier startup and pilot fuel for flare and gas boiler operation.

DESIGN BASIS

CHP Plant Capacity

The selected capacity of the CHP plant is 10-12 MJ/s district heat and 5-6 MW electrical capacity. This plant size can be adjusted to the annual heat demand of I/S Skive Fjernvarme's consumers as a base load plant. The exact capacity of the CHP plant is determined by the heat demand of the gas engines. The fuel heat input of the gasification plant is the following:

- base load operation 19.5 MJ/s
- extended load operation 28.0 MJ/s

Fuel

The design fuel is wood pellet, of 9.5 % av. moisture content. Selected fuel properties are the following:

- fuel heating value:

HHV	kJ/kg (d.b.)	20260
LHV	kJ/kg (d.b.)	18990

- fuel properties as fed:

moisture content	%w	9.5
pellet size	mm	8 (diameter)
	mm	10-30 (length)
density	kg/m^3	550-650

Design Assumptions

Gas Engine 3xJMS620GS (Jenbacher AG, Austria)

Capacity	kW	1968 @ BMEP=13 bar
Efficiency	%	37.8 @ BMEP=13 bar

BMEP = Brake Mean Effective Pressure

Startup fuel	biomass derived gas	
Gas supply pressure	mbarg	250
Gas supply temperature	°C	40

Gasifier

Confidential

Plant General

Annual operation	h/a	8000
Technical lifetime	years	15

PLANT PERFORMANCE

Overall Plant Performance

The design of the Gasification Plant is based on the overall CHP plant performance, which was calculated based on the above-described assumptions. The overall plant performance is the following:

		Base load	Extended load
Fuel consumption:			
• Fuel flow as received	t/h	4.13	5.95
• Fuel heat input as received	kJ/s	19488	28037
Generation:			
• Gross Power	kW	5904	5904
• Auxiliary Power	kW	483	697
• Net Power	kW	5421	5207
• Net District Heat (50/94 °C)	kJ/s	11480	13222

Gas production exceeding 17000 kW is led gas boilers

Gasification Plant Performance

Condifidential

Emissions

Air emissions

Flue gas from gas engine:

CO	mg/m^3n	<500 * (with catalyst)
NOx	mg/m^3n	<550 * (LeaNOX**)
SOx	negligible, (wet scrubbing)	
Dust	negligible, (filter and wet scrubbing)	

** Dry exhaust gas at O_2=5%** Low-NOx combustion system developed by Jenbacher AG*

Flue gas from flare:

Destruction efficiency 97.5-99.5%

Solid wastes

Gasifier and filter ash	t/h	0.079 (base load – design)

Liquid waste

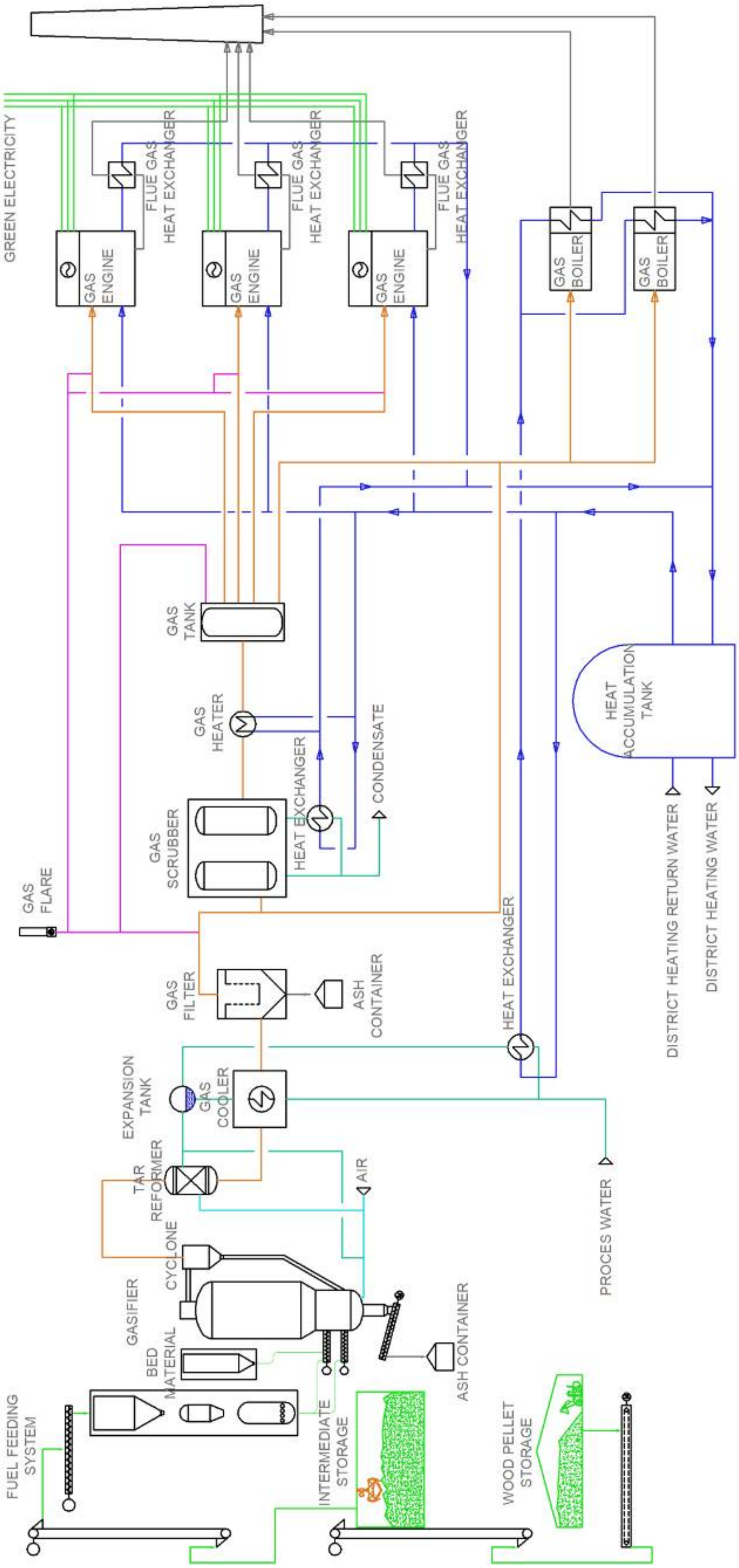
Process condensate from scrubber:	t/h	0.54 (base load – design)

Own consumption

The CHP plant's own consumption is at base load as follows:

Electric power (gasification plant)	kW	490
Electric power (power plant)	kW	14
LFO (flare)	kg/s	0.002
District heat (gasification plant)	kJ/s	20

PLANT DESIGN



14 Annex 2 - List of current Danish gasification plants

The listings below represent a collection of projects selected by the market actors. The list covers demonstration plants and plants in commercial operation.

14.1 Babcock & Wilcox Vølund A/S

Plant name	**Harboøre Varmeværk (DH plant)**
Location	Industrivej 1, 7673 Harboøre
Year/month of commission	1993
Owner type (Domestic, industrial, energy provider etc.)	Joint ownership (BWV & Harboøre Varmeværk)
Fuel	Wood chips
Capacities (Input and output)	Please see above for energy balance
Principles/description	Please see above for process description
Actual operational hours	> 130.000/90.000 hours (Gasifier/Gas engine)
Observed annual efficiencies	app. 92%
Investment and public funding	> 110 MDKK
Status (In operation, not in operation etc.)	In operation
Number of plants of same type	1
Contact information	

14.2 BioSynergi Proces ApS

Plant name	**Castor pilot plant**
Location	Græsted, Denmark
Year/month of commission	2003
Owner type (Domestic, industrial, energy provider etc.)	Manufacturer owned
Fuel	Forest wood chips, moisture content up to 52 %, wet basis
Capacities (Input and output)	340 kW thermal electricity 75 kW heat 165 kW
Principles/description	Open Core fixed bed gasifier
Actual operational hours	3800 h with electricy production, 6000 h in total
Observed annual efficiencies	Not used for regular production
Investment and public funding	Yes
Status (In operation, not in operation etc.)	Used for development projects
Number of plants of same type	0
Contact information	BioSynergi Proces ApS

14.3 DONG Energy A/S

Plant name	**6MW demonstration plant** PSO project B4C
Location	DONG Energy Asnæs, Kalundborg
Year/month of commission	1/3 2011
Owner type (Domestic, industrial, energy provider etc.)	Private, DONG Energy is 100% owner
Fuel	Straw
Capacities (Input and output)	6MWth, corresponding to 1.5 tonnes/h
Principles/description	Low temperature circulation fluidised bed
Actual operational hours	At present during commissioning
Observed annual efficiencies	
Investment and public funding	Total project is DKK 90 million, DKK 35 million from PSO
Status (In operation, not in operation etc.)	During commissioning
Number of plants of same type	0
Contact information	andbo@dongenergy.dk

14.4 EP Engineering ApS

Plant name	**CCG Phase A**
Location	Herlufsholm School and Manor
Year/month of commission	August 2010
Owner type (Domestic, industrial, energy provider etc.)	Domestic
Fuel	Wood chips
Capacities (Input and output)	Demonstrated 400 kW boiler capacity. Can be improved.
Principles/description	Vibrating fluidized fuelbed.
Actual operational hours	Around 1000
Observed annual efficiencies	-
Investment and public funding	More than 5 mio. DKK/public funding 0
Status (In operation, not in operation etc.)	In operation
Number of plants of same type	1
Contact information	EP Engineering +45 40 615 600

14.5 Organic Fuel Technology A/S

Plant name	**OFT CDP 1000**
Location	Aagårdsvej, Ødum, 8370 Hadsten and (Pier 1, Harbour, Randers)
Year/month of commission	2008
Owner type (Domestic, industrial, energy provider etc.)	Industrial (oil production only)
Fuel	Mainly straw (as pellets)
Capacities (Input and output)	100 kg of straw / ~30 liter of raw oil)
Principles/description	
Actual operational hours	150 – 200 running hours (batch process)
Observed annual efficiencies	
Investment and public funding	
Status (In operation, not in operation etc.)	OFT CDP 1000 operates as a test bed periodically with an output of ~30 liter.
Number of plants of same type	1
Contact information	

14.6 Stirling DK ApS

Plant name	**Flensburg**
Location	Langballig, Germany
Year/month of commission	2009/12
Owner type (Domestic, industrial, energy provider etc.)	Energy provider
Fuel	Wood chips
Capacities (Input and output)	400 kW input, 70 kWe and 280 kWth output
Principles/description	CHP plant with 800 kW updraft gasifier and two Stirling engines
Actual operational hours	~2,000 hours on each engine
Observed annual efficiencies	15 % (elec.)
Investment and public funding	Investment: ~ €500,000, public funding: ?
Status (In operation, not in operation etc.)	In operation
Number of plants of same type	0
Contact information	Annabell Möller, tel.: +45 88184807 @ am@stirling.dk

Plant name	**DTU**
Location	Lyngby, Denmark
Year/month of commission	2009/09
Owner type (Domestic, industrial, energy provider etc.)	State org.
Fuel	Wood chips
Capacities (Input and output)	200 kW input, 35 kWe and 140 kWth output
Principles/description	CHP plant with 200 kW updraft gasifier and one Stirling engine
Actual operational hours	3,000 hours
Observed annual efficiencies	15 % (elec.)
Investment and public funding	Investment: ~ €242,000, public funding: 0
Status (In operation, not in operation etc.)	In operation

Number of plants of same type	2
Contact information	Jakob Falther, tel.: +45 88184806 @ jbf@stirling.dk

Plant name	**Barrit**
Location	Barrit, Denmark
Year/month of commission	2010/10
Owner type (Domestic, industrial, energy provider etc.)	Agriculture
Fuel	Wood chips
Capacities (Input and output)	600 kW gasifier, 35 kWe and 140 kWth output
Principles/description	CHP plant with 200 kW updraft gasifier and one Stirling engine
Actual operational hours	200 hours
Observed annual efficiencies	15 % (elec.)
Investment and public funding	Investment: ~ €170,000 (second-hand plant), public funding: 0
Status (In operation, not in operation etc.)	In operation
Number of plants of same type	2
Contact information	Jakob Falther, tel.: +45 88184806 @ jbf@stirling.dk

Plant name	**Ireland**
Location	Carlow, Ireland
Year/month of commission	2011/01
Owner type (Domestic, industrial, energy provider etc.)	Research Institute
Fuel	Wood chips
Capacities (Input and output)	800 kW gasifier, 35 kWe and 140 kWth output
Principles/description	CHP plant with 200 kW updraft gasifier and one Stirling engine
Actual operational hours	100 hours
Observed annual efficiencies	15 % (elec.)

Investment and public funding	Investment: ~ €260,000, public funding: ?
Status (In operation, not in operation etc.)	In operation
Number of plants of same type	2
Contact information	Jakob Falther, tel.: +45 88184806 @ jbf@stirling.dk

Plant name	**BlackCarbon**
Location	Barrit, Denmark
Year/month of commission	2008/12
Owner type (Domestic, industrial, energy provider etc.)	Industrial
Fuel	Un-treated wood
Capacities (Input and output)	400 kW input, 35 kWe and 140 kWth output
Principles/description	CHP plant with 400 kW pyrolysis unit and one (1) Stirling engine producing 23 kg biochar pr. hour (when operated at nominal load 300 kW input to pyrolysis unit)
Actual operational hours	2,400 hours
Observed annual efficiencies	10 % (elec.)
Investment and public funding	Investment: ~ €250,000, public funding: ?
Status (In operation, not in operation etc.)	In operation
Number of plants of same type	0
Contact information	Gitte Videcrantz, tel.: +45 88184804 @ gv@stirling.dk

14.7 Weiss A/S

Plant name	**500 kWe twostage in Hillerød**
Location	Hillerød Forsyningsselskab
Year/month of commission	2011
Owner type (Domestic, industrial, energy provider etc.)	Destrict heating
Fuel	Wood chips
Capacities (Input and output)	1500 kW input 500kWe output 900kWth output
Principles/description	Gasproduction from wood chips, in at two stage gassifier. Wifh no gascleaning the gas is used in a engine.
Actual operational hours	0
Observed annual efficiencies	0
Investment and public funding	The project is founded by PSO with 10 mill. And the investment is expected to be 20 mill.
Status (In operation, not in operation etc.)	The equipment is expected to be installed in august 2011.
Number of plants of same type	Viking gasifier 20 kWe Hadsund gasifier 200 kWe.
Contact information	

14.8 Aaen A/S - Skive District Heating

Plant name	**I/S Skive Fjernvarme**
Location	Skive
Year/month of commission	2008
Owner type (Domestic, industrial, energy provider etc.)	Private municipal approved district heating company
Fuel	Wood pellets
Capacities (Input and output)	See description above
Principles/description	See description above
Actual operational hours	6.500 hrs.
Observed annual efficiencies	Electricity: 0,24 Heat: 0,70
Investment and public funding	Investment DKK 280 mio.; public funding DKK 35 mio.
Status (In operation, not in operation etc.)	Partly in operation
Number of plants of same type	1
Contact information	bs@aaenas.dk

15 Annex 3 - List of Danish gasification R&D projects

The listings below represent a collection of projects selected by the market actors. The list covers R&D projects.

15.1 Babcock & Wilcox Vølund A/S

Project title	**Dry wood gasification**
Partners	None
Objective	Improve our combined heat&power gasification concept
Progress	Postponed
Budget	500.000 DKK
Funding	Internal
Contact information	Kent Thomsen, Manager R&D, ket@Volund.dk

15.2 BioSynergi Proces ApS

Recordings of 10 projects from Risø library are available at:

http://iis-03.risoe.dk/netahtml/risoe/ENS/efp_uk.htm

Suggestion: Run a search with the term BioSynergi as request.

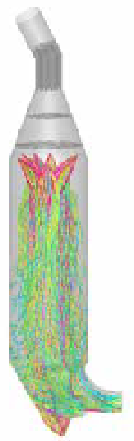
15.3 Dall Energy

Evaporative cooling in biomass gasifiers

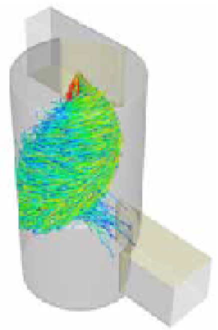
Shell and tube heat exchangers get problems with fouling and tar condensation, as the passage ways are narrow and the coolers have cold surfaces within them.

Evaporative cooling is known as a low cost cooling technology for large industrial plants such as cement plants.

The gases are cooled, whereafter the particles are removed in a simple bag filter.



"Cooling tower" design for gas coolers above 10 MW.
Cooler design by Spraying Systems Co.



"Compact Cooler" design for gas coolers below 10 MW.
Cooler design by Dall Energy

In evaporative coolers the passage ways are large and there are no cold surfaces.

Problems with fouling and tar condensation will therefore be overcome.

We can use evaporative cooling technology in biomass gasifiers!

In the ERANET project new gas cooling and cleaning technologies has been developed and tested.

An evaporative cooler was successfully cooling gasification gas with a high tar content to about 250°C.

Project partners:
Dall Energy, DTU, DFBT, Anhydro, ECN, Dahlman.

Acknowledgement:
The project has been supported by Energinet.dk

15.4 Danish Gas Technology Center

Project title	Forgasning - Fase I - Afklaring af rammer og organisatoriske forhold
Partners	DGC
Objective	Afklaring af rammer og organisatoriske forhold
Progress	Finished
Budget	500.000 kr.
Funding	DONG Distribution, HMN Naturgas, Københavns Energi, Energinet.dk
Contact information	Niels Bjarne Rasmussen, DGC

Project title	SNG from Thermal Gasification of Biomass - Biomass potentials and energy efficiency
Partners	DGC, RISØ
Objective	To describe the state of the art of existing gasification technologies and gas upgrading and give an evaluation of the available feedstock.
Progress	Finished
Budget	637.000 kr.
Funding	ForskNG, DONG Distribution, HMN Naturgas, Københavns Energi, Energinet.dk
Contact information	Betina Jørgensen, DGC

Project title	Forgasning - Fase 2 Økonomi - Teknik - Miljø
Partners	DGC
Objective	Afklaring af de tekniske, økonomiske og miljømæssige aspekter.
Progress	½
Budget	1.5 mio
Funding	DONG Distribution, HMN Naturgas, Københavns Energi, Energinet.dk, Naturgas Fyn
Contact information	Niels Bjarne Rasmussen, DGC

Project title	Detailed analysis of bio-SNG technologies and other RE-gases
Partners	DGC, RISØ
Objective	The purpose of the project is to analyse high efficiency bio-SNG production technologies, potential available biomass and different aspects of the interaction between the bio-SNG gases and the natural gas grid.
Progress	Not started
Budget	2.4 mio kr
Funding	ForskNG, DONG Distribution, HMN Naturgas, Københavns Energi, Energinet.dk
Contact information	Niels Bjarne Rasmussen

15.5 DONG Energy A/S

Project title	**B4C – Biomass for Conversion** Part of the demonstration project
Partners	Risø-DTU,CHEC-DTU, DJF-AAUC, Calderys, DFBT
Objective	Demonstrate the technology, understand the fundamentals
Progress	Mechanical construction finalised
Budget	DKK 90 million
Funding	DKK 35 million
Contact information	andbo@dongenergy.dk

15.6 Danish Technological Institute

Project title	**CATAR**
Partners	
Objective	Gas cleaning
Progress	
Budget	
Funding	EUDP
Contact information	

Project title	**EUROBIOREF**
Partners	
Objective	Gas cleaning
Progress	
Budget	
Funding	FP7
Contact information	

Project title	**Torrefaction demonstration and pilot plant**
Partners	
Objective	Utilisation of pyrolysis gas from torrefaction
Progress	
Budget	
Funding	EUDP
Contact information	

Project title	**Forbedret ressourceudnyttelse af shredderaffald**
Partners	
Objective	Test of pyrolysis method
Progress	
Budget	
Funding	MST
Contact information	H.J.Hansen

15.7 DTU Chemical Engineering

Project title	1. Production of liquid biofuels 2. Production of high value liquid fuels from biomass syngas 3. B4C Biomass for Conversion - Ash chemistry in a circulating fluidized bed 4. Treatment of Lignin and waste residues by flash pyrolysis
Partners	Haldor Topsøe, DONG Energy, Risø DTU,
Objective	1. Initiate steps to provide knowledge for gasification based liquid fuel production 2. Improved understanding of entrained flow biomass gasification and synthesis of higher alcohols 3. To improve the understanding of the chemistry of K, Cl and S in the LT-CFB concept 4. One of the objectives: To investigate if

	Tar/char mixtures can be used as a pump-able slurry
Progress	
Budget	
Funding	1. EFP 2. Danish Agency for Science Technology and Innovation 3. Energinet.dk/DONG Energy 4. Energinet.dk
Contact information	See contact list in annex

The following is a perspective on gasification from DTU Chemical Engineering:

Historically the development of gasification technologies have followed three lines:

- Development of coal gasification technology to be applied for provision of a gas that can be used for liquid fuel and chemicals synthesis. The technology has only been used in areas where oil was not available or for a limited production of chemicals
- Development of pressurized gasification used in combined cycle solid fuel power plants. The objective has been to obtain a high electrical efficiency. The technology has generally not been competitive with pulverized coal fired boilers. The solid fuel combined cycle technology is only slightly more efficient than traditional coal fired plants with advanced steam data, but it is much more expensive and obtains only a low availability.
- Development of small scale (often below 1 MW) fixed bed biomass gasifiers. It has been the objective in many projects to develop a technology for small scale combined heat and power plants. The actual number of operational electricity producing units has been very limited. The application of wood and straw on power producing combustion units as grate-, fluid bed – and suspension fired boilers has increased significantly the last 20 years, and the combustion units have been more competitive than the gasification technology.

New conditions arising the last ten years have made the gasification technology more relevant:

- The large use of renewable energy (wind mills) for power supply means that a CO_2 neutral technology with a large and fast electricity load adaption capability is wanted.
- It is wanted to reduce CO_2 emissions also from the transport sector. One of the possible technologies is the production of liquid fuels based on biomass gasification
- USA want a reduced dependency on foreign oil supplies and gasification of domestic solid fuels used for liquid fuel synthesis is a possible useful technology
- A possible efficient CO_2 sequestration technology is based on gasification

DTU Chemical Engineering position on the gasification strategy is summarized below:

- Small scale fixed bed technologies, below 5 MW, will probably have limited market potential, and will only thrive if large technological specific subsidies is provided
- The main gasification technology drivers on a European scale will be to provide CO_2 neutral electricity adaption capacity and provide CO_2 neutral liquid transport fuels for heavy traffic and air traffic. A driver may also be to obtain domestic fuel supplies if oil prices continue to rise.
- This will lead to a market for the following technologies: Intermediate to large scale gasifiers that can operate on biomass and waste as well as use co-firing with coal. There will also be a need for technologies for pretreatment and feeding, gas conditioning and cleaning and synthesis of liquid fuels.
- The main reactor technologies will be based on atmospheric or pressurized fluid bed and entrained flow reactors. The whole plant technologies are generally large and complex and the technological developments can appropriately be done as cooperation projects of companies and universities that also include foreign institutions.
- As a University we believe that funding of knowledge build-up on technologies that are relevant some years ahead is important. Such funding insures that specific knowledge is available when industrial development takes place.

A broad range of research equipment for high temperature studies is available at DTU Department of Chemical engineering. This includes the following equipment:

- Entrained flow gasifier
- Small fluidised bed for de-fluidisation studies
- High temperature ash viscosity meter
- Pressurised high temperature liquid fuel synthesis unit
- TGA and fixed bed reactors that can be used for gasification reactivity studies

Further to the market perspectives for the technologies:

- Entrained flow gasification - Global
- LT-CFB. Gasifier for high alkali biomass that supply the gas to a boiler – Initially northern Europe. Later global
- Development of catalysts for the synthesis of liquid fuels – DK/Global
- Pre-treatment of biomass with the objective to provide a product that easily can be injected into a pressurised gasifier – Global

And perspectives on how the technologies differ:

- Entrained flow gasification – Only limited public knowledge is presently available on entrained flow gasification of biomass
- LT-CFB. Gasifier for high alkali biomass that supply the gas to a boiler – This is a unique Danish patented technology
- Development of catalysts for the synthesis of liquid fuels – The work is directed towards developing catalysts for production of higher alcohols that are an appropriate gasoline additive
- Pre-treatment of biomass with the objective to provide a product that easily can be injected into a pressurised gasifier - Only limited public knowledge is presently available on pressurisation of tar/char mixtures

The researchers Anker Degn Jensen and Peter Arendt Jensen at CHEC see a need for further research and development in the following fields:

- Fundamental studies on fuel conversion and ash transformation in gasification systems
- Improved understanding of biomass ash rheology and volatilization in entrained flow gasifiers
- Improved understanding of ash behavior in the LT-CFB systems
- Improved understanding of the influence of fuel and operation conditions on fluid bed de-fluidization
- Optimization of gas cleaning and conditioning systems including removal of tar, particulates, and N and S species from syn-gas
- Improved methods for pretreatment and feeding of biomass and waste into pressurized systems
- Development of entrained flow reactor technology optimized for waste and biomass conversion
- Further development of reactors and catalysts for gas (methane) and liquid fuels production
- Development and operation optimization of advanced multi product gasification plants
- Development of gasification concepts used for CO2 sequestration.

15.8 EP Engineering ApS

Project title	**Gasification Based Micro Steam Power Plants**
Partners	EP Engineering ApS/Herlufsholm School and Manor
Objective	To demonstrate a high efficiency power plant based on a high efficient oil free cam less drive steam engine.
Progress	Being established during 2011
Budget	Total around 6.5 mill. DKK
Funding	Energinet.dk 2.0 mill. DKK
Contact information	EP Engineering +45 40 615 600

15.9 FORCE Technology

Project title	**Green Fuel Cell**
Partners	FORCE, Risoe-DTU, CIRAD, ECN, DTU, CEA, TKE, ICT
Objective	Development and test of two gasifier systems coupled to a fuel cell, including advanced gas cleaning systems
Progress	Finished
Budget	6 mill. €

Funding	50% EU research program, 50% national and in-kind
Contact information	François Broust CIRAD Persyst / UPR Biomasse - Energie 73 rue Jean-François Breton - TA B-42/16 34398 Montpellier Cedex 5 FRANCE Tél : +33 4 67 61 58 43 - Fax : +33 4 67 61 65 15

Project title	**LT-CFB** forgasser, videreudvikling og kommercialisering
Partners	FORCE, DFBT, DTU-Mek, Anhydro
Objective	Continued development of the LT-CFB gasifier, support for establishment of a demonstration unit and optimization in order to realize the commercial potential in the technology.
Progress	Finished
Budget	5.6 mill. DKK
Funding	72 % PSO-program, 28 % partners
Contact information	Peter Stoholm DFBT c/o Forskerparken CAT Universitetsparken 4000 Roskilde

Project title	**IEA Task 33 Gasification of Biomass**
Partners	FOERCE, Approx. 10 international member from the IEA member countries
Objective	Support the national representative in Task 33, gasification in surveys on market and technology for gasification, in organizing events etc.
Progress	Finished
Budget	0.3 mill. DKK
Funding	70 % EFP-program, 30 % FORCE Technology
Contact information	Anders Evald FORCE Technology, Kgs. Lyngby Hjortekærsvej 99 , 2800 Kgs. Lyngby Phone: +45 72 15 77 00, direct: +45 72 15 77 50

Project title	**Lift-off** - Multi agricultural fuelled staged gasification with dry gas cleaning
Partners	FORCE, CIRAD, Gjoel Fjernvarme, TKE, Armines,

	NTUA
Objective	Establishment of a 1.5 MW(th) CHP demonstration plant with a fixed bed gasifier and dry gas cleaning
Progress	Finished
Budget	0.7 mill. €
Funding	45 % EU research program, 55 % partners and national programs
Contact information	Laurent van de Stenne CIRAD 73 rue Jean-François Breton - TA B-42/16 34398 Montpellier Cedex 5 FRANCE Tél : +33 4 67 61 58 43 - Fax : +33 4 67 61 65 15

15.10 Haldor Tøpsøe

We are active in various projects in laboratory to demonstration phase and have an EUDP project together with DTI and Chimneylab.

15.11 Organic Fuel Technology A/S

Project title	**Laboratory test bed placed in Aars. Information strictly confidential**
Partners	
Objective	Test of basic microwave conditions in relation to rawmaterial
Progress	
Budget	
Funding	
Contact information	

15.12 Stirling DK ApS

Project title	**EUDP08-I: Biomass and biofuel based poly-generation for off-grid and grid-connected operation**
Partners	Stirling DK, FORCE Technology, Barritskov, Amager Forbrænding
Objective	To demonstrate the applicability of Stirling engine technology in a range of practical applications. Specifically, the aim of the project is:

	- to make research in possible off-grid solutions. This will require new mechanical engine technology and new control strategies - to develop and demonstrate a Stirling engine based plant which can operate under off-grid conditions and thus prove the potential for the technology as a substitute product for diesel generators - to develop a modular system that enables simple and low-cost transport and erection of the plants - to demonstrate the fuel flexibility of the technology with a range of solid and liquid biological fuel types - to demonstrate alternative use of the heat generated in situations where heat is not needed.
Progress	Plant commissioned and in operation. Fuel test and measurements to be performed.
Budget	DKK 7.6 mil.
Funding	DKK 5.0 mil.
Contact information	Mads Brix Nielsen 88184819 mbn@stirling.dk

15.13 Skive District Heating

Project title	**Process reliability and control**
Partners	Carbona, BW Electronics, Haldor Topsøe
Objective	A very reliable process control for a continuous operation and plant performance.
Progress	New
Budget	Estimated 4 mio. DKK
Funding	EUDP?
Contact information	

Project title	**Gas cleaning**
Partners	Haldor Topsøe
Objective	Cleaning of the product gas from hydrocarbons and ammonium

Progress	Design layout terminated
Budget	Estimated 5 mio. DKK
Funding	EUDP?
Contact information	

16 Annex 4 - List of Danish gasification stakeholders

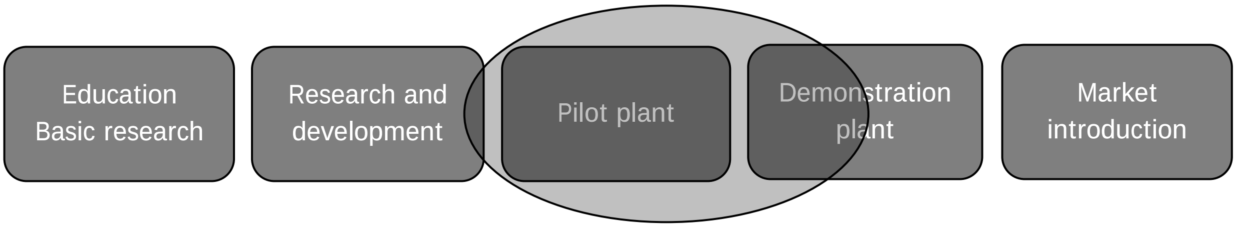
16.1 Danish technology suppliers

16.1.1 Ammongas A/S

Contact data

Company name:	Ammongas A/S
Address:	Ejby Mosevej 5, 2600 Glostrup
Contact person/position:	Anker Jacobsen
Telephone numbers:	43636300
Mail address:	aji@cool.dk
Website:	www.ammongas.dk

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	3	4	4
Turnover, M DKK	2	3	4
Export share	0	0	30%

Ownership

Company, share owned (A/S).

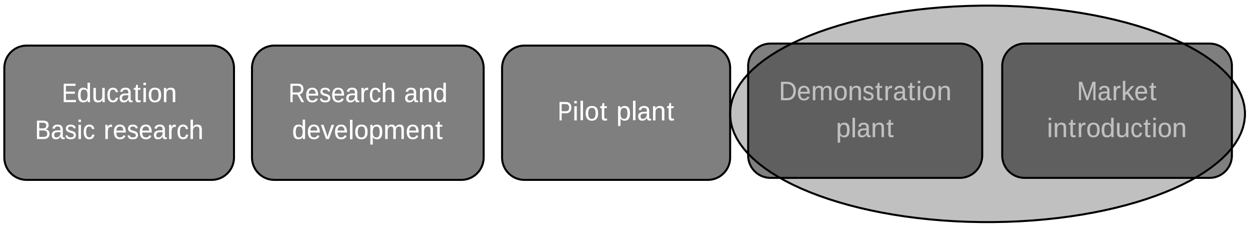
16.1.2 Babcock & Wilcox Vølund A/S

B&W babcock & wilcox vølund

Contact data

Company name:	Babcock & Wilcox Vølund A/S
Address:	Falkevej 2, 6705 Esbjerg Ø, Denmark
Contact person/position:	Thomas Hopp, Department Manager, Gasification
Telephone numbers:	0045 21296092
Mail address:	thh@volund.dk
Website:	www.volund.dk

Area of operation



Demonstration plant operated in Harboøre (Denmark) since 1993.
Gas engine operation at same plant since 2001.

Economic key figures

	2008	2009	2010
Number of employees	361	389	387
Turnover, M DKK	580	632	697
Export share	73%	82%	88%

Ownership

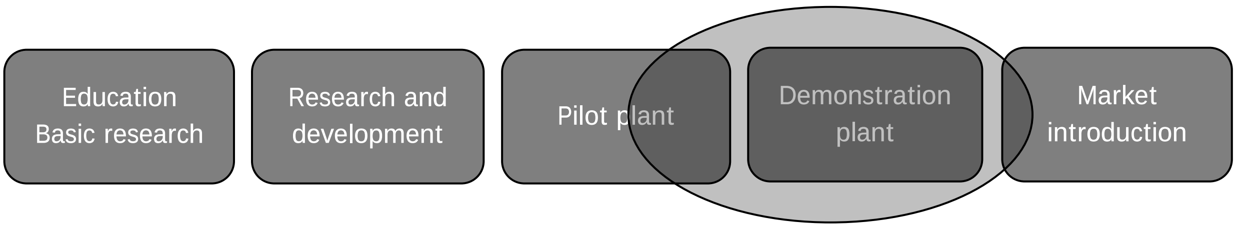
Babcock & Wilcox Vølund is 100% owned by The Babcock & Wilcox Company in Barberton, Ohio, USA.

16.1.3 BioSynergi Proces ApS

Contact data

Company name:	BioSynergi Proces ApS
Address:	Slotsbakken 108, 2970 Hørsholm
Contact person/position:	Henrik Houmann Jakobsen, Managing director
Telephone numbers:	+45 45 86 14 30
Mail address:	hhj@biosynergi.dk
Website:	www.biosynergi.dk

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	4	4	5
Turnover, M DKK	n/a	n/a	n/a
Export share	0	0	0

Ownership

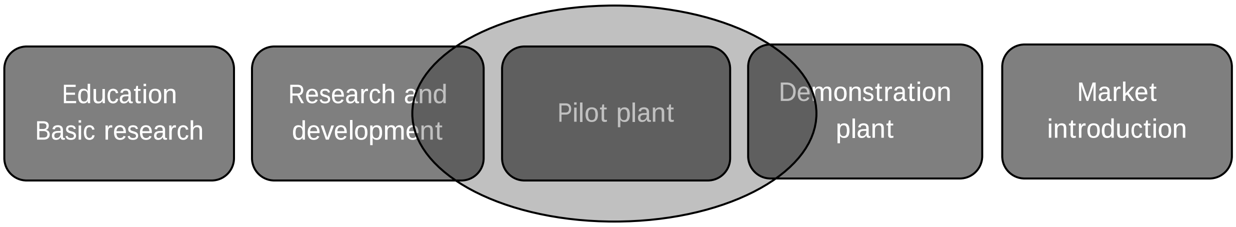
-

16.1.4 Dall Energy A/S

Contact data

Company name:	Dall Energy
Address:	Venlighedsvej 2
Contact person/position:	Jens Dall Bentzen
Telephone numbers:	+45 2987 2222
Mail address:	jdb@dallenergy.com
Website:	www.dallenergy.com

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	2	2	2
Turnover, M DKK	2	3	4
Export share	0	0	0

Ownership

Dall Energy holding 75,1%
Spraying Systems 24,9%

16.1.5 Danish Fluid Bed Technology ApS

Contact data

Company name:	Danish Fluid Bed Technology ApS (DFBT)
Address:	Universitetsparken 7, DK-4000 Roskilde
Contact person/position:	Peder Stoholm, owner
Telephone numbers:	+45 4674 0234
Mail address:	peder.stoholm@catscience.dk
Website:	

Area of operation

Activities within technologies for combustion and gasification. DFBT's objective is to contribute to the development of efficient and environmentally friendly processes for recovery of biomass and waste.

Ownership

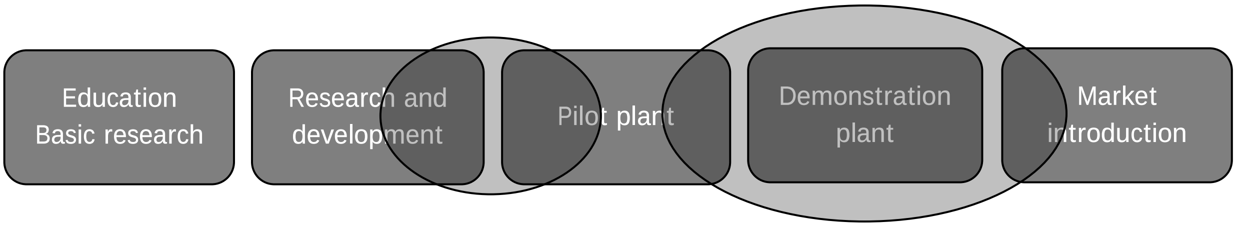
The company is fully owned by Peder Stoholm.

16.1.6 DONG Energy

Contact data

Company name:	Pyroneer A/S (under establishment), 100% owned by DONG Energy Power
Address:	Kraftværksvej 53, 7000, Fredericia
Contact person/position:	Anders Boisen/Manager Pyroneer
Telephone numbers:	99 55 76 72
Mail address:	andbo@dongenergy.dk
Website:	www.ltcfb.com (www.pyroneer.com, under establishment)

Area of operation



At present a 6MWth demonstration plant is in the commissioning phase. The gasifier will gasify straw, and the produced gas will be combusted together with coal at unit 2. Furthermore we are initiating R&D activities within the field of gas cleaning such as dust filtrating. The gas cleaning activities is associated with an existing 100 KW pilot gasifier.

Economic key figures

	2008	2009	2010
Number of employees*	5,644 (FTE)	5,865 (FTE)	5,874 (FTE)
Turnover, M DKK**	13,890	10,818	11,330
Export share	?	?	?

* Figures are from entire DONG Energy A/S

** Figures are only from the business unit Power (Generation)

Ownership

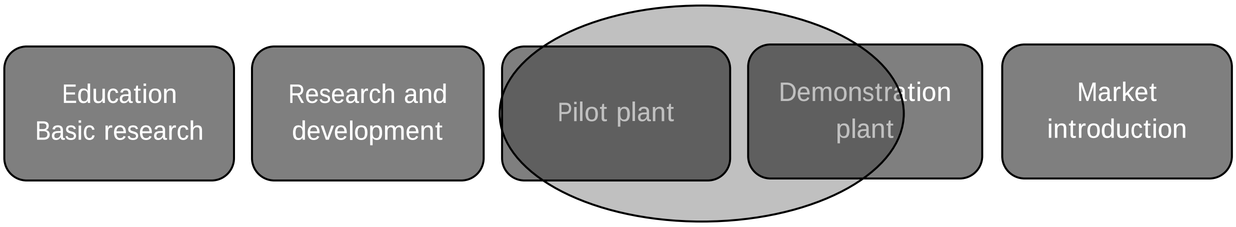
Pyroneer A/S is 100% owned by DONG Energy Power.

16.1.7 EP Engineering

Contact data

Company name:	EP Engineering ApS
Address:	ScionDTU, Diplomvej 373N. 2800 Kongens Lyngby
Contact person/position:	Nils Peter Astrupgaard/CEO
Telephone numbers:	+45 40 615 600
Mail address:	npa@ep-engineering.dk
Website:	www.ep-engineering.dk

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	0	0	2
Turnover, M DKK			4,7
Export share			0

Ownership

100% owned by ENVIPOWER Holding ApS.

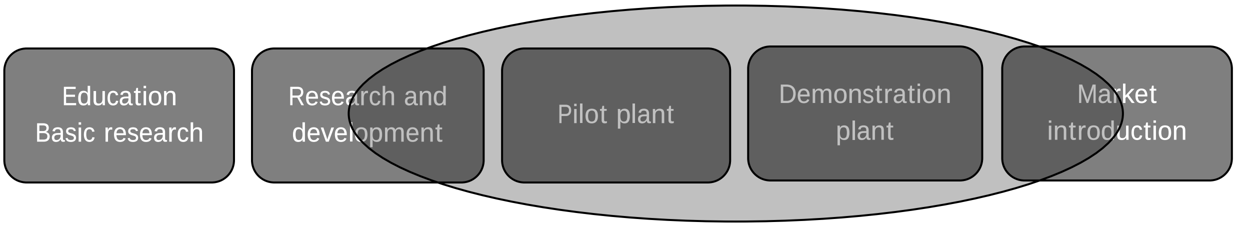
16.1.8 Haldor Topsøe

HALDOR TOPSØE
CATALYSING YOUR BUSINESS

Contact data

Company name:	Haldor Topsøe
Address:	Nymøllevej 55, DK2800 Kgs. Lyngby
Contact person/position:	Poul Erik Højlund Nielsen, Niklas Jakobsson
Telephone numbers:	004545272451, 004545272607
Mail address:	pehn@topsoe.dk, nika@topsoe.dk
Website:	www.topsoe.com

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	~1900	~2000	~2100
Turnover, M DKK	5 000	4200	4200
Export share	>95 %	>95 %	>95 %

Ownership

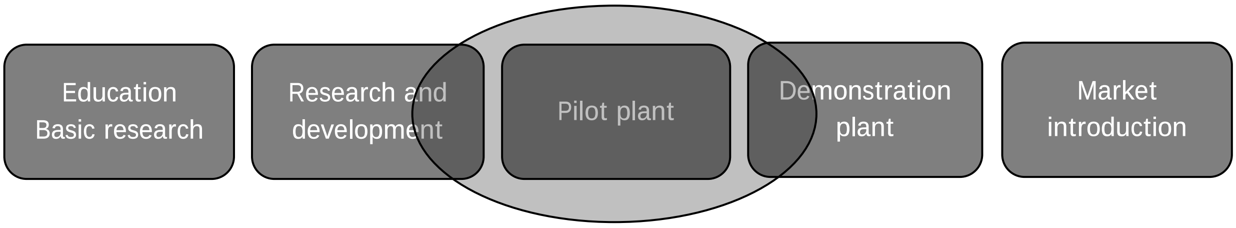
Family owned company.

16.1.9 Organic Fuel Technology

Contact data

Company name:	Organic Fuel Technology A/SS
Address:	Kantorparken 35 8240 Risskov
Contact person/position:	Erik Rose Andersen, CEO
Telephone numbers:	+45 30429679
Mail address:	Erik.rose@organicfueltechnology.com
Website:	www.organicfueltechnology.com

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	2	2	2
Turnover, M DKK	0	0	0
Export share	0	0	0

There has in 2008, 2009 and 2010 in average been 4 employees. All employees are hired on a consulting contract.

Ownership

OFT Holding, Danmark A/S	50.000 dkr.
OFT Holding, Danmark II A/S	765.000 dkr.
J. G. Invest og Consult ApS	500.000 dkr.
Maskinfabrikken REKA Holding A/S	500.000 dkr.
Verdo A/S	1.000.000 dkr.
	2.815.000 dkr.

With an option of 7 x more

OFT Holding, Danmark A/S 8.000.000 dkr

16.1.10 TK Energi A/S

Contact data

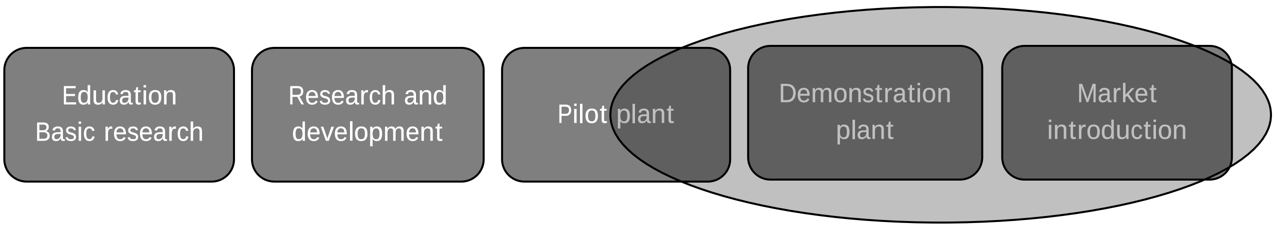
www.tke.dk

16.1.11 Stirling DK

Contact data

Company name:	Stirling DK Aps
Address:	Diplomvej 373 Syd, 2800 Kgs. Lyngby
Contact person/position:	Mads Brix Nielsen / Project Manager
Telephone numbers:	+45 88184819 / +45 60606980
Mail address:	mbn@stirling.dk
Website:	www.stirling.dk

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	12	23	27
Turnover, M DKK	-	-	-
Export share			

Ownership

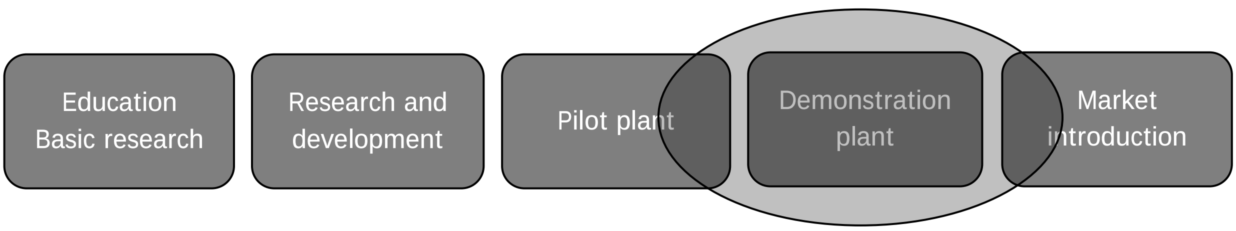
Aps owned by capital investors.

16.1.12 Weiss A/S

Contact data

Company name:	Weiss A/S
Address:	Ved Stranden 1, 9560 Hadsund
Contact person/position:	Bjarne Skyum/ project manager
Telephone numbers:	+45 96520444/+45 40405492
Mail address:	bjs@weiss-as.dk
Website:	www.weiss-as.dk

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	81	20	39
Turnover, M DKK	149,7	29	110
Export share	81	-	-

Ownership

Owned by Envikraft Invest A/S.

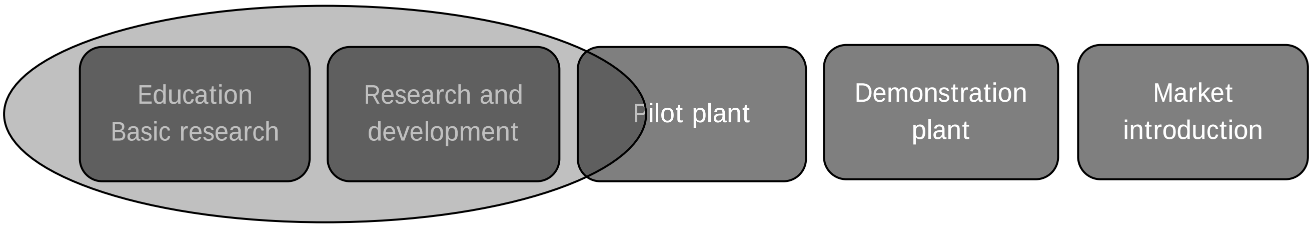
16.2 Danish universities

16.2.1 DTU Chemical Engineering (CHEC)

Contact data

Company name:	DTU kemiteknik
Address:	Søltofts Plads, bygning 229, 2800 Kgs Lyngby
Contact person/position:	Anker Degn Jensen / Peter Arendt Jensen
Telephone numbers:	45 25 28 41 / 45 25 28 49
Mail address:	aj@kt.dtu.dk / paj@kt.dtu.dk
Website:	http://www.kt.dtu.dk/

Area of operation



Economic key figures

	2008	2009	2010
Number of employees			4500 + students
Turnover, M DKK			
Export share			

Ownership

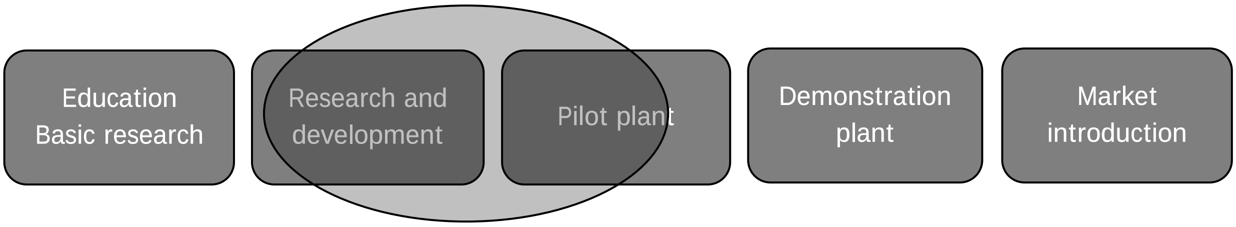
DTU - University owned by the Danish state.

16.2.2 Risø-DTU

Contact data

Company name:	Risø DTU
Address:	
Contact person/position:	Ulrik Henriksen
Telephone numbers:	21 32 50 10
Mail address:	ubhe@risoe.dtu.dk

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	10	10	10
Turnover, M DKK			
Export share			

Ownership

-

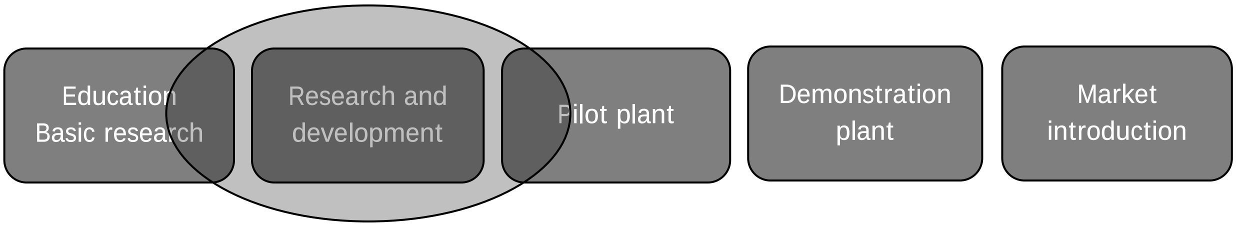
16.3 Danish Advanced Technology Group Companies

16.3.1 Danish Gas Technology Centre

Contact data

Company name:	Danish Gas Technology Centre
Address:	Dr Neergaards Vej 5 B
Contact person/position:	Niels Bjarne Rasmussen
Telephone numbers:	21471752, 20169600
Mail address:	nbr@dgc.dk dgc@dgc.dk
Website:	www.dgc.dk

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	36	37	36
Turnover, M DKK	28.5	30.4	30.9
Export share, M DKK	1.3	4.2	2.6

Ownership

DGC is a public limited company. It is now owned by:
HMN Naturgas (38.4 per cent)
DONG Energy (36.0 per cent)

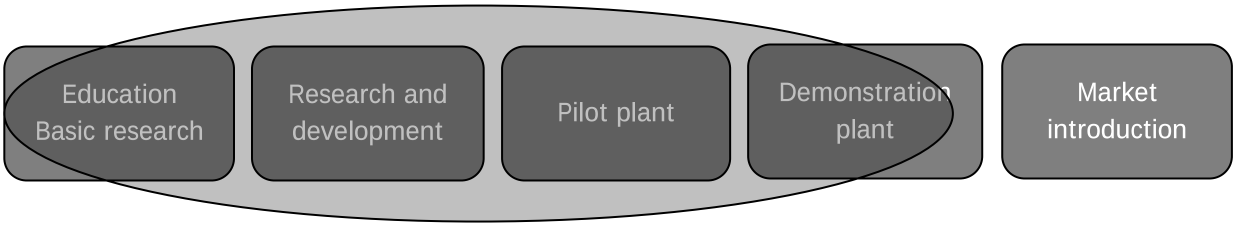
Energinet.dk (15.6 per cent)
Naturgas Fyn (6.0 per cent)
Københavns Energi (4.0 per cent)

16.3.2 Danish Technological Institute

Contact data

Company name:	Danish Technological Institute
Address:	Kongsvangs alle 29, DK8000 Aarhus C
Contact person/position:	Hans Ove Hansen
Telephone numbers:	+45 7220 1316
Mail address:	hoh@dti.dk
Website:	

Area of operation



Economic key figures

	2008	2009	2010
Number of employees	2	2	2
Turnover, M DKK	2 mio	3 mio	4 mio
Export share	0	0	0

Ownership

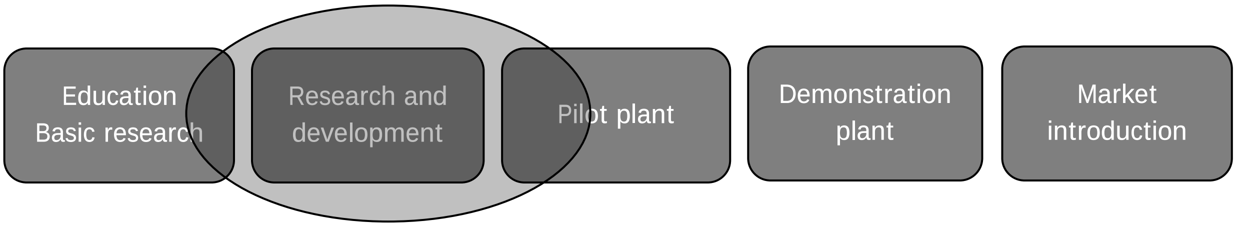
-

16.3.3 FORCE Technology

Contact data

Company name:	FORCE Technology
Address:	Hjortekærsvej 99, 2800 Kgs. Lyngby
Contact person/position:	Anders Evald
Telephone numbers:	+45 72 15 77 00
Mail address:	aev@force.dk
Website:	www.forcetechnology.com www.forcebioenergy.dk

Area of operation



FORCE is a technology service provider and R&D organization. In gasification technology we assist tech-nology owners with supporting services such as measurements and documentation, test runs, market studies, fuel diversification investigations, feasibility studies etc.

Economic key figures

	2008	2009	2010
Number of employees	1216	1198	Not published yet
Turnover, M DKK	905	1065	Not published yet
Export share	45 %	55 %	Not published yet

Export share includes turnover in subsidiaries in other countries.

Ownership

FORCE Technology is a self-owned entity.

16.4 Other important stakeholders

16.4.1 COWI A/S

Contact data

www.cowi.com

Area of operation

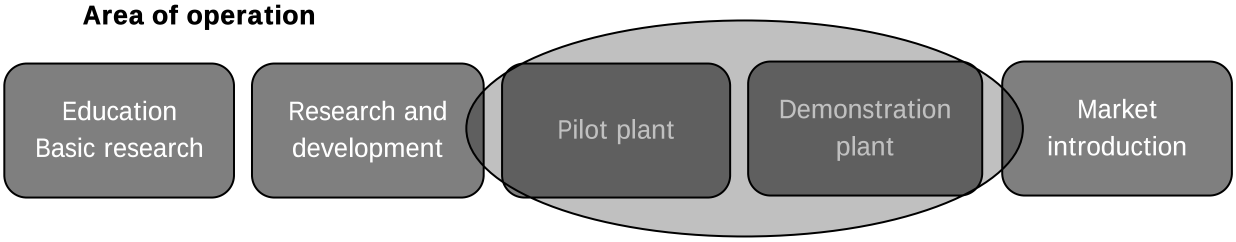
COWI A/S is involved with the staged down-draft gasifier.

16.4.2 Skive Fjernvarme I/S

Contact data

Company name:	I/S Skive Fjernvarme
Address:	Marius Jensensvej 3, 7800 Skive
Contact person/position:	Benno Jørgensen, General Manager
Telephone numbers:	+45 9752 0966
Mail address:	benno@skivefjernvarme.dk
Website:	www.skivefjernvarme.dk

Area of operation



I/S Skive Fjernvarme's is hosting a gasification plant from Carbona and is interested to get the technology (and the plant) fully developed ready for operation without large problems.

Economic key figures

	2008	2009	2010
Number of employees	22	23	24
Turnover, M DKK	130,2	101,9	92,7
Export share	0 %	0 %	0 %

Ownership

The company is a general partnership.

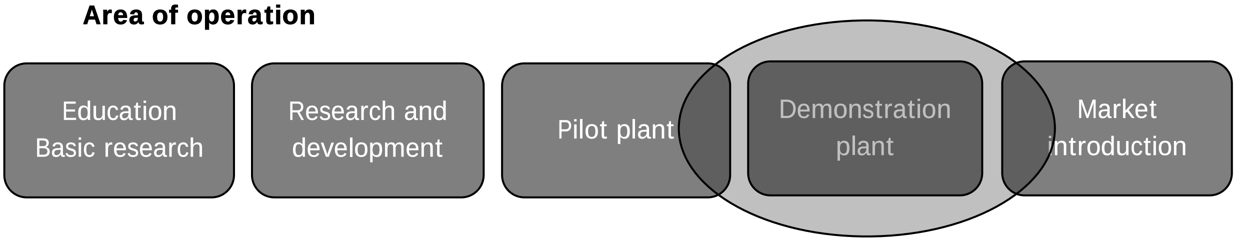
16.4.3 AAEN Consulting Engineers A/S

AAEN A/S
RÅDGIVENDE INGENIØRER

Contact data

Company name:	AAEN Consulting Engineers A/S
Address:	Ndr. Strandvej 46, 8240 Risskov
Contact person/position:	Bettina Skjoldborg, Project Manager and Partner
Telephone numbers:	+45 8617 5055
Mail address:	aaen@aaenas.dk
Website:	www.aaenas.dk

Area of operation



AAEN A/S has assisted I/S Skive Fjernvarme as a client adviser during the company's planning and im-plementation of a Biomass Gasification Gas Engine (BGGE) plant based on low-pressure fluidized bed ga-sification and gas engines.

Economic key figures

	2008	2009	2010
Number of employees	11	11	12
Turnover, M DKK	9,65	9,4	N. a.
Export share	41 %	53 %	N. a.

Ownership

The company is a joint stock company.

17 Annex 5 – Questionnaire used in the survey

DI Bioenergi og FORCE Technology
Forskning, udvikling og demonstration af termisk biomasseforgasning

FORCE TECHNOLOGY

Få indflydelse på udviklingen af forgasningsteknologi - udfyld spørgeskema!

Introduktion
Ved at udfylde dette skema og returnere det til FORCE Technology senest 25. marts 2011 påvirker du den fremtidige udvikling af teknologi til termisk forgasning af biomasse i Danmark. Skemaet er en central del af projekt " Oplæg til dansk FUD-strategi for termisk biomasseforgasning", der løber fra januar til juni 2011 og gennemføres af FORCE Technology for DI Bioenergi med finansiering fra Energinet.dk og EUDP samt virksomheder i forgasningsbranchen.

Formål og baggrund
Projektet har til formål at udarbejde et oplæg fra industriens repræsentanter til en strategi for forskning, udvikling og demonstration af teknologi til termisk forgasning af biomasse. Strategien skal være med til at forme grundlaget for, hvorledes indsatsen med fremtidige forsknings-, udviklings- og demonstrationsprojekter fokuseres. Udmeldingen fra puljerne er, at en strategi er et nødvendigt grundlag for at forgasningsprojekter kan støttes fremover.

Baggrunden for strategiprojektet er, at biomasse er og bliver den væsentligste bidragyder til forsyningen med vedvarende energi i Danmark og globalt på kort og mellemlangt sigt. Dansk baserede forgasningsteknologier - både til fremstilling af kraftvarme og til energibærere - har en vigtig rolle at spille. Men der er behov for at fokusere og målrette den teknologiske udviklingsindsats, så teknologierne kan medvirke til at indfri de nationale mål for anvendelse af vedvarende energi, uafhængighed af fossile brændstoffer og CO_2-fortrængning og samtidig fremme dansk industris vækst- og eksportpotentiale på området.

Metode og anonymitet
Projektet har en kortlægningsfase og en analysefase. Kortlægningen sker via dette skema og kræver aktiv medvirken fra leverandørvirksomhederne. Hvis en teknologi skal medtages i strategien, skal den være beskrevet i dette skema. Indholdet i skemaet benyttes efterfølgende som grundlag for analysen, der skal beskrive potentialet i dansk baserede teknologier og pege på, hvor indsatsen kan fokuseres. Analysen gennemføres af FORCE Technology sammen med en fokusgruppe med international deltagelse. Derfor skal skemaet udfyldes på engelsk.

Skemaet er opbygget i fire dele. Første del omhandler informationer om virksomheden. Anden del skal indeholde en generel beskrivelse af forgasningsteknologien. Indholdet skal give overblik og kunne offentliggøres uredigeret i slutrapporten. Tredje del skal indeholde en beskrivelse af aktuelle projekter og ligeledes kunne offentliggøres. Sidste del behandles fortroligt og skal indeholde oplysninger om teknologiens udviklingsstade og fremtidige FUD-behov. Indholdet benyttes kun i anonymiseret form.

Skemaet er i denne version udformet ret kompakt, men du kan let udvide det, så det passer til besvarelsen. Hvis din virksomhed arbejder med flere forskellige teknologispor, bedes du venligst udfylde et skema for hvert spor.

Projektets resultater fremlægges i en foreløbig rapport, der sendes i høring - forventeligt i maj 2011. Tiden er knap og skemaet bedes udfyldt og returneret til undertegnede i FORCE Technology hurtigst muligt og **senest 25. marts 2011**. Bidrag, der indløber herefter medtages ikke.

Med venlig hilsen

Morten Tony Hansen • mail: mth@force.dk • telefon: 7215 7755 • mobil: 2269 7205

Skema til kortlægning af forgasningsbranchen   Side 1/9

DI Bioenergi og FORCE Technology
Forskning, udvikling og demonstration af termisk biomasseforgasning

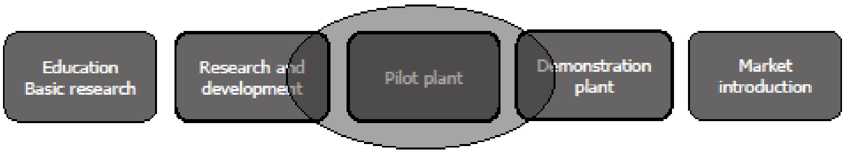
1. Company information

1.1. Contact data

Company name:	
Address:	
Contact person/position:	
Telephone numbers:	
Mail address:	
Website:	
CVR no.:	

1.2. Area of operation

Please indicate your area of operation in the development chain by moving and adjusting the oval correspondingly



Supplementary information:

1.3. Economic key figures

	2008	2009	2010
Number of employees			
Turnover			
Export share			

1.4. Ownership

Please describe the ownership structure in the company

Skema til kortlægning af forgasningsbranchen Side 2/9

2. Gasification technology - part for publication

If your company is working with more different gasification technologies or concepts, please complete one form for each.

2.1. General description

2.1.1. What is the name or working name of the concept or technology if any?

2.1.2. What is the main purpose of the gas from your technology?

[ ] Combustion for generation of heat and power
[ ] Internal combustion engine for generation of heat and power
[ ] Gaseous fuel
[ ] Liquid fuel
[ ] Other, please specify:

2.1.3. What is the main product from your technology?

2.1.4. Which by-products are generated?

2.1.5. Which residues are generated?

2.1.6. Technology rationale or specialty: Does the technology solve a problem such as disposal of a residue, is it particularly efficient, is it simple or inexpensive, does it have particularly low or positive environmental effects, is it particularly easy to operate, reliable, adjustable, etc.?

2.1.7. What is ultimately the thermal input capacity of your technology?

[ ] 0 - 1 MW
[ ] 1 - 15 MW
[ ] 15 - 200 MW
[ ] 200+ MW

2.1.8. Which market does the technology address? Which customers in which countries or regions?

2.1.9. How does the technology differ from other, similar technologies?

2.1.10. On which step in the development chain is the technology currently?

[ ] New concept
[ ] Pilot plant
[ ] Demonstration plant
[ ] Market ready
[ ] Commercially available

2.1.11. Total number of plants and total number of operating hours?

______ plants

______ operating hours

2.1.12. How many years will pass from now until the technology is commercially available?

2.1.13. What are the next development areas to be addressed with the technology?

2.2. Further specifications

2.2.1. Gasifier principle?

[ ] Downdraft
[ ] Updraft
[ ] Open core
[ ] Entrained flow
[ ] Circulating fluid bed
[ ] Multiple steps
[ ] Other, please specify:

2.2.2. Fuel type(s) and moisture content?

2.2.3. Energy balance

Input		Output	
Unit used, MW or other unit (please specify):			
Fuel input (LHV)		Power	
Own power consumption		Heat	
		Gases	
		Liquids	
		Other	
		Losses	
Total		Total	
Please check that input = output			

Please state the basis:

[ ] Nominal or operational data?
[ ] Theoretical or demonstrated performance?
[ ] Number of operational hours?
[ ] Single plant or average of _____ plants?

2.2.4. How are nitrogenous compounds/emissions - such as NH_3 and HCN - handled?

2.3. Process description

Please describe the process in words. The description should include fuel feeding system, temperature levels, char processing, product gas quality (e.g. lower heating value), handling of other products and residues, tar content, gas cleaning and/or processing, gas utilisation (engine, steam boiler), residue handling.

Please include 1-2 photos and a process diagram.

DI Bioenergi og FORCE Technology
Forskning, udvikling og demonstration af termisk biomasseforgasning

3. Gasification projects

Please describe recent and current gasification projects in which your organization is involved.
Please copy and insert a table for more plants or projects.

3.1. Demonstration plants and commercial plants

Plant name	
Location	
Year/month of commission	
Owner type (Domestic, industrial, energy provider etc.)	
Fuel	
Capacities (Input and output)	
Principles/description	
Actual operational hours	
Observed annual efficiencies	
Investment and public funding	
Status (In operation, not in operation etc.)	
Number of plants of same type	
Contact information	

Please attach one photo of each project in your reply mail - clearly marked with plant name

3.2. R&D projects

Project title	
Partners	
Objective	
Progress	
Budget	
Funding	
Contact information	

Skema til kortlægning af forgasningsbranchen Side 6/9

4. Technology details and RD&D demand (confidential part)

This part will remain with FORCE Technology and DI Bioenergy and only be used in generalised form elsewhere.

4.1. Details on market information

Anticipated market for the technology for your company

Region/country	Customer type	Plant scale	No. of plants in 2020

Please add more rows if needed.

Any comments to your input in the market information table?

4.2. Challenges

Please describe the technical challenges you face with the technology in the scope of making it commercially available. Details on the time needed to make the technology commercially available and the next development areas to be addressed with the technology.

4.3. Description of RD&D demand

Please distribute a **total of 36 votes** in the table below - 12 for each category. Choose freely how to place your votes within each category, e.g. put all votes on one focus area or one vote on 12 areas or something in-between.

Focus area	Research	Development	Demonstration
Basic pyrolysis process			
Basic gasification process			
Fuel pretreatment			
Fuel feeding			
Gas cleaning			
Gas engines (internal combustion)			
Gas turbines			
Gas burner			
Control of charcoal production			
Process stability			
Gas homogeneity			
Ash recycling			
More demo plants			
Follow up on demonstration units			
Liquid products			
Gaseous products			
Plant load control (regulerbarhed)			
Maintenance demand			
Fuel flexibility			
Operational reliability			
Efficiency			
Optimisation and investment reduction			
Total *(each category should equal 12)*	0	0	0

Further comments to your votes in the table above?

Other general demands for RD&D for Danish based companies in the gasification business? Please qualify.

4.4. Funding demand

4.4.1. How large a total investment within RD&D is needed in order to make your gasification technology move from the current step as stated in question 2.1.10 to the next step in the development chain?

DKK 0-10 mill.	DKK 10-30 mill.	DKK 30-100 mill.	DKK >100 mill.

How large a share of support from public funds would you need? (Percent)

4.4.2. How large a total investment within RD&D is needed in order to make your gasification technology ready for demonstration?

DKK 0-10 mill.	DKK 10-30 mill.	DKK 30-100 mill.	DKK >100 mill.

4.4.3. How large a total investment within RD&D is needed in order to make your gasification technology commercially available?

DKK 0-10 mill.	DKK 10-30 mill.	DKK 30-100 mill.	DKK >100 mill.

4.4.4. Further comments as to funding and financing issues?