

Final report

1.1 Project details

Project title	Partnerskab for Termisk Forgasning
Project identification (program abbrev. and file)	EUDP 14-I, Journalnr.: 64014-0138
Name of the programme which has funded the project	Energiteknologisk Udviklings- og Demonstrationsprogram
Project managing company/institution (name and address)	Dansk Gasteknisk Center Danish Gas Technology Centre
Project partners	Dansk Gasteknisk Center, Ea Energianalyse, Dall Energy, BioSynergi Proces, Danish Fluid Bed Technology, Gengas Holding
CVR (central business register)	12105045
Date for submission	05-07-2018

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1.2 Short description of project objective and results

English

The objective is to coordinate, strengthen and target the Danish RD&D work for thermal gasification in a way that thermal gasification can fulfil its potential in the envisioned future Danish energy system.

The EUDP-project consists of the following work packages (WP):

- WP1 Status for thermal gasification
- WP2 Thermal gasification and the Danish energy system
- WP3 Strategy for thermal gasification
- WP4 Framework conditions
- WP5 Implementation of strategy
- WP6 Organizing the start-up of the partnership

The work packages of the project have been executed by the members of the Partnership and selected players who have been involved through the project. All work packages have been completed, and the reports are available at the Partnership's website:

www.forgasning.dk .

Danish

Formålet er at koordinere, styrke og målrette den danske FUD-indsats for termisk forgasning, således at termisk forgasning kan udfylde sin rolle og sit potentiale i det forventede fremtidige danske energisystem

EUDP-projektet har følgende arbejdsplaner:

- WP1 Status for termisk forgasning
- WP2 Termisk forgasning og det danske energisystem
- WP3 Strategi for termisk forgasning
- WP4 Rammebetingelser
- WP5 Implementering af strategien
- WP6 Organisering af opstart af partnerskabet

De forskellige arbejdsplaner i EUDP-projektet er gennemført af partnerskabets medlemmer og andre udvalgte aktører, som er blevet inddraget løbende gennem projektet. Alle arbejdsplaner er afsluttet, og rapporterne kan findes på partnerskabets hjemmeside:

www.forgasning.dk .

1.3 Executive summary

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A wide range of knowledge institutions and companies are supporting the project and the association Partnership for Thermal Gasification. This partnership is open for all interested players. The association was funded by the Energy Technology Development and Demonstration Program (EUDP) at the 2014 round of application. The Partnership for Thermal Gasification held its founding general meeting on 20 November 2014.

The work packages of the project have been executed by the members of the Partnership and selected players who have been involved through the project. All work packages have been completed, and the reports are available at the Partnership's website:

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The secretariat of the Partnership for Thermal Gasification is located at DGC. During the course of the project, the partnership has arranged three events, the latest being a workshop on 27 April 2017 at DTU Risø. In addition to the mentioned workshops, the partnership has published six articles in "Ingeniøren" and "BioPress" based on our project results. The five subreports published by the project are available at www.forgasning.dk.

The project has identified new cooperation partners, such as the "Dansk Skovforening", "HedeDanmark" and "Skovdyrkerne". Joint dissemination of project results to politicians prior to the energy negotiations in 2018 has been completed.

1.4 Project objectives

This project aims to establish the framework needed for thermal gasification to become a possible active component of the new energy future. The outset will be the 2011 strategy paper for thermal gasification in Denmark (Strategy for research, development and demonstration of thermal biomass gasification in Denmark, 2011). As described in this work, thermal gasification has several possible ways of contributing to a fossil-free future by providing a part of the way by transforming a multitude of bio fuels into other fuels such as gaseous fuels, liquid fuels or for direct use in the combined heat and power production.

The objective of the proposed partnership is to unite the Danish thermal gasification community in order

- a) to clarify the current status, strengths and weaknesses of gasification in Denmark
- b) to clarify where and how thermal gasification most beneficially can be integrated in the future energy supply system
- c) to formulate strategies for future technological development and innovation needed for thermal gasification in order to fulfil the foreseen role in the future energy system
- d) to facilitate an improvement of the regulatory framework for thermal gasification
- e) to provide a framework where the majority of the needed competences needed to implement the strategy for thermal gasification will be present for future cooperation.

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WP5 is to be regarded as the individual project applications for RD&D funds reflecting the Partnership's work and strategy. This work package was thought to be financed by fees from members. As, however, the membership was smaller than budgeted, there was no budget to organize common applications, but each member has been active in producing applications within the field.

1.5 Project results and dissemination of results

Below we give further details of the work of the Partnership for Thermal Gasification. Reports of the work are available at the Partnership's website (www.forgasning.dk). There is a total of six work packages in the EUDP project.

Work Package 1 has listed and examined the technologies that are relevant in Denmark and for Danish utilizations of technology for thermal gasification. In Denmark, concepts have been developed within the main types of gasifiers:

- Fixed bed (updraft and downdraft)
- Circulating fluid bed
- Entrained flow.

The below Table 1 (in Danish) shows the different types of gasifiers categorized according to technology tracks. If a type of gasifier is relevant for several tracks, we have chosen the track best suited for the Danish conditions. Products from all tracks can be used for Combined Heat and Power or for direct heat ("spor 1"). SGN (Substitute Natural Gas). "Direkte" (with oxygen in the gasification agent). "Indirekte" (without oxygen in the gasification agent). HT (Hydrothermal conversion). Data are from 2016.

Table 1 Gasifier types and applications

Forgassertyper og teknologispor	Teknologispor →	Direkte		Indirekte		HT	I drift
		1	2	3	4	5	
Anvendelse → (X, + = primær, sekundær/delvis)		KV/ var- me	KV SNG bio- olie	Bio- olie SNG KV	SNG KV bio- olie	SNG Bio- olie	
Forgassertyper ↓	Brænd- sel						
Fluid Bed (CFB), Carbona/Andritz, Skive	træ- pellets	X	+				x
Updraft, Vølund, Harboøre	flis	X					x
Fluid Bed, LT-CFB, Pyroneer, DONG, Kalund- borg	halm	X					
Viking to-trin, Weiss, DTU/Risø, Hillerød	flis	X					
Downdraft, Biosynergi, Hillerød	flis	X					
Cyklonforgasser, MEVA, Hortlax, Sverige	træpul- ver	X					x
Fluid Bed, CFB, Varö Plant, Sverige	tør bark	X					x
Xylowatt, Belgien	tør flis	X	+				x
Sublimator, Frichs, Havndal	halm			X	+		(x)
Alternating gasifier, Ammongas/B&W-Vølund	flis			X	+		
Fluid Bed (FICFB), Güssing, Østrig	flis				X		x
Fluid Bed (CFB), GoBiGas, Göteborg Energi	pellets /flis				X		x
Fluid Bed, CFB, MILENA, ECN, Holland	flis				X		
"Falling Bed", Concord Blue, Tyskland	affald				X		x
WoodRoll, Cortus, Köping, Sverige	flis				X		
Heat Pipe Reformer, Highterm Research, Graz	flis				X		
Hydrotermisk forgasning af våd biomasse	våd bio- masse					X	

Work package 2 implemented a socio-economic modelling of how to integrate thermal gasification in the energy system in 2050. A socio-economic analysis excludes framework conditions such as subsidies and taxes relating to the technology. The modelling was based on gasification technologies described in the Energy Agency's Technology Data Catalogue with the assumptions of the Catalogue for technological development, including optimization of efficiencies and reduction of investment and operational costs. The analysis showed that the costs of

thermal gasification of wood under the assumptions used are only marginally higher than biogas from liquid manure and manure/straw. The costs of thermal gasification of straw will be lower than the price of biogas. In conclusion, thermal gasification and biogas are at the same cost level and considerably below the costs of methane through electrolysis. One of the particularly positive results was the production of bio-SNG based on waste fractions.

Work package 3 consists of the preparation of a strategy for continued research, development and demonstration of thermal gasification technologies.

Thermal gasification has the potential of facilitating the use of biomass and waste in more flexible power and CHP plants as well as the potential of supplying green gas to the transport sector and to industrial purposes. Flexible power and CHP plants are considered to be a crucial tool for implementing Denmark's vision of an energy system without fossil fuels when wind and solar make up the major part of electricity production in Denmark and neighbouring countries.

Some of the advantages of the gasification technology are listed below:

- A better possibility of recirculating ashes and nutrients
- Energy utilization of the very large and often very challenging biomass residual products from the processes of the society
- Solution to some of the challenges of drug residues, micro plastic and heavy metal in the society's material flow

Danish research environments and Danish companies are world leaders in gasification technologies and processes that may play a role in energy systems worldwide, and the market for gasification technology is large in Denmark and abroad.

There is still a clear need for targeted research, technology development and demonstration as well as for investment in full-scale installations in order for biomass gasification to reach a commercial breakthrough.

The work package demonstrates that there is a job for professionals in the field of thermal gasification to make politicians and decision makers aware about the special advantages and opportunities of thermal gasification and its potential in an energy system and industry in this field.

The below Table 2 (in Danish) summarizes the described activities where thermal gasification may contribute to a fossil-free energy system in Denmark and provide attractive export technologies for countries all over the world.

Table 2 Necessary activities for gasifier developments

Område	Handlingsbehov	Rolleliste
Teknologiudvikling generelt	Øge driftssikkerhed Reducere omkostninger Demonstrere synergier	Universiteter, udviklere, leverandører
Forgasning til kraftvarmeanlæg	Løse tilbageværende, tekniske udfordringer på eksisterende teknologi Rammebetingelser skal skabe tryghed i lang tid Fremme eksisterende teknologi fremfor nye koncepter Informere politikere bedre	Universiteter, udviklere, leverandører Myndigheder Støtteprogrammer Partnerskaber, brancheforeninger
Forgasning forkoblet kraftværk	Undersøge markedet i DK og udlandet Demonstrere synergier og værdisætte miljøydelse	Rådgivere, udviklere, leverandører
Forgasningsbaseret bio-SNG	Demonstrationsanlæg i Danmark Undersøge pladser og tidsperspektiver for biobrændstoffabrikker Ligestille støtte til bio-SNG uanset teknologi og brændsel	Udviklere, leverandører Rådgivere Myndigheder
Forgasning til flydende brændstoffer	Forskning, udvikling og demonstration af gasrensning Demonstrere forgasning af restprodukter	Universiteter, udviklere, leverandører
Forgasning i industrien	Demonstrere forgasningsanlæg i industri Overveje incitamentter til at erstatte fossiler med VE i industriprocesser	Leverandører, industrivirksomheder Myndigheder
Gasrensning	Videreudvikling af gasrensningsteknologi - fokus på svovlforbindelser	Universiteter, udviklere, leverandører
Opskalering er vejen til billigere forgasningsanlæg	Undersøge pladser og tidsperspektiver for store forgasningsanlæg Forskning, udvikling og demonstration indenfor opskalering af kendte koncepter	Rådgivere Universiteter, udviklere, leverandører
Forgasning og svære brændsler	Tværfaglig forskning, udvikling og demonstration af termisk forgasning af sekundære ressourcer	Universiteter, udviklere, leverandører
Energisystemintegration og teknologisamspil	Udvikling og demonstration af teknologisamspil og polygeneration Modellering og planlægning af energisystemet med termisk forgasning	Universiteter, udviklere, leverandører Myndigheder og rådgivere

Work package 4 examined the framework conditions for thermal gasification and evaluated the future framework conditions. In addition, the work package modelled the business economics of investments in thermal gasification plants in Denmark and made comparisons with alternatives in LCoE calculations (Levelised Cost of Energy). Here alternative methods for supplying identical energy services are compared. Four different applications of thermal gasification were examined and compared with other relevant ways of covering identical needs. These applications were:

- CHP production with combustion engine (Fixed bed gasifier)
- Gasifier cofiring a CHP plant with boiler and steam turbine
- Bio-SNG (green natural gas) from gasification of biomass and waste (Circulating fluid bed gasifier)
- Production of biodiesel by means of the Fischer-Tropsch process (Entrained flow gasifier)

Assumptions and conclusions from the work package are briefly described below in short sections.

CHP production

Regarding electricity, EU is pushing for electricity subsidies to be given equal status with other RE technologies. If that happens, the heating price for gasification CHP will be significantly higher than the heating price for the cheapest alternative technology. If the subsidy schemes were to continue as today, and gasification CHP can be integrated as basic load systems with 8,000 full-load hours, gasification CHP would be able to be competitive in terms of business economics. However, this situation is estimated to be less likely. With 5,000 full load hours, which are considered more realistic, gasification CHP (and biogas CHP), even with high subsidies, will not be able to compete with alternative heat production technologies. Without subsidies, gasification CHP will be 2-3 times more expensive than alternative heating technologies; also at 8,000 full load hours.

Cofiring gasifiers

Cofiring gasifiers may in certain circumstances be cost-effective for gasification of both straw and waste, where the gas is fired into a larger biomass CHP plant. If today's level of subsidy is maintained, cofired gasification of straw will be very attractive in terms of business economics, and even without subsidies it seems that cofired gasification of waste at biomass fuelled plants will be profitable in terms of business economics.

Bio-SNG from gasification of biomass

It is realistic that subsidies for bio-SNG will be given equal status with upgraded biogas, but it is unlikely that the subsidy level will rise by 2030. With subsidy equality with biogas, bio-SNG from gasification of biomass can be competitive in relation to natural gas and upgraded biogas if costs are reduced to approx. half of today's level, which corresponds to the projections in the technology catalogue. Without technology improvements, bio-SNG will cost more than triple of natural gas by 2030. Emphasis should therefore be placed on enhanced R&D efforts to facilitate gasification of biomass for bio-SNG production and exploit the potential of bio-SNG from biomass.

Bio-SNG from gasification of waste

Bio-SNG from gasification of certain waste fractions (e.g. RDF) can compete with incineration of waste by 2030. In fact, calculations show that gasification of waste can be the cheapest way of dealing with waste when used to produce bio-SNG sold on the natural gas grid. In addition, calculations show that gasification of RDF waste can be the cheapest way to produce bio-SNG - even without subsidies. However, as in the case of bio-SNG production from biomass, this requires a substantial development of gasification technology. Without technology development, waste gasification will not be competitive with waste incineration plants.

Liquid bio fuels

Without subsidies, the Fischer-Tropsch syn-diesel is not expected to be competitive with fossil diesel by 2030. With the anticipated technology improvement, however, the extra cost of F-T syn-diesel compared to fossil diesel is reduced to only 30% by 2030. This corresponds to a CO₂ reduction price of approx. DKK 560/ton, which is not considered to be a high price for green transition in the transport sector. In the field of transport, mandates are expected to become a driving force in which F-T syn-diesel is to compete with alternative second generation biofuels such as FAME, HVO, bioethanol and green gas. Today, F-T syn-diesel is not prioritized to fulfill mandates, but with significant technological development, the fuel will have a long-term potential from a business economics perspective.

The work done in work package 4 does show interesting business economic perspectives by 2030 for some of the gasification technologies and fuels investigated. As can be seen, significant technology development is a prerequisite for these perspectives to be realized.

Work package 5 is implementing the strategy. The work package is to be regarded as the individual project applications for RD&D funds reflecting the Partnership's work and strategy. This work package was thought to be financed by fees from members. As, however, the membership base was smaller than budgeted, there was no budget to organize common applications, but each member has been active in producing applications within the field.

Work package 6 has supported the operation of the partnership's secretariat at DGC. During the course of the project, the partnership has arranged three events, the latest being a workshop on 27 April 2017 at DTU Risø. The Workshop included a short discussion of a possible strategy for thermal gasification. The participants were all experienced in different fields of and with different technical approaches to thermal gasification. They joined forces and suggested a list of items for the strategy. This list can be seen in Annex 7 of the Strategy report.

In addition to the mentioned workshops, the partnership has published six articles in "Ingeniøren" and "BioPress" based on our project results. See Annex.

The five subreports published by the project are available at www.forgasning.dk, see Annex.

1.6 Utilization of project results

The method of analysis regarding framework conditions and business economic calculations has been adapted through the project and could be used for other countries with other framework conditions and/or other technology data.

The project has identified new partners with mutual interests, such as the "Dansk Skovforening", "HedeDanmark" and "Skovdyrkerne". Joint dissemination of project results to politicians prior to the energy negotiations in 2018 has been completed. The results of the project have been presented at meetings with four political parties, the Minister for Energy and the Energy Political Committee.

1.7 Project conclusion and perspective

Gasification has gained more space in professional journals in the form of a series of articles and more attention among opinion makers and politicians, e.g. in the new energy initiative from the Danish government (April 2018). This can provide a basis for new favourable framework conditions and thus economic interest in gasification in industry.

Annex

The website for Partnerskab for Termisk Forgasning (Partnership for Thermal Gasification): www.forgasning.dk comprises a long list of references regarding gasification, including the subreports (in Danish) of the project:

WP1 Status for termisk forgasning (Status for thermal gasification)

- Delrapport 1: Status for termisk forgasning - Leverandører og teknologier, internationalt (Subreport 1: Status for thermal gasification – International suppliers and technologies)
- Delrapport 2: Status for termisk forgasning i relation til danske forhold (Subreport 2: Status for thermal gasification relating to Denmark)

WP2 Termisk forgasning og det danske energisystem (Thermal gasification and the Danish energy system)

- Rapport: Integration af termisk forgasning i det danske energisystem (Report: Integration of thermal gasification in the Danish energy system)

WP3 Strategi for termisk forgasning (Strategy for thermal gasification)

- Rapport: Strategiudspil termisk forgasning (Report: Strategy proposal for thermal gasification)

WP4 Rammebetingelser (Framework conditions)

- Rapport: Rammebetingelser for termisk forgasning (Report: Framework conditions for thermal gasification)

In addition, six articles (in Danish) have been published in "Ingeniøren" and "BioPress" based on the project results:

<https://ing.dk/artikel/eksperter-enige-forgasning-vejen-gron-transport-ad-bakke-207090>

<https://ing.dk/artikel/darlige-stottevilkar-blokerer-udviklingen-forgasning-207087>

<http://www.biopress.dk/PDF/termisk-forgasning-i-et-preset-marked>

<http://www.biopress.dk/PDF/dode-traeer-i-skoven-udleder-bade-co2-og-metangas>

<http://www.biopress.dk/PDF/termisk-og-biologisk-forgasning-kan-blive-et-fint-makkerpar>

<http://www.biopress.dk/PDF/ny-strategi-for-termisk-forgasning-af-biomasse>