Final report

1.1 Project details

Project title	3rd Generation gasification
Project identification (program abbrev. and file)	EUDP II 2012 j.nr. 64012-0251
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	1Rgi Møllevænget 2, Hostrupskov, 6200 Aabenra, DK
Project partners	Frichs, Gasification DK, DTU, Chimneylab
CVR (central business register)	32372236
Date for submission	25/8 2015

1.2 Short description of project objective and results

1.3 Executive summary

1.4 Project objectives

1.5 Project results and dissemination of results

1.6 Utilization of project results

1.7 Project conclusion and perspective

1.2 Short description of project objective and results

The project aims to develop cogeneration based on biomass gasification in an updraft gasifier. The current status for plants based on updraft gasifiers can deliver an electrical efficiency of approx. 25%, but there are significant challenges and additional costs associated with the treatment of wastewater from the gas cleaning process. By optimizing the interaction between the gasification plant and the combustion engine, and thereby minimizing construction costs of the wastewater treatment facility, CAPEX will be reduced.
The project demonstrated the methods necessary, both in terms of reducing the need for waste water treatment and the use of the tar residue from the gas cleaning as an engine fuel.

Projektet sigter mod at udvikle kraftvarmeproduktion på grundlag af forgasning af biomasse i en modstrømsforgasser. Den aktuelle status for anlæg baseret på modstrømsforgassere kan levere en elektrisk virkningsgrad på ca. 25%, men der er store udfordringer og yderligere omkostninger forbundet med behandlingen af spildevand fra rensningen af gassen. Ved at optimere interaktionen mellem forgasningsanlægget og forbrændingsmotoren, og derved minimere anlægsomkostninger til vandrensningen, vil CAPEX reduceres.
Projektet demonstrerede de nødvendige metoder der er nødvendige, både med hensyn til at reducere behovet for spildevandsbehandling og brugen af tjære / bio olie fra rensning af gassen som motorbrændstof.

1.3 Executive summary

The main object in the project was to demonstrate that by changing the operation points of both engine and gas cleaning system, it would be possible to reduce the need for a waste water cleaning system. In the run of the project it was also planned to demonstrate that it was possible to operate a diesel engine on the bio oil residue part of the gas cleaning residues. The result should be that the overall plant performance should be more efficient when producing electricity and / or that the overall CAPEX of the plant should be reduced.

The updraft gasification testfacility at Gasification.dk and 1rgi was operated in order to test the gascleaning at a variety of temperatures, in order to find the operation point where a bio-oil fraction with a minimum of water was produced when cleaning the gas. This was achiwed and a portion of bio-oil was produced and made available for the work in WP 4, the gas composition was controlled and the amount of condensate was measured at relevant temperatures, thereby fulfilling milestone 1 of the project.

WP 4 demonstrated the use of the tar / bio-oil as engine fuel, and the milestone 2 was considered achieved, as the engine operated primarily on tar, with only 25% RME addition. The test was continued to see how far it was possible to go, and ultimately to test if the engine could operate on 100 % tar, which surpassed our expectation, so from the engine experiment it can be concluded that it is potentially possible to use bio-oil / tar from updraft gasification as a diesel fuel.

The results were achieved on a small high speed engine. This is very promising in relation to the use of a full-scale stationary engine where combustion conditions is significantly improved and the combustion chamber dimensions will be significantly larger and the speed lower, all working in favor of better conditions for the combustion of the tars / bio oil.

Further tests will be necessary to fully investigate the use of tar from updraft gasification. It will be necessary to do long-term operation of the motor used, and to be able to take it apart to examine wear and possible deposits. It will also be necessary to carry out the bio-oil operation on a larger diesel engine operated on pure bio-oil, where the mapping of the performance and emissions, and subsequent inspection of the engine can be performed.

With the succesful operating of the gas engine with a fuel gas with high moisture content milestone 3 achived. The engine completed the test whitout any problems other than could be attended trough preparation and management of condensate in the intake system. A clear drop in efficiency and engine stability operating at very high levels of water content is expected to be encountered by lambda control and other active engine operation control systems.

All in all, the removal of the wastewater system and the added complexity of the engine installation and the bio oil pre-treatment will amount to a reduced CAPEX of approx 20% and at the same time the calculations and results shown in this project amounts to an overall increment in electrical efficiency from 25% to 30%.

The electrical efficiency in the area of 30% will be a new benchmark for wood gasification systems in the range of 1 to 7 MW electric, and together with a reduced CAPEX, it will strongly increase the position of this technology on the market.

1.4 Project objectives

The project evolved according to the plan with only minor changes. During the project it was necessary to make smaller adjustments to the time schedule, but the entire planned task where performed, and the agreed milestones were reached. From the start of the project, it was expected that the planned time schedule would need changes due to problems or complications found during the demonstration work done in the work packages, especially during WP 4 and 5. The risk was that the demonstration in these work packages failed or that major changes where needed on the machinery used in these WP’s. Fortunately this wasn’t the case, and the results reached actually exceeded our expectations in especially 2 points - operation point of gas engine with added water vapour, and the use of bio oil / tar residues for engine operation.

1.5 Project results and dissemination of results

The main object in the project was to demonstrate that by changing the operation points of both engine and gas cleaning system, it would be possible to reduce the need for a waste water cleaning system. In the run of the project it was also planned to demonstrate that it was possible to operate a diesel engine on the bio oil residue part of the gas cleaning residues. The result should be that the overall plant performance should be more efficient when producing electricity and / or that the overall CAPEX of the plant should be reduced.
These are the main themes covered in the project, and the results and observations are in the following described according to the work packages originally planned.

WP1: Project management and planning of the overall project period.

The overall project plan was discussed on the first project meeting, and the overall plan for the project was accepted by all the participants. The plan was further discussed on project meetings, but overall there were only minor changes and delays so the original time schedule and project plan wasn’t changed for the project. The delays were reported as part of the communication to EUDP on a quarterly basis.

The basic work package structure was maintained for the planned work, and used as the basic project plan.

WP2: Gas cleaning

During WP 2 several test were performed covering both operation with alternative feed stocks and several test giving insight in the operation of the gas cleaning operating at changing temperature intervals.

The goal of the first series of test was to check gas composition and to make sure that it was within the values chosen as reference. At the same time enough bio oil was produced in order to support the work planned in WP 4. The amounts of tar / bio oil produced should cover characterisation work, mixing experiments and fuel for the planned operation of the diesel engine.

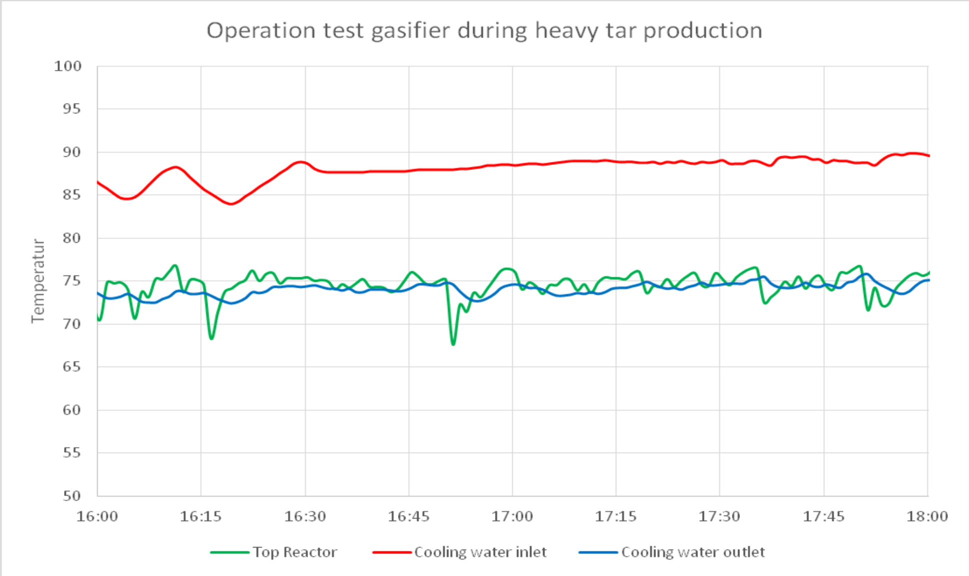
The allowable span for the gas quality values can be seen in table 2.1 below representing, showing the normal range to be within for the full scale gasifier. The test gasifier unit was operated inside the span given below, thereby producing the quality of tar or bio oil needed, and at the same time it was operating within the operating window where stable and comparable to the operation of the full size units.

	Low	High	CALC				
	v/v d%	v/v d%	v/v d%	v/v w%	w/w d%	w/w w%	kg/m3
H2	**0,15**	**0,22**	**0,20**	0,19	0,017	0,017	0,017
CH4	**0,03**	**0,05**	**0,05**	0,05	0,034	0,033	0,034
CO	**0,25**	**0,28**	**0,27**	0,25	0,317	0,306	0,317
CO2	**0,07**	**0,08**	**0,08**	0,07	0,141	0,136	0,142
N2	**0,50**	**0,37**	**0,41**	0,39	0,491	0,474	0,490
H2O				0,04		0,035	0,036
	1,00	1,00	1,00	1,00	1,000	1,000	1,04

Table 2.1: Clean gas composition, high and low values.

Together with the gas composition, the temperature of the gas leaving the top of the gasifiers is logged, as this as well as the gas quality gives an important diagnose of the operation of the gasifier. The goal is to keep it as stable as possible, and between 75 and 90°C, as shown in figure 2.1 below

The gas values are within the expected range, and the focus is then drawn on the condensates. The heavy tars are separated over the entire test run in order to produce an amount sufficient for the later planned engine test. In all approx. 25 l was produced, and 10 l was reserved for the engine test, and the rest is for testing mixing and solubility in different types additives or thinning agents in preparation for the engine test.



Figur 2,1:Gasifier operation temperature

The amount of condensate in the gas was testet by means of cooling the gas to 20°C, and collecting the condensate in a bottle. The gas was extracted from the gaspipe after the cooling and cleaning section, as the purpose was to measure the amount of water in the gas, to secure that the amount of condensate followed the temperature after the cleaning as expected, and not just passing on a large amount of condensate as aerosols.

The gas cleaning was operated at temperature intervals to demonstrate how much water was carried on with the gas at the respective temperatures. The demonstration of the ability to operate the gas cleaning at high temperature, producing a gas cleaning condensate with only a minor amount of water, the tests were performed from clean gas temperatures starting @ 30°C and upwards. Due to the overall importance of this, this was chosen as the milestone 1.

Below picture shows the condensate from 3 high temperature runs, with the last one, gas cleaning @ 95°C, showing only a very small amount of water.

Picture 2.1: condensate from gascleaning.

This was the primary goal of MS1, the ability to operate the gas cleaning at a temperature where a bio oil product was produced, and the water fraction was minimized.

To prepare for the engine test in WP 4, it was important to find an additive that could be used to thin the bio oil, as it was expected that it was requested in order to operate the diesel engine. To get closer to the viscosity of standard diesel oil, a number of tests were made with different thinning agents

The thinners used are listed below:

#1 ethanol, butanone

With ethanol a special phenomenon occurred, quickly getting the nickname Giraffe oil, on the inside of the glass bottle, showing that this was not the perfect thinner for the bio oil.

Picture 2.2: 1: Bio oil / Ethanol - 2: isopropyl alcohol – 3(4): Rapeseed oil - 5: RME

#2 isopropyl alcohol

Showed better results, as can be seen on picture 2,2, but due to flammability, further tests was conducted with rapeseed oil in 2 different qualities

#3 Rapeseed oil industrial production incl. extraction

#4 Rapeseed oil, cold pressed, showed same result as # 3

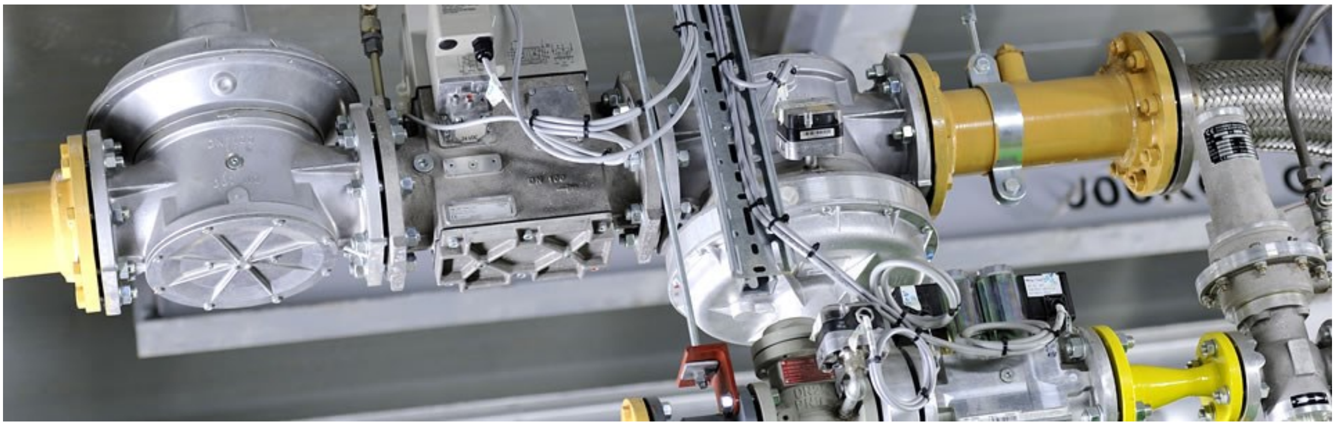
#5 Bio diesel, RME

The best result overall was with isopropyl alcohol and RME, and as RME is a fuel used in diesel engines, this was chosen for the further work.

To test for longer term issues several tests were performed and the bottles stored and checked for sedimentation, showing only minor sediments on the RME, confirming this as the choise of additive / thinner for the continued work.

WP3: Gas ramp

The gas train is supplying the gas from the gasifier to the engine, and the normal procedure is to use a gas train build for natural gas. The use of a standardized unit can be accepted when the gas is clean and dry. The picture below shows a standard gas train.



Picture 3.1: Traditional gas train

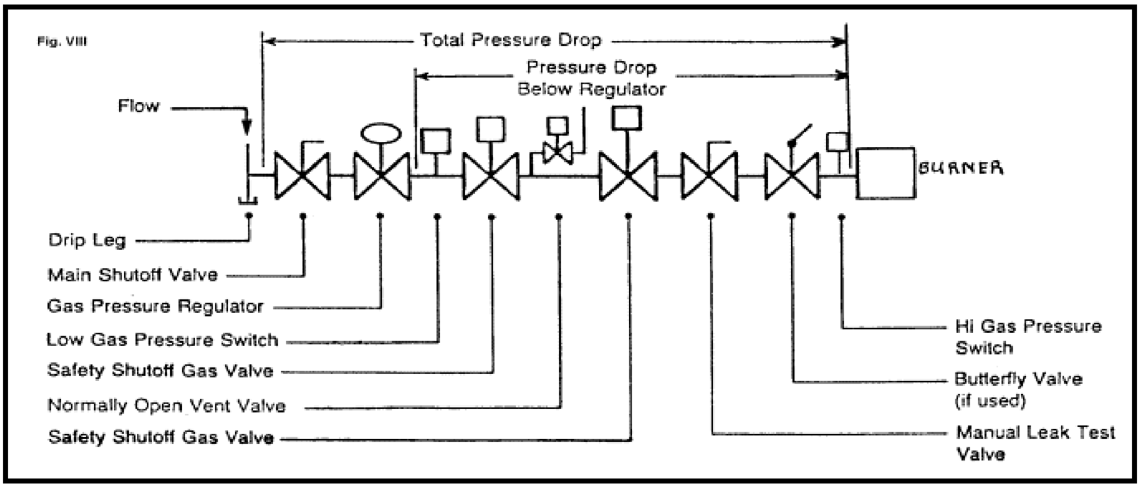
With the changes in operation parametes for the engine and gascleaning, the following points would cause the standard unit to malfunction or cause problems during operation.

1. Changing the dew-point of the gas going to the engine.
2. Requirement of a low pressure drop – and the ability to handle larger volumetric flow due to the higher amount of water vapour.
3. Risk of small amounts of condensate.

Based on this, several options was discussed, ranging from a (relative) high pressure gas system to a "zero" pressure system.

It was decided to go along with the zero pressure system, as this was rated as the best option. A side effect is that no boosting of the gas is necessary, or at least – if needed due to pressure drop superseding the values for the engine / gas mixer, it would only be a minor pressure boost achieved with a fan, capable of handling gas.

The figure below shows the standard schematics of a gas train – basically it is the same for both a burner and an engine. The basic parts needed is the main shut of valve – a manual valve that, in case of gas leaks or other dangerous situations, makes it possible to interrupt the gas supply to the engine installation. This valve must be placed outside the engine room. The 2 safety shut of valves coupled with a bleed valve can be of the ball valve type, securing the desired low pressure drop, and the bleed valve is of the normally open type, and opens when the 2 main valves are closed. This is done to secure that any leaks in the valve internals is neutralized and any pressure build up isn't possible. This way it is secured that there is a safe break in the gas supply line in case of shut down.



Picture 3.2: Gas train example

The gas train will be as simple as possible, without any pressure regulators as used when dealing with natural gas, as the gasifier system used are capable of following the turn up/down of the engines, supported by the volume in the gas pipe and gas cleaning system.

The advantage of using a pressure feed system would be that the components used could be smaller and measured on CAPEX, more attractive, but stable operation and low energy consumption outweighs this, making the unit build especially for low pressure drop and capability to handle small amounts of condensate, the best choice.

Picture 3.3: Gas train with low pressure drop and ball valve.

The picture above represents a gas train with low pressure drop and ball valve.

WP 3 Result:

Type of gas train and principle of operation is chosen, and necessary components identified. A system with low pressure drop is chosen as the design guide line.

WP4: Bio oil products from the gas cleaning, characterisation and engine operation.

The amount of tar in gas from updraft gasification represent a significant part of the total calorific value of the gas. It is therefore interesting to check if this tar / bio-oil can be used as fuel in a diesel engine, and thereby increase the proportion of electricity that can be produced from the gas. To investigate whether the tar from updraft gasification can be used as fuel in a diesel process, a chemical-analytical characterization of the tar has been carried out, and the calorific value has been determined calorimetrically. Subsequently a test was performed using the bio oil as a fuel in a slightly modified diesel gen-set.

Characterization of the bio oil / tar

The tar from the updraft gasification used in the experiment was received from 1Rgi. The tar comes from a biomass updraft gasifier operated on wood chips. The tar is condensed from the product gas.
The tar was of relatively low viscosity and manageable during the experiments. It has been analyzed chemically using GCMS analysis - both the main component of tar, and the separated aqueous phase. From the analyzes it could be stated that the water phase contains tar and that the primary tar substances in this are acetic acid, ketones such as acetone, guaiacol- and phenols compounds - see Figure 4.1.

These are all relatively light tars and have a relatively small content of mono- aromatics (and no poly-aromatic). The main component of the tar was analyzed to be primarily mono-aromatic guaicol connections with different single-chain radicals substituted - see Figure 4.2.

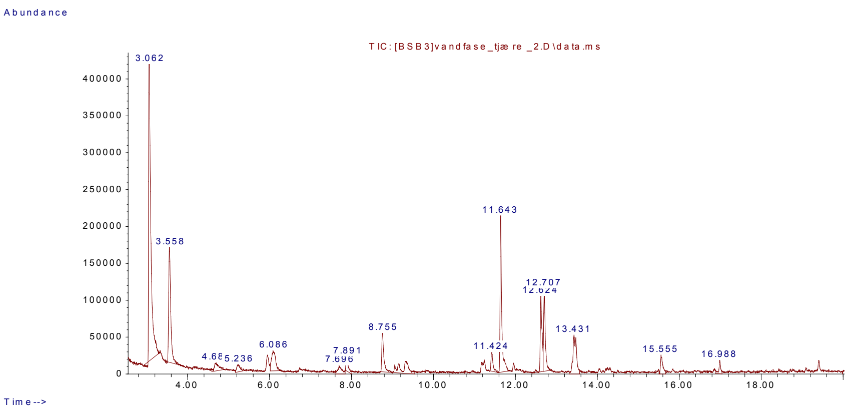
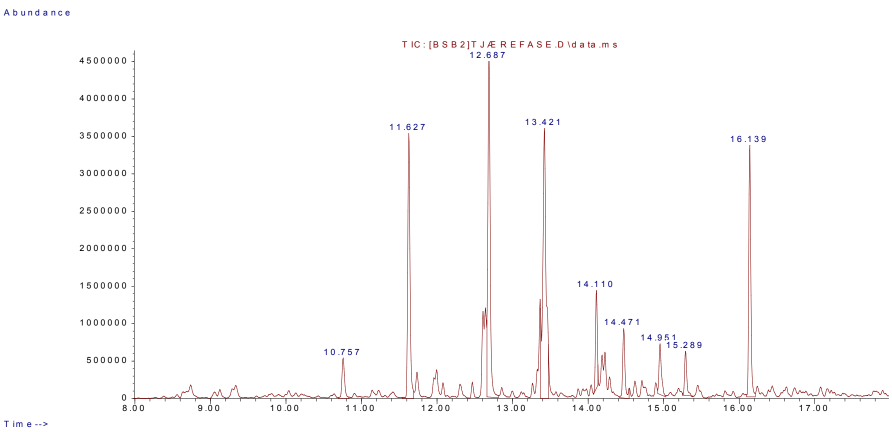


Figure 4.2 – GCMS analysis of the residual water from the bio oil / tar



Figur 4.3 – GCMS analysis of the main tar / bio oil constituents (no water)

The main components of the tar were also tested in a calorimeter, and the heating value was measured at 24.9 MJ / kg.

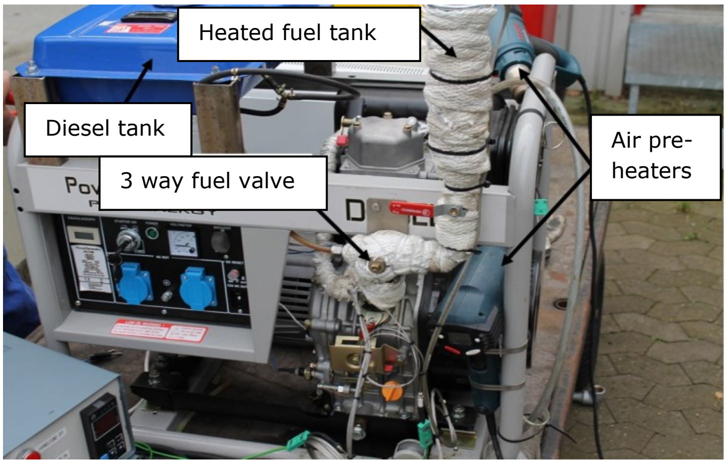
Before analysis and experimental work progressed, a clear water phase in the tank was separated from the tar see Figure 4.3.

The water was as far as possible poured from within the trial -. The RME / biodiesel used (rapsmethylether) is from the Danish biodiesel producer Emmelev.

Figure 4.4 – Bio oil with a clear waterphase.

Engine test

The motor is a diesel engine of common type, with a output of 5 kW nominal and 5.5 kW max. the displacement is 418 cm^3. The engine is modified so that the fuel inlet can be directed from 2 separate tanks by a 3-way valve. This way diesel or bio oil / tar can be directed to the motor. The tar is poured in a small heatable tank mounted on the engine frame (tar tank), and is about 4 dl by volume. Both the 3-way valve and tar tank is fitted with an adjustable tracing (heating) and insulation. Thermocouples are mounted at the 3-way valve and the bottom of the tar tank, and in addition, there is a thermocouple mounted just at the inlet to the combustion chamber.
The air inlet is equipped with two heat guns in order to preheat the inlet air for the engine.
The engine is installed with a 50 Hz generator, and the load can be adjusted, using two 2 kW electric loads (adjustable 1-2 kW) to control the load on the engine. Engine layout can be seen in Figure 4.4.



Fuel preparation:

The fuel for the tests were prepared, preheated at 80°C and filtered before adding it to the fuel tank on the engine, this is primarily to protect the engine's fuel injection system for against larger particles. The tests on the engine included tests at idle and at load.
The used tar and RME blends can be seen in Table 4.1, together with the engine operating temperatures.

Sample (tar-RME)	Tar[%v]	RME [%v]	Air inlet [°C]	T - Fuel [°C]**
50-50	49,8	50,2	60	60
75-25-A	*	*	60	60
75-25-B	75,0	25,0	100	65-70
90-10	88,9	11,1	105	72
100-0	100,0	0,0	104	70

*Table 4.1 – Fuel mix in engine tests. *Exact mix-rate not known. **measured at 3-way valve.*

Figure 4.6 shows the heating of fuel, the filter and condensate from a mixture while heating.

Figure 4.5: Heating of fuel batch (left), condensate during heating (middle) and filter(right).

All the samples were easily manageable and flowed easily through the filters. Filtration of the sample with 50-50 mixture, a gummy substance separated out as a semi-solid viscous, tacky layer, and was left in the filter (see Figure 4.7). It could indicate that the RME at higher concentrations reacts with tar and form heavier compounds.

The 75-25-A sample left small grains in the filter (see Figure 4.7), but 75-25-B test showed no separation. The 90-10 and 100-0 samples, showed no separation in the filter.

Figure 4.6 – Separation by mixing. 75-25-A (left.), 50-50 (midlle and right).

Testing the fuel on the engine:

A total of 5 trials was performed with tar-RME tests on the engine. Before each test, the engine was started and operated on diesel for about 5-10min. After each test, the engine was again operated on diesel for 5-10min. in order to clean the injection system. Prior to the tests the tar mixture in the tank is heated to 60 ° C for 50-50, 75-25-A and to 80 ° C for 75-25-B and the 90-10, 100-0.

Experiments with mix 50-50
Starting with the 50-50% mix, the engine was started a multiple of times as the engine cut out the first couple of times. This probably was due to a cold engine and after operation to stable temperatures stable idle was achieved, with only a slight drop in engine revolutions when switching from diesel to tar/RME mixture.

The load was increased to 4 kW, and significant soot in the exhaust and visible smoke was observed. A slight increase in knocking was observed. The operation was stable over a total of 18min before the test was stopped.

Experiments with mix 75-25 A
Start and idling on tar-RME test went smoothly. Stable operation were achieved at idle and again a decrease in speed and slightly increased knocking compared to the operation of diesel.
Shortly after the connection of 4 kW electric load, heavy smoke and soot was visible together wih excessive vibration. The load was turned off relatively soon after, but the engine ended up stopping completely. After restarting and stable idle for a few minutes on diesel, a 2 kW electrical load were connected, with the same result as at 4 kW: Increased knock, smoke and engine stop. Subsequently, the engine restarted in stable idling on diesel. After that the engine could not run in the stable idling with the 75-25-A sample.

Experiments with mix 75-25 B
The air inlet temperatures and the fuel mix temperature were raised to 100 ° C and about 65-70 ° C respectively. The temperature in the tar tank was measured at 75 ° C.
The transition from diesel to tar-RME went smoothly at idle. Stable operation were achieved at idle and again a decrease in speed and slightly increased knocking in the engine was observed compared to the operation on diesel.
When connecting the 4 kW load, the engine immediately achieved stable operation without smoke or increased knocking from the engine.
To evaluate the importance of the air inlet temperature the heating of the air intake was turned down. After starting with a air temperature of 100 ° C changes in operating was first observed at 67 ° C, as the motor showed slightly unstable operation with small cut-outs. These were significantly stronger at 57 ° C and at 33 ° C, the engine stopped.

Given the results with the 75-25-A sample it indicates that the air and tar inlet temperatures are relatively important for engine operation.

At this point the milestone 2 was considered achieved, as the engine operated primarily on tar, with only 25% RME addition. The test was continued to see how far it was possible to go, and ultimately to test if the engine could operate on 100 % tar.

Experiments with mix 90-10
The inlet temperatures of the air and tar (at the 3-way valve) were, respectively, 102 ° C and 72 ° C. The temperature in the tar tank was measured at 75 ° C.
The transition from diesel to tar-RME mix went smoothly at idle. Stable operation was achieved at idle and again a decrease in speed and slightly increased knocking in the engine was observed, compared to the operation of diesel.
When connecting the 4 kW load, the engine developed some soot and began to knock and cut out. After re-starting and stable idling on diesel, a 2 kW load was connected. The engine showed stable operation at 2 kW load. Again the connection of the 4 kW load was attempted, but again it resulted in soot and engine cut out after 2min operation. After raising the inlet air to 106 ° C another restart attempt was made to connect the 3 kW load, and stable operation was obtained, but with smoke and soot. Subsequently, 2 kW load was connected and stable operation optained.
A stress at 2 kW were performed with air inlet temperature continuously lowered from 100 ° C. The engine was stable down to 78 ° C were small cut outs were observed. Subsequently, at 77 ° C to 74 ° C heavy sooting was observed and the engine load was ramped down continuously until the engine was idle. At about 70 ° C, the first cut outs were observed and at 44 ° C the engine stopped.

Experiments with mix 100-0
The inlet temperatures of the air and tar (at the 3-way valve) were 104 ° C and 70 ° C. The temperature in the tar tank was measured at 86 ° C.
The transition from diesel to tar went smoothly at idle. Stable operation were achieved at idle and again a decrease in speed and slightly increased knocking was observed compared to the operation on diesel.
A 1 kW load were connected without operational problems, and also 2 kW without changes in operation. At 3 kW load stable operation was achieved, but with smoke and soot. At 4 kW load a lot of smoke and knocking, and the engine was put back on idle.
A stress test with 2 kW load were performed, with air inlet temperature continuously lowered from 104°C. Changes in the operation were observed, when the temperature reached 77°C and the engine began to smoke and pulsate. At 70°C it started to smoke (soot). At 55°C, the engine was put on idle, because of the soot and knocking, and at 44 °C inlet temperature the engine stopped.

The results of all the experiments are summarized in Table 4.2.

Fuel mix (tar-RME)	**Air inlet temperature [°C]**	**Fuel Inlet temperature [°C]**	**Engine @ idle**	**Engine @ 2 kW**	**Engine @ 3 kW**	**Engine @ 4 kW**	**Minimum air inlet temp for stable operation [°C]**
50-50	60	60	Stable	-	-	Soot, stable	
75-25 A	60	60	Stable	Soot, stop	-	Soot, stop	
75-25 B	100	65-70	Stable	-	-		67 @ 4kW load
90-10	105	72	Stable	Stable	Soot, stable	Soot, stop	78 @ 2kW load
100-0	104	70	Stable	Stable	Soot, stable	Soot, stop	77 @ 2kW load

WP 4 result

A chemical description of the applied tar / bio-oil was performed, and from the mixing test performed in WP 2 it was concluded that it is possible to mix the bio-oil with RME. The aim was to improve the ignition characteristics bio oil / tar, and thereby be able to use the mix as fuel in a diesel process. This was followed by a series of engine tests with different mixtures of bio-oil and RME. It was shown that under the correct operating conditions, it is possible to achieve stable operation at 100% bio-oil.

From the engine experiment it can be concluded that it is potentially possible to use bio-oil / tar from updraft gasification as a diesel fuel. And it has been possible to achieve stable operation with pure bio-oil as fuel on a small motor with very small dimensions, and at a relatively high speed of 3000 rev / min. This is very promising in relation to the use of a full-scale stationary engine where combustion conditions is significantly improved and the combustion chamber dimensions will be significantly larger and the speed lower at 1500 revs / min, all working in favor of better conditions for the combustion of the tars / bio oil.

Further tests will be necessary to fully investigate the use of tar from updraft gasification. It will be necessary to do long-term operation of the motor used, and to be able to take it apart to examine wear and possible deposits. It will also be necessary to carry out the bio-oil operation on a larger diesel engine operated on pure bio-oil, where the mapping of the performance and emissions, and subsequent inspection of the engine can be performed.

WP5: Testing gas powered engine under changing operating conditions.

The engine and its ability to operate in a wide window of changing parameters is important if the final outcome of this work is to be a success. Normally the engine manufacturer require a gas with a relatively low dew point, which then leads to cooling and condensation of the water contained in the gas from the gasification of wood chips. This water must then be treated in a continuous process, and it must be cleaned to a very high standard in order to reuse the water and / or to lead the water to the domestic waste water system. If the engine could be operated with a higher amount of water in the air / gas mixture, the need for a separate cleaning system could be reduced.

To test a gas engines ability to operate at both higher temperature and with an air / gas mixture with a relatively high dewpoint, a series of tests was conducted, where the air was quenched with tempered water, thereby raising both water content and temperature in the air intake. The engine was a non turbocharged engine, as the concern was that droplets in the air / water mix could damage the turbocharger.

The first series of test was performed with the engine coupled directly to the quench, and operated within an array of changing temperatures and water content in the air, and the second test was performed with a fan between quench and engine intake manifold to help overcome the slightly higher pressure drop induced by the added components and quenching water flow.

The performance of the engine measured on efficiency was maintained at the lower temperatures, as can be seen in figure 5.1.

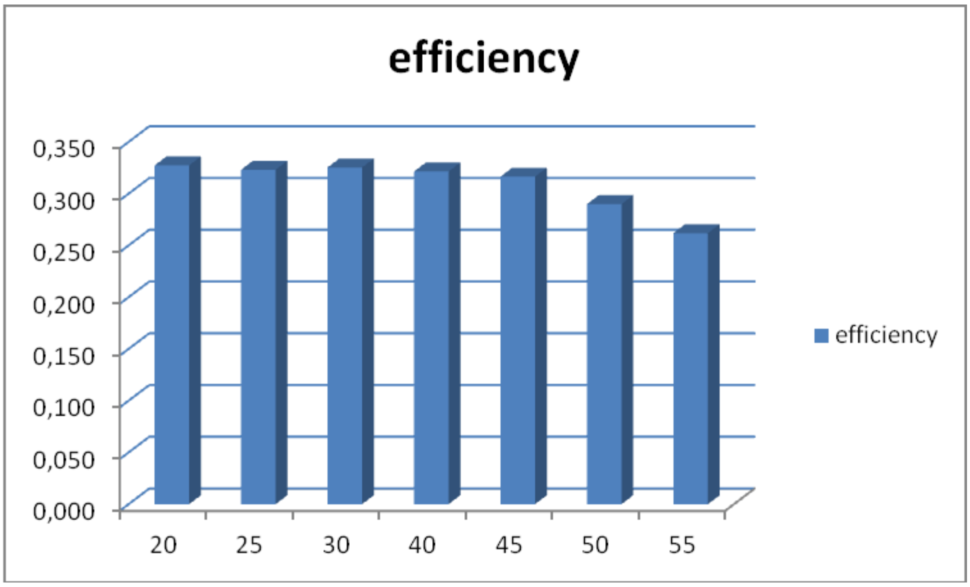


Figure 5.1: Engine efficiency at increased inlet temperatures

But when passing 45°C intake air temperature, a significant drop in fuel efficiency is observed. This corresponds with the added amount of water carried at the elevated temperatures. But taking into account the basic engine controls the efficiency remained surprisingly high up until 45°C intake air temperature. This points to the a possibility that by fine-tuning the engine, the efficiency in the 50°C and 55°C could be raised.

Looking at other parameters, the emissions, the following figure 5.2 show how emissions change with the intake air temperature span.

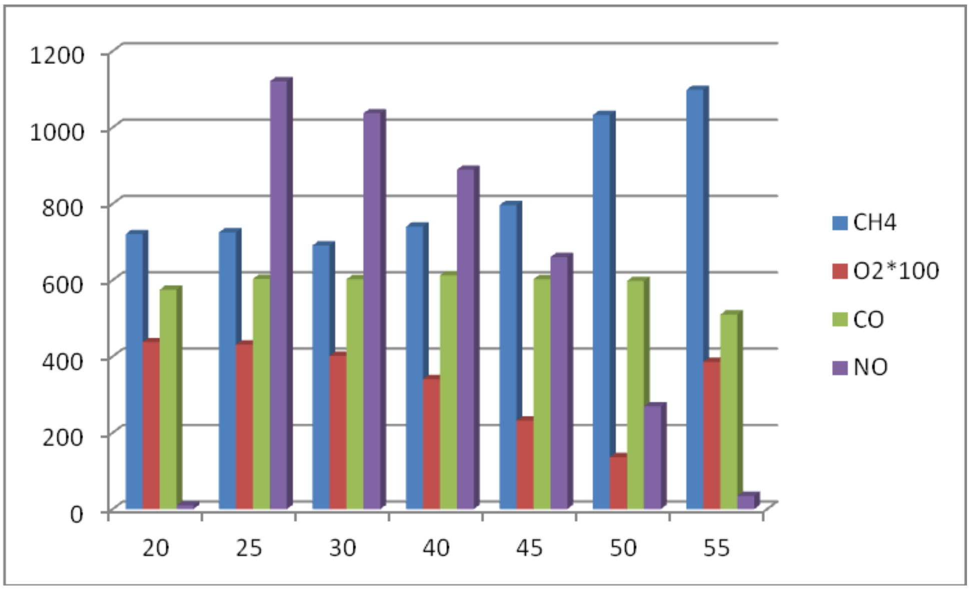


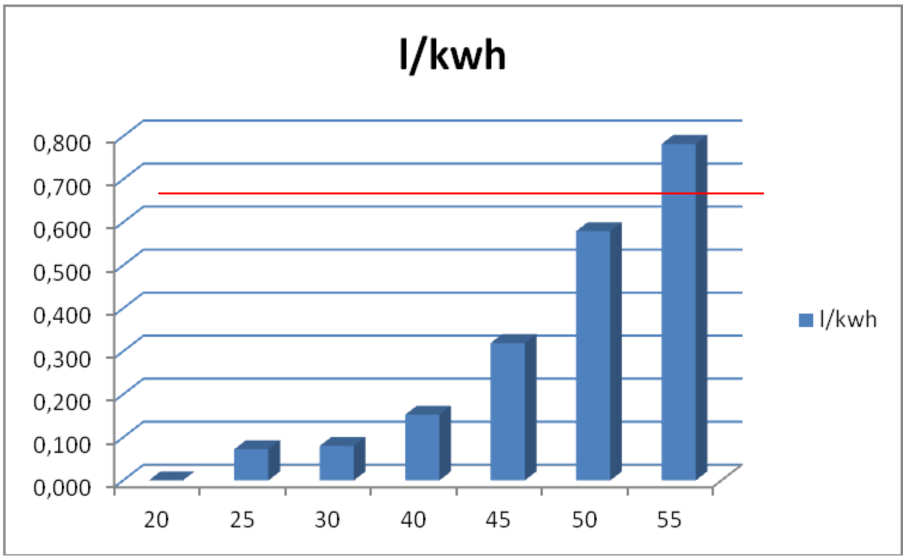
Figure 5.2: Emissons at diff. inlet temperature

This again shows a very interesting patern, where the dominant picture is a reduced NOx emission all the way trough the tempetaure range, with NOx emission being drastically reduced when the air intake temperaure rises, and thereby a larger amount of water is induced in the engines combustionchamber. The water reduces the temperature, and that could be the main explanation of the reduced NOx emission. On the other hand, the CO emission stays remarkely low even though the Oxygen level drops (measured dry, the lower O2 level is caused by the depleation of intake air with water wapor).

The slip of CH4 increases with the inlet temperature, as the combustion temperature drops because of the added water and the lower concentraton of oxygen present. This issue is more dominant here as would be the case in a fully automated engine running with lambda control, and the level of UHC – unburnt hydro carbons, needs to be investigated further.

The amount of water added to the engine intake air was the main topic of this test, and the figure can be summarized in a key figure represented by litres of water consumed by the engine pr. kWh electricity produced.

The figure to reach is 0,63 l/kWh, eneabling the total amount of water in the raw gas to be put trough the engine. The final result of the test showed that we where able to go to approximately 0,75 l/kWh, leaving a margin to the key figure of 0,63 l/kWh. The results are summarized in the figure below.



Figur 5.3: Water passing trough engine l/kWh electricity

The milestone (3) was reached with the succesfull operation of the engine, and the test was completed succesfully. The engine completed the test whitout any problems other than could be attended trough preparation and management of condensate in the intake system. A clear drop in efficiency and engine stability operating at very high levels of water content is expected to be encountered by lambda control and other active engine operation control systems.

WP6: Commercial milestone 1

The gasification plant based on updraft technology can be divided in to 4 main areas as described in the following. Each area is presented with the current price index based on a plant with gasifiers, gas cleaning, engines and waste water cleaning.

1: Gasifier and biomass handling	26 %
2: Gas cooling and cleaning	21 %
3: Gas engines and generators	23 %
4: Waste water cleaning	30 %

The demonstrated technologies in this project will change the plant configuration as follows

1: Gasifier and biomass handling:

Gasifier and biomass handling is not altered, and will not be influenced, considered the same plant size based on thermal load of the gasifiers.

2: Gas cooling and cleaning

Gas cooling and cleaning – this will be modified, and the operation and configuration will be changed to suit higher operation temperatures. Minor changes will be implied, but also a reduction in size. Overall conclusion is that the price will remain the same although the configuration is changed.

3: Gas engines and generators

The gas engines will be changed and more complex to operate. The fuel system will have to be altered compared to the standard gas train, and the intake will have to be changed to comply with the higher temperatures.
The CAPEX for the engine installation will, due to the added complexity, be raised by 20 %.

4: Waste water cleaning

The waste water cleaning is discharged and thereby 30% of the plant CAPEX is saved. Handling of the bio-oil will still be needed, and a pre-treatment system and filtering of the bio-oil is needed. This amounts to 1/5 of the cost of the water cleaning system used in the previous configuration.

All in all, the removal of the wastewater system and the added complexity of the engine installation and the bio oil pre-treatment will amount to a reduced CAPEX of approx 20% and at the same time the calculations and results shown in this project amounts to an overall increment in electrical efficiency from 25% to 30%.

The electrical efficiency in the area of 30% will be a new benchmark for wood gasification systems in the range of 1 to 7 MW electric, and together with a reduced CAPEX, it will strongly increase the position of this technology on the market.

1.6 Utilization of project results

The discoveries and the technology demonstrated in this project are of great importance to the further development of updraft gasification technology.

The achieved results are devising the future guideline for the development work planned by gasification.dk and 1rgi.

The technology will have to be developed further, and the achieved results in this project will be very important in the pursuance of both customers interested in the technology, and in investment partners for the further development process.

The next step will be to demonstrate the technology in a complete scale model, and to achieve stable operation for a combined plant for more than 100 h.

The market potential will be substancial, as the results points at a leap in electrical efficiency for the overall concept, compared to the competing technology as demonstrated in the Harboøre project.

At present there are no plans for patents based on the work in this project, but the further development work is expected to enable several patents to be issued.

By raising the electrical efficiency and at the same time maintaining or lowering the CAPEX for this scale of combined heat and power gasification plants, the technology will be an important part of a more diversified electrical generation system, moving closer to the goal of replacing fossil fuels.

1.7 Project conclusion and perspective

The objective of the project was to demonstrate the technologies and methodes to improve the updraft gasification process.

The updraft gasification testfacility at Gasification.dk and 1rgi was operated in order to test the gascleaning at a variety of temperatures, in order to find the operation point where a bio-oil fraction with a minimum of water was produced when cleaning the gas. This was achiwed and a portion of bio-oil was produced and made available for the work in WP 4, the gas composition was controlled and the amount of condensate was measured at relevant temperatures, thereby fulfilling milestone 1 of the project.

WP 4 demonstrated the use of the tar / bio-oil as engine fuel, and the milestone 2 was considered achieved, as the engine operated primarily on tar, with only 25% RME addition. The test was continued to see how far it was possible to go, and ultimately to test if the engine could operate on 100 % tar, which surpassed our expectation, so from the engine experiment it can be concluded that it is potentially possible to use bio-oil / tar from updraft gasification as a diesel fuel.

The results were achieved on a small high speed engine. This is very promising in relation to the use of a full-scale stationary engine where combustion conditions is significantly improved and the combustion chamber dimensions will be significantly larger and the speed lower, all working in favor of better conditions for the combustion of the tars / bio oil.

Further tests will be necessary to fully investigate the use of tar from updraft gasification. It will be necessary to do long-term operation of the motor used, and to be able to take it apart to examine wear and possible deposits. It will also be necessary to carry out the bio-oil operation on a larger diesel engine operated on pure bio-oil, where the mapping of the performance and emissions, and subsequent inspection of the engine can be performed.

With the succesful operating of the gas engine with a fuel gas with high moisture content milestone 3 achived. The engine completed the test whitout any problems other than could be attended trough preparation and management of condensate in the intake system. A clear drop in efficiency and engine stability operating at very high levels of water content is expected to be encountered by lambda control and other active engine operation control systems.

All in all, the removal of the wastewater system and the added complexity of the engine installation and the bio oil pre-treatment will amount to a reduced CAPEX of approx 20% and at the same time the calculations and results shown in this project amounts to an overall increment in electrical efficiency from 25% to 30%.

The electrical efficiency in the area of 30% will be a new benchmark for wood gasification systems in the range of 1 to 7 MW electric, and together with a reduced CAPEX, it will strongly increase the position of this technology on the market.