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D5.1 Seaweed derived biofuels and blend derived from fermentation

MacroFuels – Project

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MACROFUELS

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Summary

This delivery report deals with engine testing of ethanol and ABE produced in WP3. The engine tests were conducted at the Danish Technological Institute's engine laboratory in Aarhus, Denmark.

DTI has analysed the octane number, ignitability limits, flame speed, flash point, volumetric energy content and solubility limits. The engine tests have been performed, partly on an engine mounted in a test bench and partly during driving with a real car on a chassis dynamometer and during driving in real traffic situations.

In the tests, a 10% mixture of ethanol or ABE in a reference petrol is used. Reference petrol is either petrol without the addition of alcohol which is used for engine bench testing or commonly available petrol that is used for the test car. In all the tests, the two MacroFuels blends are benchmarked against measurement results obtained on 100% reference petrol.

The tests have been carried out to verify whether a modern car can be operated on petrol blends containing ethanol or ABE produced by algae biomass via a biochemical production process. The engine tests included transient emissions measurements (FTIR) to examine the exhaust gas composition for both regulated and non-regulated emissions, including aldehydes, methane, ethanol and various other hydrocarbons.

With the engine in the test bench, it has been investigated whether ethanol and ABE affect the combustion properties. The engine has been operated in load modes that are representative of the load that the engine will experience during real driving. Via the pressure sensors built into the engine's combustion chamber, the development of the combustion process is examined, and the associated flue gas emissions are measured.

In addition, the two MacroFuels have been tested by real driving in a car, partly on the chassis dynamometer and partly in real driving situations representing city driving, rural road and highway driving. In these situations, the transient behaviour of the car is investigated, and the associated emissions are measured.

The results from the tests have been very successful. The combustion properties of the two MacroFuels blends used have been trouble-free. No issues with cold or hot start of the engine and the transient characteristics have been fully in line with the operation on the reference fuel.

No significant challenges regarding the emissions are observed. We see variations of the emissions from the different test methods, but the emissions are within acceptable limits applicable to the modern EURO 5 engines we have used in this test program.

Contents

1 INTRODUCTION

During this project three different fuels, i.e. ethanol, ABE and furanic fuels are produced. This report covers description of work including test procedures and results carried out by the Danish Technological Institute during engine testing of ethanol and ABE. Engine testing of the furanic fuel is covered in a separate delivery report: D5.2.

This deliverable compares the seaweed derived fuel blends with commercial grade fuels as available for the consumer. The fuels were analysed for among others octane number, ignitability limits, flame speed, flash point, volumetric energy content and solubility limits (Sections 2 and 3).

Ethanol and ABE are considered to have a great potential to be used as a substitute for fossil petrol, but the two alternative fuels cannot be used purely in our current engine technology. They must be mixed in and used as an additive to petrol. Modern cars are designed to run on petrol mixed with a lower percentage, normally 5 to 10% alcohols. In the engine and car tests carried out in this project fossil petrol are mixed with 10 weight% MacroFuels, that is ethanol and ABE, and both fuels are tested in an engine dynamometer and in a real car tested on a chassis dynamometer and during real driving testing on different road types in real traffic.

The engine testing in the laboratory and on the road is done with the engine/car in standard configuration i.e. no modifications are done to engine ECU (Engine Control Unit) settings or the aftertreatment system (three-way catalytic converter and lambda sensors etc.). The tests are carried out to identify any problems using MacroFuels compared to reference petrol. The goal is to identity whether the produced and refined alcohols from the MacroFuels project can be a blending component in conventional fossil petrol and thereby reduce the CO_2 emission from our transport sector.

Precision instrumentation for transient emissions measurements (FTIR) has been used to examine the exhaust gas composition for both regulated and non-regulated emissions, including aldehydes, methane, ethanol and various other hydrocarbons (Section 3.2).

2 MATERIAL AND METHODS

2.1 Fuels

Two different MacroFuels fuels was delivered to DTI's engine testing facility in Aarhus, Denmark.

Table 1: Fuels received for testing

Fuel	Supplier [name]	Production process [Type]	Amount [Litre]	Water content [vol.%]
Ethanol	DTI	Fermentation	≈ 8	8
ABE	TNO	Fermentation	≈ 8	1
Reference Fuel	OK Denmark	Standard production	≈ 200	0

Commercially available petrol in Denmark contains 5.75% ethanol. In relation to the combustion tests performed in this work package, this ethanol content is not appropriate because the two produced MacroFuels fuels, ethanol and ABE are alcohols. In a test situation the existing 5.75 % ethanol would interfere with the engine test results including combustion characteristics and emissions. To solve this issue, we have purchased a batch of reference petrol, which is petrol without the addition of ethanol. The reference petrol contains the ordinary additive package as found in the commercial grade petrol. The reference petrol is supplied by the Danish oil company OK.

In the engine tests carried out in this work package, we have chosen to use a mixture of 10 weight% MacroFuels in 90weight% reference petrol. In the following we have used the abbreviation "E10" which covers the fuel mixture of ethanol and reference petrol and "ABE10" which covers the mixture of reference petrol and ABE. A fuel mixture containing the 10% MacroFuels is appropriate as it does usually not cause difficulties with engine operation but at the same time it gives clear and measurable results about engine operation, combustion process and flue gas emissions.

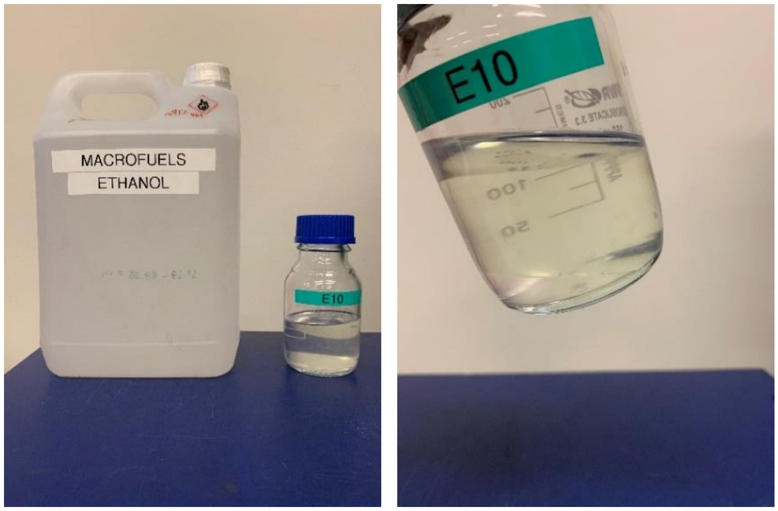
Ethanol produced was produced and delivered with a purity of 92%. ABE was preliminary produced with a purity of approximately 77%. Miscibility tests showed, as explained later, that the water content was too high for fuel purposes as a water phase was formed both in the ABE itself and in the final fuel blending for testing. After dewatering the ABE fuel reached a purity of 99% which was excellent for fuel purposes.

2.1.1 Solubility Limits

Both ethanol and ABE are produced via a fermentation process. Alcohols produced by fermentation normally contain a residual amount of water. In relation to engine fuel, water content is undesirable for reasons of miscibility and corrosion.

To test whether the solubility limits have been exceeded in the 10% mixture used, ethanol and ABE mixing tests have been performed.

Figure 1: Ethanol as delivered and in the final fuel blend



Ethanol as received was a clear homogeneous liquid without any phase shifting. After blending to the final E10 fuel for testing, the blend formed a clear visible ethanol/water phase as seen on the left hand picture in figure 1 after some hours of stand still. We decided to use this for the engine tests which could be done as we have a continuous fuel fixing facility on the test engine. During the tests the fuel could be kept suitably mixed, but this issue should be addressed if this MacroFuels ethanol shall be used as a commercially available engine fuel. The water content must be reduced, presumable to below 1% before it can be used as motor fuel.

Figure 2: ABE as delivered, in the first preliminary fuel blend test and the final successful homogenous fuel blend.

The first indications from TNO showed that the ABE produced had a water content of approximately 23%. To verify if ABE with this high-water content could be used as a motor fuel a preliminary fuel mixing test was made. As shown on the middle picture in figure 2 above the ABE fuel blend forms a clear, considerable and unwanted water/ABE phase. It was agreed with TNO that they processed the ABE further in a dewatering process which reduced the water content to 1%.

The fuel blend test was the repeated with ABE containing 1%water which went very well. As shown on the right-hand picture in figure 2 above the reference petrol and ABE mixed successfully to a homogeneous fluid and no water/ABE phase was formed even after many hours of stand still. ABE containing 1% water was used in the following engine and car tests.

2.1.2 Fuel analysis

Octane number and higher heating values (HHV) for the three fuels used for testing are analysis performed by laboratory tests. Analysis reports are enclosed to appendix. Data marked with an * (asterix) have been obtained from table references in the literature.

Table 2: Fuel analysis

Analysis	Unit	Ref. Petrol	E10	ABE10	Remarks
Octane number	RON	94,0	96,2	94,1	EN 228
Flash Point*	°C	-16	14	35	Figures for the pure substances are given
Density*	kg/m3	745	749	751	Figures for blends
Hydrogen	%mass	14,00	13,85	13,95	Figures for blends.

content*					Used for LHV calculation
Higher Heating Value	MJ/kg	45,5	43,8	44,8	ASTM D240
Lower Heating Value	MJ/kg	42,4	40,8	41,8	Calculated on basis of HHV and hydrogen content
Volumetric Energy Content	MJ/l	31,6	30,5	31,4	Calculated on basis of LHV and density.

The octane number is at the same level when comparing the reference petrol and ABE10. When comparing the reference petrol with E10 we see a significant increased value.

The flash point for the two alcohols are remarkable higher compared to reference petrol which can cause cold engine start difficulties. But since petrol represent the vast majority of the fuel mixture used for testing the flash point will be close to the pure petrol flash point. As expected, we do not see any cold start challenges in our tests.

E10 and ABE10 has a slightly lower volumetric energy content compared to reference gasoline. The difference, however, has no significance in the context of engine operation.

2.2 Test Setup and Test Procedures

Combustion analysis and associated emission measurements under static and dynamic load situations has been carried out with the E10 and ABE10 fuels. Both fuels were tested in a test bench set-up, in a car on a chassis dynamometer and in a car during real driving situations.

2.2.1 Test bench

The engine was mounted in a 330 kW fully programable AVL engine dynamometer. During the tests cylinder pressure, ignition delay, rate of heat release was continuously logged together with the corresponding engine load. Throughout the test, both regulated and unregulated emissions were measured.

Figure 3: The test engine located in the test bench, left hand picture and the TI personnel controlling the test conditions from the control room, right hand picture.

2.2.2 Emission measurement equipment

Two types of emission measurement equipment were used during testing.

Table 3: Equipment used for emission measurement.

Equipment	Make and type	Gas components	Equipment used for:
FTIR	Antaris IGS	Water, CO, CO_2, CH_4 (methane), NO (Nitric oxide), NO_2 (Nitrogen oxide), N_2O (Nitrous oxide), NH_3(Ammonia), SO_2 Sulphur dioxide, CH_2O (Formaldehyde), C_2H_6 (ethane), C_2H_4 (Ethene) C_2H_2 (Acetylene), C_3H_8 (Propane), C_3H_6 (Propene), C_2H_5O (Aldehyde)	- Dynamometer testing
PEMS*	AVL M.O.V.E	CO, CO_2, NO, NO_2, O_2	- Dynamometer testing - Chassis dynamometer - RDE* road testing

*PEMS: Portable Emission Measurement System.
*RDE: Real Drive Emission

2.2.3 Test Engine

The test engine used is a four cylinder 1,2 TSI engine form Volkswagen. It is a widely used engine found in many of the cars form the Volkswagen Group and the engine is very representative for the engines used in our cars today.

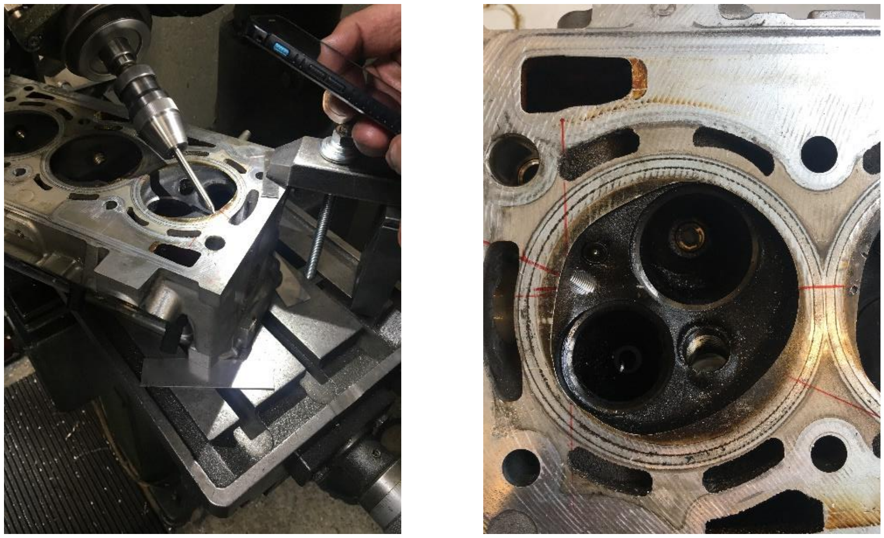
Table 4: Test engine key figures.

Manufacture	Volkswagen
Engine type	EA 111, 1.2 TSI, Euro 5
Engine code	CBZA
Fuel	Petrol
Power	63 kW@4300 rpm.
Torque	160 Nm @ 1500 – 3000 rpm.
Mileage	≈ 65.000 km.

The test engine was kept in standard configuration and no modifications was made to the engine control unit or to the aftertreatment system (three-way catalytic converter including lambda and temperature sensors)

The only, though very significant, modification made to the engine was the mounting of a pressure sensor in the combustion chamber of the no.1 cylinder. The pressure sensor has very small physical dimensions and its location in the combustion chamber has no influence on the combustion itself.

Figure 4: Drilling the mounting hole for the combustion pressure sensor, left hand picture and final position for pressure sensor in the threaded hole beside the injection nozzle shown on right hand picture.



The cylinder head was disassembled from the engine itself and after precision measurement of the cylinder head geometry a suitable place was chosen for the pressure sensor. As the cylinder head is provided with a large number of cooling-water and oil ducts, inlet and outlet valves and mountings for spark plug and injection nozzle the space for the pressure sensor was limited. We located a suitable spot where the pressure sensor was successfully mounted. We got support from a specialist workshop to do the drilling of the pressure sensor mounting hole including threading.

2.2.4 Load Points

An important element of the engine tests is to determine operating points that are representative of a car's daily usage pattern. To determine the operating points, we analysed the operational data from the RDE tests and converted this data into a measurement plan that represents idle, city road driving, urban road driving and motorway driving.

Table 5: Four-mode test schedule for the test engine.

Test schedule for the VW test engine					
Mode [No.]	**Torque [Nm]**	**RPM [min.$^{-1}$]**	**Power [kW]**	**Load [%]**	**Torque [%]**
1 (Idle)	0	800	0	0	0
2 (City)	30	1500	4,7	7	19
3 (Urban)	60	2000	12,6	20	38
4 (Motorway)	100	3000	31,4	50	63

2.2.5 RDE/PEMS Testing

The car used for the tests is a Volkswagen. A car from any other car producer could have been used, but it has important to choose a car type that is widely used and representative for the cars driving on the European roads today.

The car was kept in standard configuration – no modifications made to engine or aftertreatment system.

Figure 5: Test car being fueled with MacroFuels for RDE/PEMS testing, left hand picture and co-driver preparing the data acquisition and system control computer for the RDE/PEMS testing, right hand picture.

During testing, the car was equipped with the PEMS equipment (Portable Emission Measurement System) The PEMS equipment is mounted on the car and consists of a gas analyser measuring CO, CO_2, NO, NO_2, and O_2 content. Simultaneously the particulate emissions from the car is measured. The flue gas mass flow and temperature are measured by the flow tube unit seen under the system.

A weather station located on the car roof is recording the climatic conditions during the test and a GPS sensor is logging the route driven. The system control computer is located inside the car and the connected display gives feedback to the driver about route details and reports any need for speed changes or adjustment of driving style.

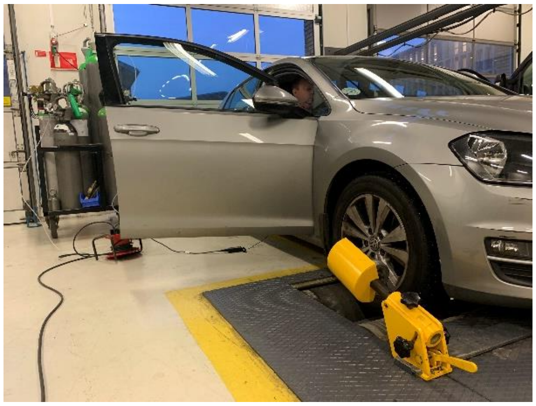
The PEMS route driven is approx. 80 km. long, taking about one and a half hour to drive. The route is distributed between 1/3 city driving, 1/3 rural roads and 1/3 motorway.

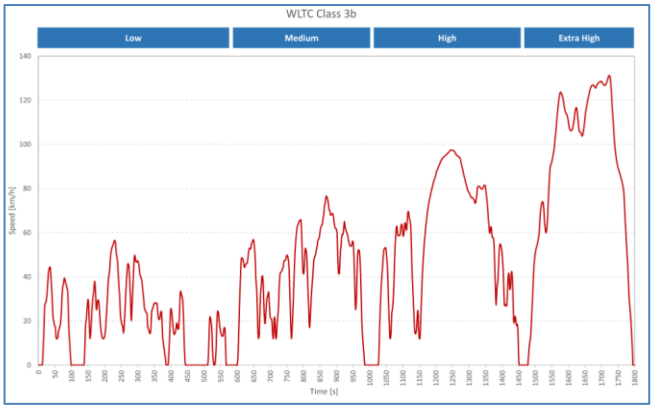
The PEMS testing method is an EU recognised method used by the car manufacturers as an obliged element during type testing. DTI holds a full accreditation to perform the PEMS testing.

2.2.6 Chassis Dynamometer Testing

The test car was also driven on a chassis dynamometer in order to further verify the transient behaviour of the car when driving on E10 and ABE10.

Figure 6 Test car on the chassis dynamometer, left hand photo and the WLTP test cycle used for transient testing right hand figure.





The WLTP, World-wide harmonised Light vehicle Test Procedure, is a transient test procedure developed using real-driving data, gathered from around the world. WLTP represents everyday driving profiles.

3 RESULTS AND DISCUSSION

The results of the measurements from the engine test bench and from the real car driving are presented below. Four reporting charts, each covering one load mode are presenting the results from the engine testing where combustion characteristics have been investigated. The reporting below is a zoom-in on selected graphs. A complete set of graphs covering the engine testing results are attached to this report's appendix section. Corresponding emission figures to the load points driven on the testbench are enclosed in this section.

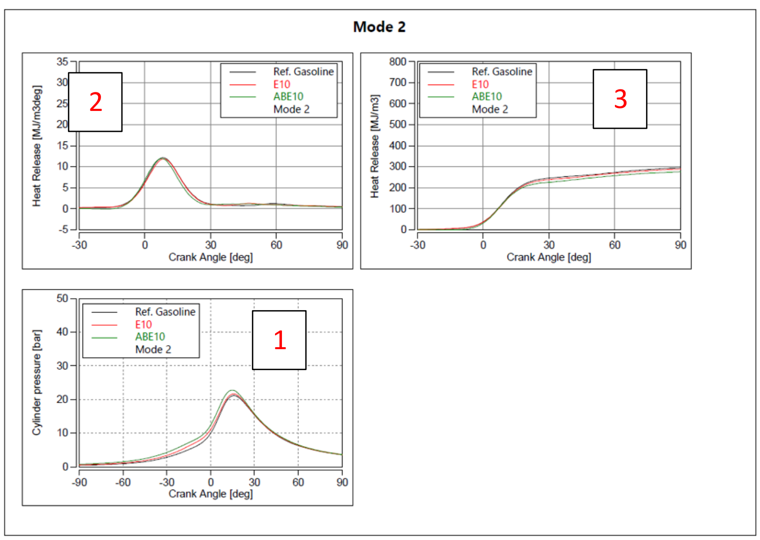
Results from the transient emission testing during the WLTP measurements on the chassis dyno and from RDE measurements are included in this section.

3.1 Cylinder Pressure Measurements

The aim is to investigate how the combustion process proceeds with E10 or ABE10 compared to the reference fuel and further to investigate whether unwanted pressure oscillations occur during the combustion cycle.

Via the cylinder pressure measurements, the rate of heat release is calculated and finally the ignition timing (ignition delay) is determined and reported.

Figure 7: Combustion reporting chart. Here the reporting chart for the no.2 test mode is shown.



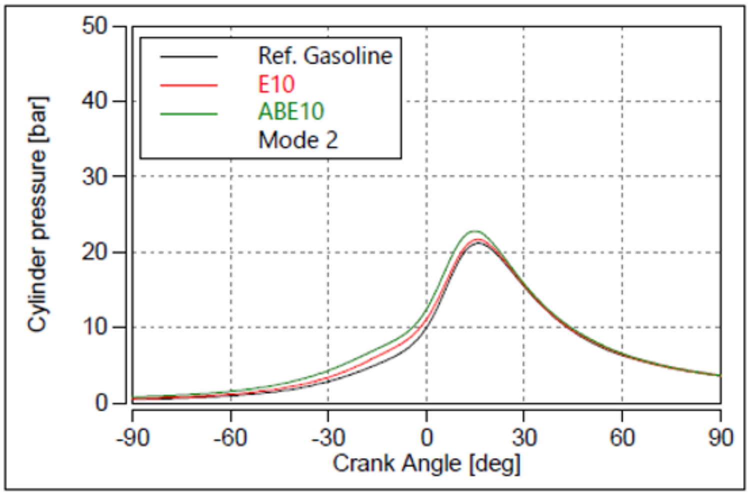
The combustion reporting chart consists of three graphs with the following information:

1. Cylinder pressure
2. Rate of heat release
3. Accumulated rate of heat release

3.1.1 Cylinder pressure measurement and detection of oscillations

The cylinder pressure occurring during a single combustion stroke is measured and recorded with the pressure sensor located in the combustion chamber on the test engine.

Figure 8: Cylinder pressure measurement. Here the no.2 test mode pressures are shown.



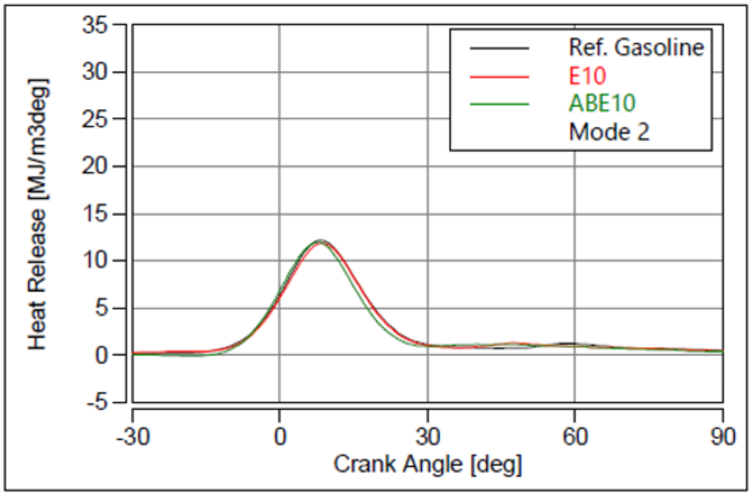
The interesting part of the pressure diagrams is to consider whether undesirable pressure gradients occur during the combustion stroke and further to consider if the flame speed and combustion velocity is kept within appropriate limits. The above figure shows the combustion pressure in the combustion chamber (y-axis) as a function of the crank angle degrees (x-axis) during the no.2 test mode.

For all test modes, it can be seen and concluded that undesirable pressure gradients do not occur using E10 or ABE10. When comparing the combustion processes, it is seen that the pressure curves within negligible limits has the same profile for all three fuels. No pre-combustion (self-ignition) challenges are seen in any of the fuels.

3.1.2 Rate of Heat Release

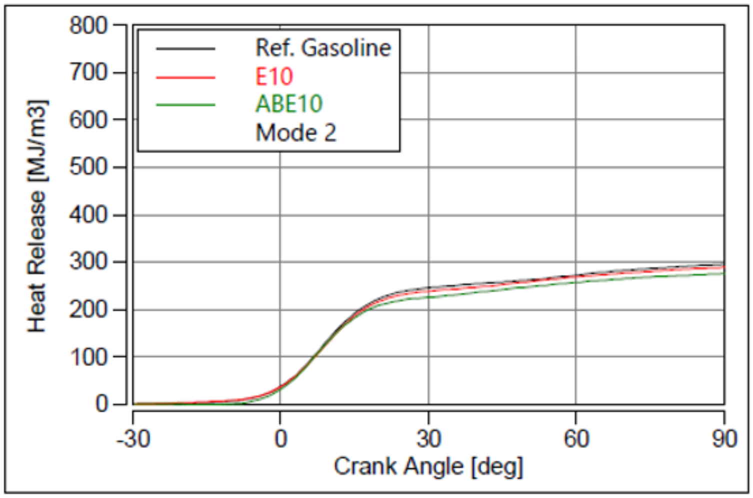
Based on the recorded cylinder pressure the heat release rates are calculated.

Figure 9: Rate of heat release. Figures from the no.2 test mode is shown.



The calculated heat release rates covering E10 and ABE10 show a very fine progress during the combustion stroke that is fully in line with the reference fuel.

Figure 10: Accumulated rate of heat release. Figures from the no.2 test mode is shown.

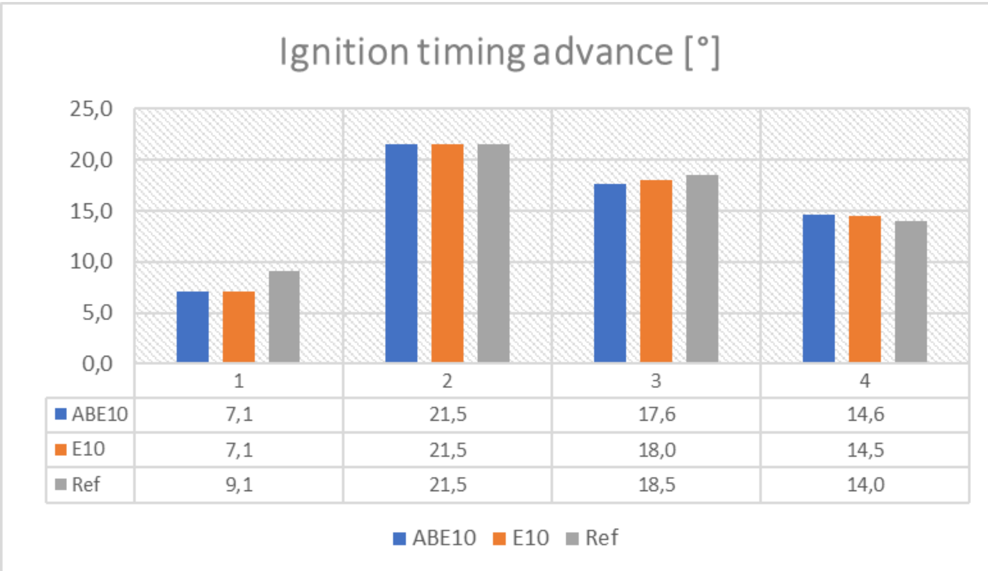


The calculated heat release rates seen during all load modes show a smooth combustion progress without peaks or “ringing” due to engine knock.

3.1.3 Ignition delay

The progress of the pressure curves does not indicate any issues concerning ignition delay. For a further study, we have logged the ignition timing advance from the engine. Ignition timing advance is controlled by the engine's ECU (Engine Control Unit) and is an expression of how well the engine adapts to operating on ethanol and ABE.

Figure 11: Ignition timing advance.



In mode 1 (idle), an earlier time of ignition is seen on E10 and ABE10, but this is within acceptable limits and the difference is not significant. In the other modes of operation, ignition timing advance is on level with the reference fuel.

3.1.4 Flame speed and combustion velocity

An important property to investigate when testing a new and alternative fuel is the rate of flame speed and thus combustion velocity. Slow flame propagation is undesirable as it leads to an increased exhaust temperature and loss of efficiency. In addition, there is a risk of thermal damage to the turbocharger and the after-treatment system, especially three-way catalytic converter due to overheating.

To investigate this, we measured the exhaust temperature in the engine exhaust port immediately before the turbocharger. As seen from the measurements shown in the chart below, the exhaust temperatures are within very small margins at the same level for the three fuels. We can conclude that we have no issues to handle concerning flame speed and combustion velocities with the tested MacroFuels.

Table 6: Exhaust gas temperatures.

Exhaust gas temperature [°C]			
Mode	Ref. Fuel	E10	ABE10
1 (Idle]	234	240	245
2 (City road)	465	461	464
3 (Rural road)	567	572	575
4 (Motor way)	663	667	666

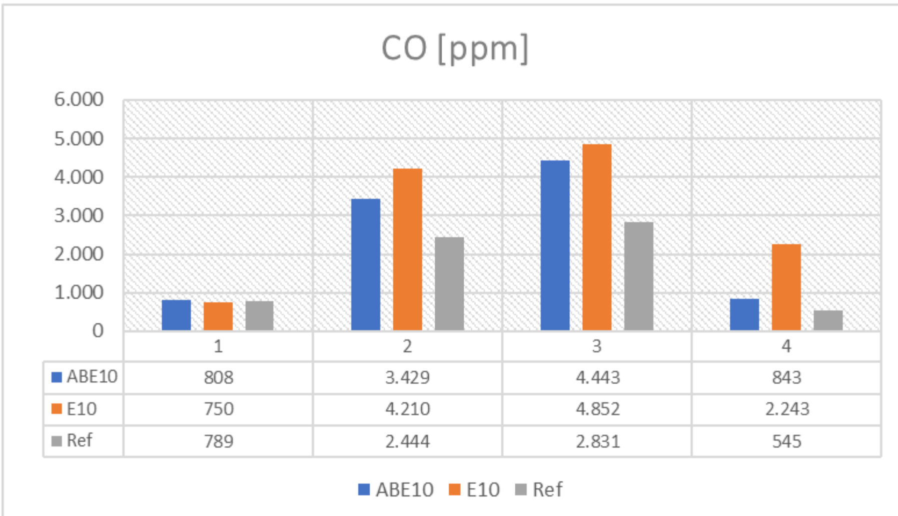
3.2 Emission Measurements test bench

During engine testing the flue gas emissions from E10 and ABE10 are compared with the emissions from the reference petrol. Emissions are measured in each mode of operation and both regulated emissions and the so-called unregulated emissions, have been measured and recorded.

3.2.1 Exhaust gas composition – regulated emissions

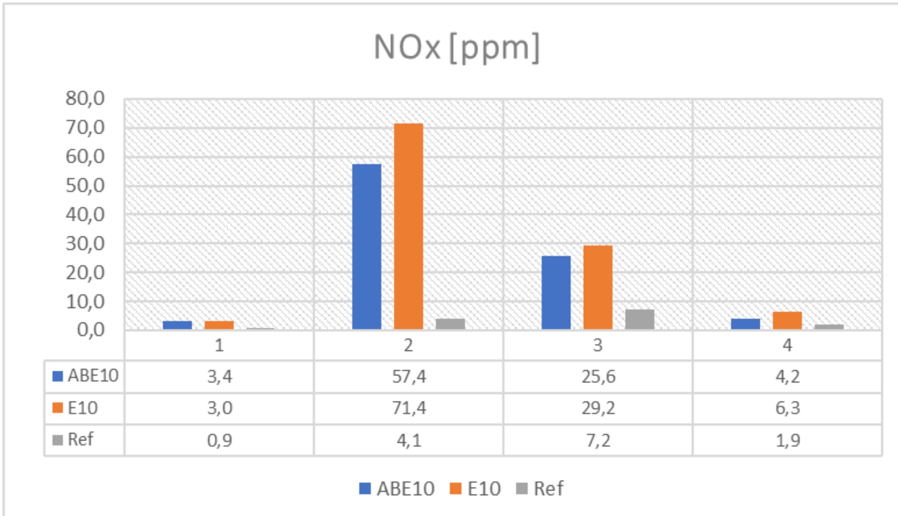
Regulated emissions are CO, NO_x (sum of NO and NO_2) and particulates.

Figure 12: CO emissions.



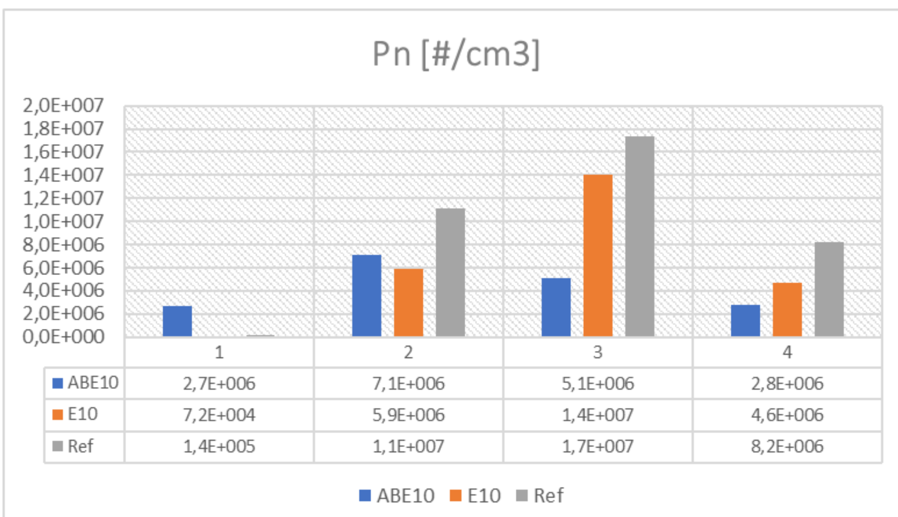
In mode 1 the CO emissions are equal. In the higher loads, mode 2 and 3 we see the lowest CO emission on the reference fuel. At the highest load, mode 4 we see the highest CO emission on E10.

Figure 13. The NO_x emisions.



The NOx emissions in mode 1 and 4 are negligible. In the middle loads, mode 2 and 3 we see a higher NOx emission on E10, and ABE 10 compared to the reference fuel.

Figure 14 Particulate emission.

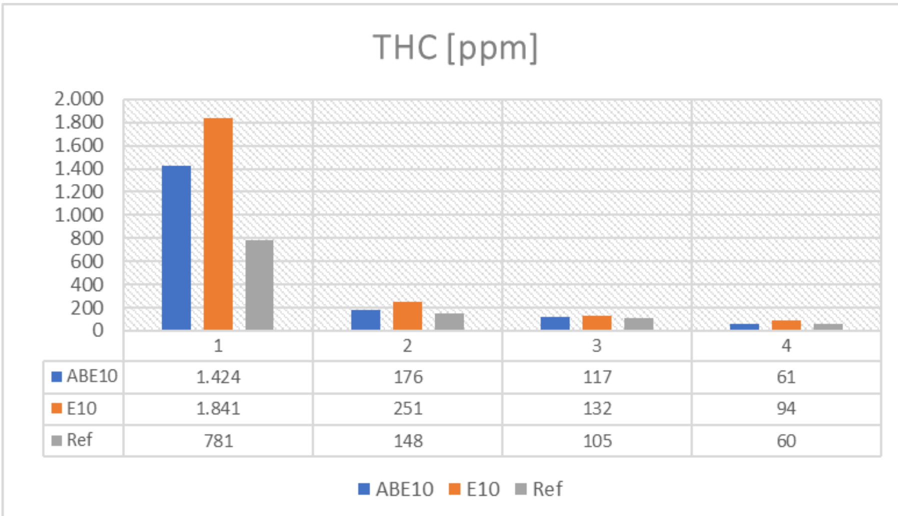


In general, slightly lower particle emissions are seen when operating on E10 and ABE10.

3.2.2 Exhaust Gas Composition – unregulated emissions

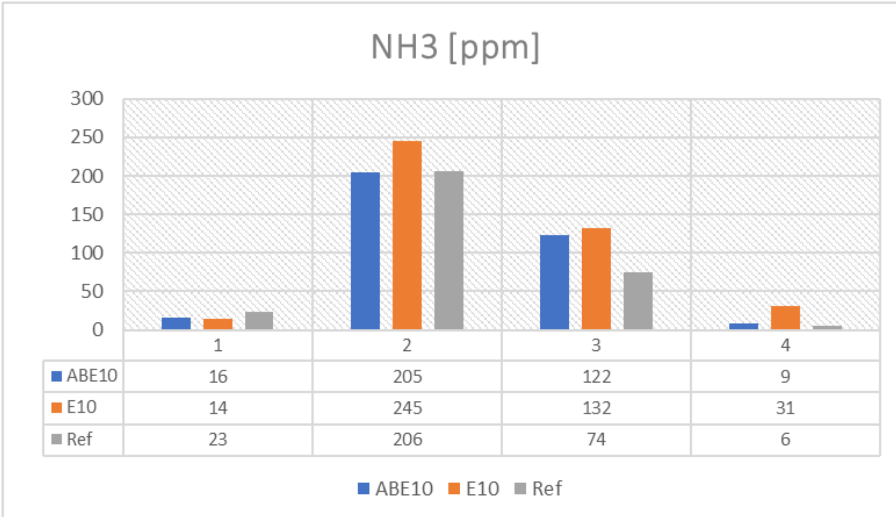
In all operating modes we have measured the concentration of the unregulated emissions with the FTIR equipment. We measured concentrations of the substances listed in **Fejl! Henvisningskilde ikke fundet.** which include aldehydes, methane, ethanol and other hydrocarbons. The only unregulated emissions we have been able to detect at measurable level are THC and NH_3.

Figure 15:The THC concentrations.



The THC concentrations are highest in mode 1 where E10 and ABE10 shows a slightly higher THC concentration in the flue gas than released from the reference fuel. In the higher operating modes, mode 2, 3 and 4, the THC emissions are on par with the reference fuel

Figure 16: NH3.



The NH3 concentration is highest in mode 3, but the difference between the three fuels is negligible. The same trend is seen in the other operating modes.

3.3 Emission measurement transient testing

As described in Section 2, transient tests and emissions measurements have been performed with a car on the chassis dynamometer and when driving on the road. At both methods, we have performed emission measurements with the PEMS equipment.

3.3.1 Chassis Dynamometer Testing

Figure 17:Emission figures from WLTP testing.

Gas component	Distance specific [g/km and #km]		
	Ref. Fuel	ABE10	E10
CO	0,024	0,043	0,124
CO2	126	128	134
NO	0,08	0,07	0,11
NO2	0,00	0,00	0,00
NOx	0,78	0,71	1,11
PN	8,2E+11	6,7E+11	1,1E+12

At the chassis dyno we saw an increase in CO emission on ABE10 and especially on E10. The NO_x emission (sum of NO and NO_2) is however slightly lower on E10 and slightly higher on ABE10 compared to the reference fuel. The particulate emission is lowest on ABE10, but the differences are not considered to be significant.

3.3.2 RDE/PEMS testing

Figure 18:Emission figures from RDE/PEMS testing.

Ref.	Distance specific [g/km and #km]				***ABE10***	Distance specific [g/km and #km]				***E10***	Distance specific [g/km and #km]			
	Urban roads	**Rural roads**	**Motor -way**	**Trip**		**Urban roads**	**Rural roads**	**Motor -way**	**Trip**		**Urban roads**	**Rural roads**	**Motor -way**	**Trip**
CO	0,041	0,051	0,098	0,062	**CO**	0,053	0,038	0,129	0,072	**CO**	0,028	0,045	0,059	0,042
CO2	164,4	115,7	136,6	142,1	**CO2**	166,7	116,8	134,8	143,2	**CO2**	169,8	116,7	135,6	144,5
NO	0,397	0,082	0,088	0,209	**NO**	0,261	0,027	0,024	0,122	**NO**	0,224	0,039	0,034	0,116
NO2	0,000	0,000	0,000	0,000	**NO2**	0,003	0,002	0,002	0,002	**NO2**	0,001	0,001	0,001	0,001
NOx	0,385	0,078	0,082	0,201	**NOx**	0,264	0,028	0,026	0,125	**NOx**	0,225	0,040	0,035	0,117
PN	1,0E+12	7,1E+11	1,5E+12	1,1E+12	**PN**	1,3E+12	8,4E+11	1,1E+12	1,2E+12	**PN**	9,5E+11	6,7E+11	1,4E+12	9,9E+11

At the real driving emission testing we saw a slightly increase in CO emission on ABE10 and the E10 performed better in this test and went out with a slightly lower CO emission compared to the reference fuel. The NO_x emissions (sum of NO and NO_2) are negligible at all fuels. The particulate emission is lowest on ABE10 but again the differences are not considered to be significant.

4 CONCLUTIONS

The results from the tests have been very successful. As we saw from the mixability tests described in section 2 the water content in the produced MacroFuels is an issue to be addressed in the future. It is necessary that the water content reaches values presumably below a level of 1%.

The combustion test has been successfully completed and we see no challenges in using ethanol or ABE in a 10% mixture as used in these studies. We see no problems with cold- or hot start of the engine and engine operation at the various load points was carried out without detection of any unwanted pressure peaks, engine-knocking or other issues related to poor or inappropriate combustion.

When conducting the emission tests, we see differences in the in gaseous and particulate emissions in the different test situations. Both engines used for the tests, partly the engine in the test bench and the engine in the test car, are Euro 5 engines equipped with a three-way catalytic converter that significantly reduces emissions of CO and NO_x. The efficiency of a three-way catalytic converter is highly dependent on the operating temperature of the catalyst itself. On the test bench it has been fairly easy to put the engine in the same operating modes but hitting the exact operating temperature in the catalyst has not been possible. Differences in emissions from the test bench are seen when compared to emissions from the RDE test. The operating temperature in the test bench's catalyst has generally been higher than the catalyst in the test car, which is subject to wind chilling due to driving.

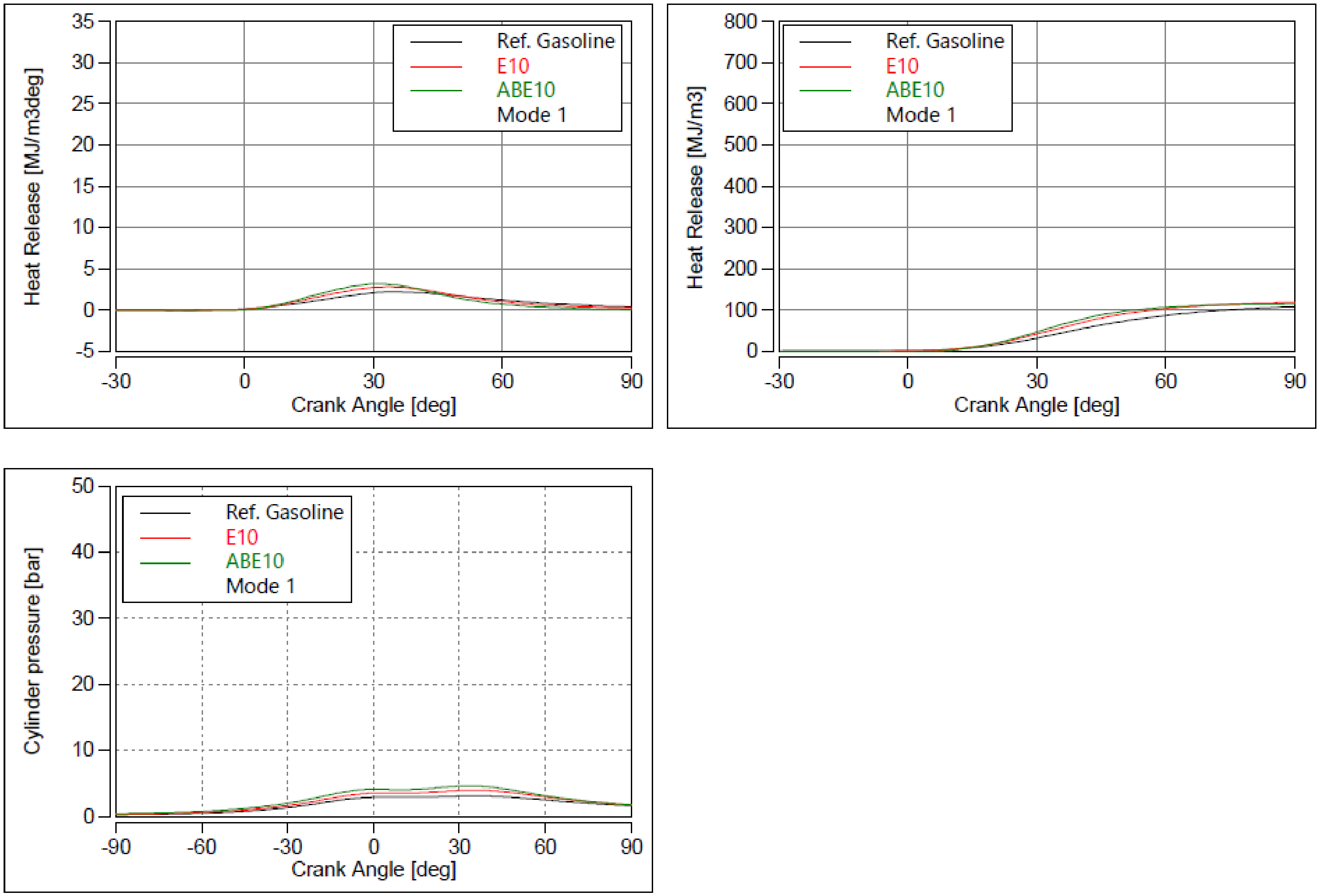
However, we conclude that the emissions from the two MacroFuels are within the acceptable Euro 5 limits and we see great potential for the further development of algae biofuels, which in large-scale use can contribute to a significant reduction in greenhouse gases from our transport sector.

5 ACKNOWLEDGEMENT

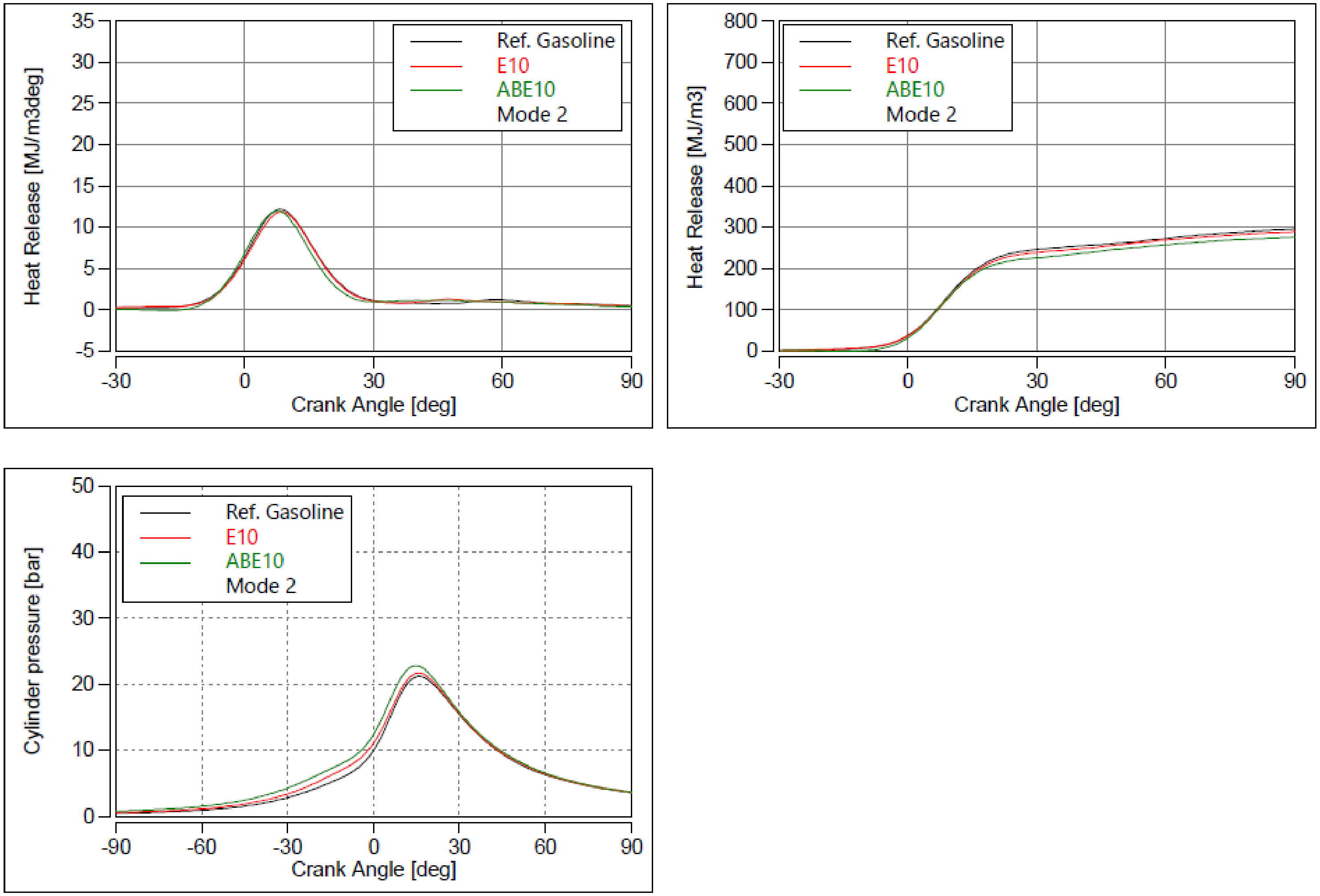
This deliverable is part of the MacroFuels project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654010.

6 APPENDIX

Mode 1


Heat Release [MJ/m3deg]
Crank Angle [deg]
Ref. Gasoline
E10
ABE10
Mode 1
Heat Release [MJ/m3]
Crank Angle [deg]
Ref. Gasoline
E10
ABE10
Mode 1
Cylinder pressure [bar]
Crank Angle [deg]
Ref. Gasoline
E10
ABE10
Mode 1

Mode 2


Heat Release [MJ/m3deg]
Crank Angle [deg]
Ref. Gasoline
E10
ABE10
Mode 2
Heat Release [MJ/m3]
Crank Angle [deg]
Ref. Gasoline
E10
ABE10
Mode 2
Cylinder pressure [bar]
Crank Angle [deg]
Ref. Gasoline
E10
ABE10
Mode 2

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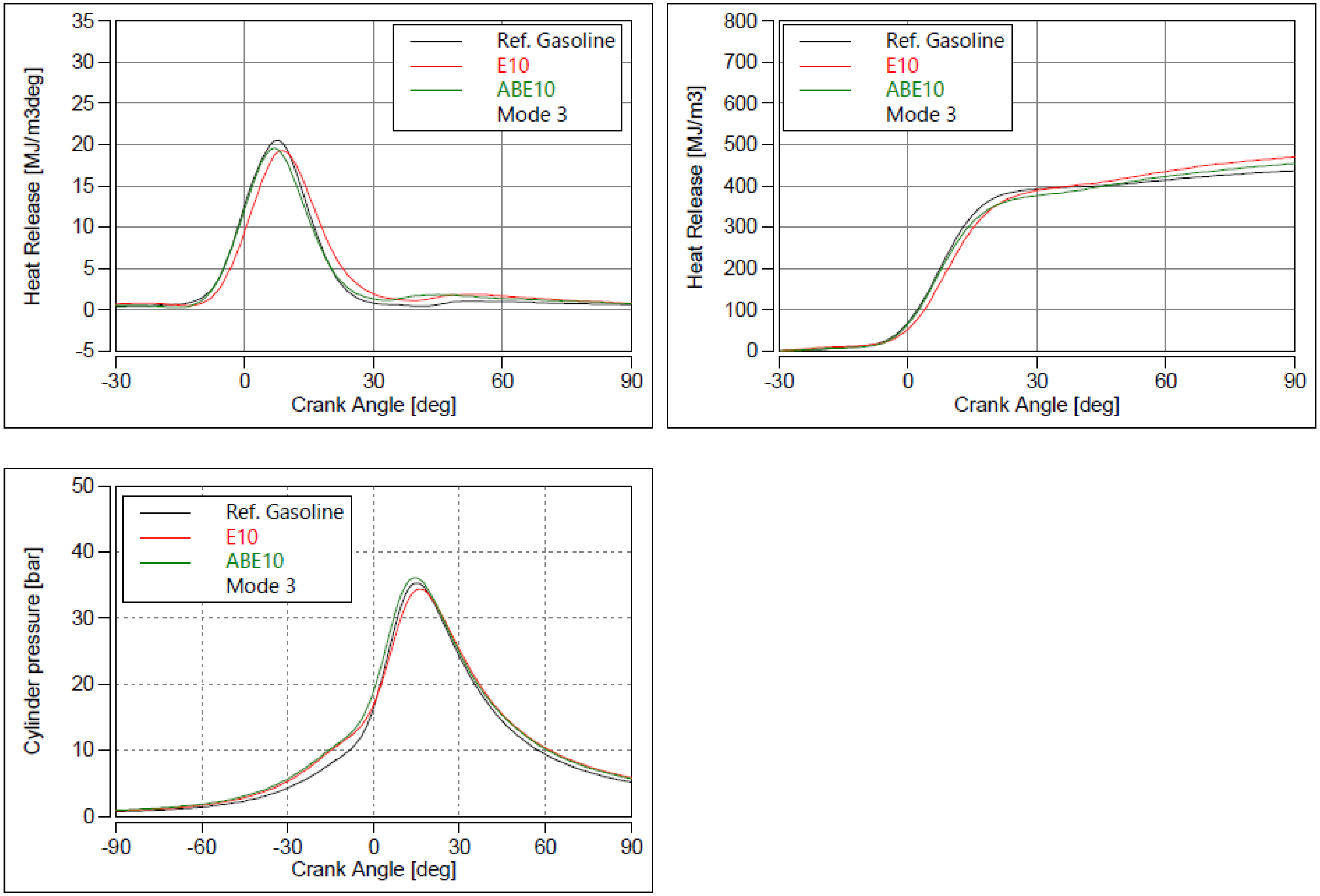
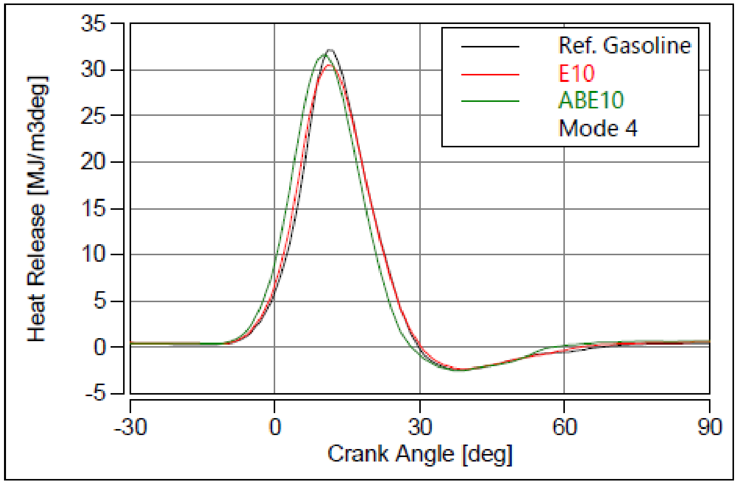
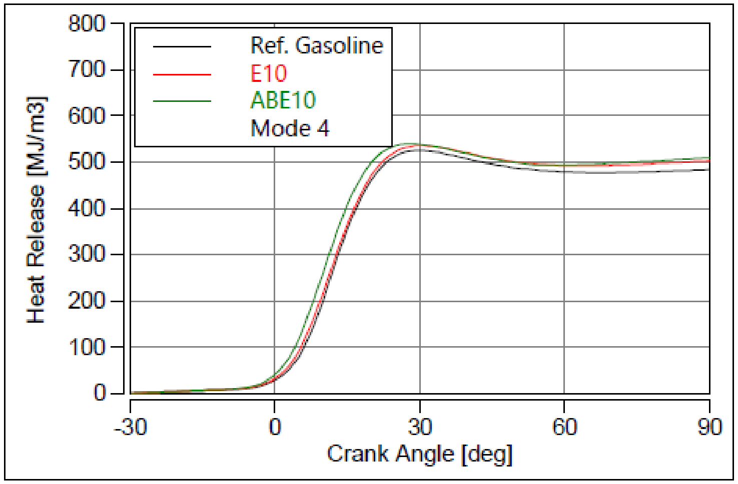
Mode 3

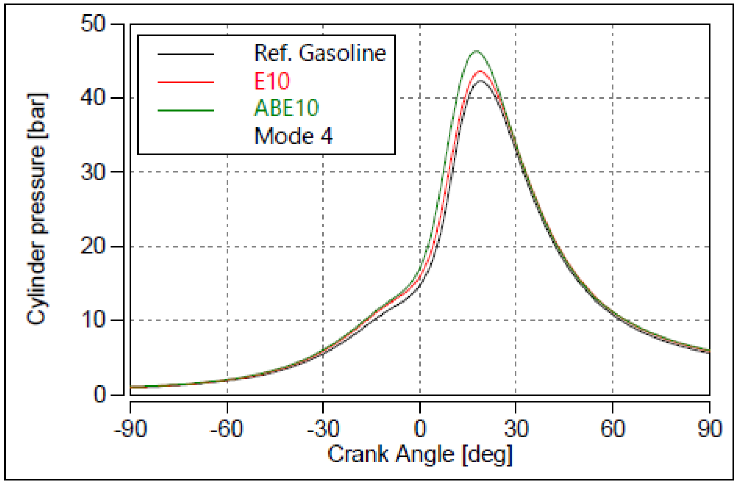


The Project is funded
by the European Union

Mode 4







MACROFUELS

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caleb brett

Certificate of Analysis

TEKNOLOGISK INSTITUT
Kongsvang Allé 29
DK-8000 Aarhus C
Danmark

Laboratory Report ID : 20-002441-0-DNK-003-00
Our Reference Number : -

Sample ID	: 3703749 / 20-002441-0-DNK-003-00	**Date Taken**	: 08-Jan-2020
Product	: Benzin	**Drawn by**	: Client
Client Reference	: -	**Date Submitted**	: 08-Jan-2020
Submitted sample		**Date Tested**	: 04-Feb-2020
Representing	: Reference Gasoline		

Method	Test	Spec Limit	Result	Units
ASTM D2699	Research Octane Number (uncorrected)		94.2	
ENISO 5164	Research Octane Number- EN 228 corrected		94.0	

Sampling location : -
Sample container : Glass (1 liter)
Sampling Procedure : Standard

This certificate has been authorised by: Susanne Kristensen on Tuesday, February 4, 2020

Susanne Kristensen
Laboratory Supervisor
Intertek Denmark A/S

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MACROFUELS

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Certificate of Analysis

TEKNOLOGISK INSTITUT
Kongsvang Allé 29
DK-8000 Aarhus C
Danmark

Laboratory Report ID : 20-002441-0-DNK-001-01
Our Reference Number : -

Sample ID	: 3703747 / 20-002441-0-DNK-001-01	**Date Taken**	: 08-Jan-2020
Product	: Benzin	**Drawn by**	: Client
Client Reference	: -	**Date Submitted**	: 08-Jan-2020
Submitted sample		**Date Tested**	: 04-Feb-2020
Representing	: Gasoline E10		

Method	Test	Spec Limit	Result	Units
ASTM D2699	Research Octane Number (uncorrected)		96.4	
ENISO 5164	Research Octane Number- EN 228 corrected		96.2	

Sampling location : -
Sample container : Glass (1 liter)
Sampling Procedure : Standard

This certificate has been authorised by: Susanne Kristensen on Tuesday, February 4, 2020

Susanne Kristensen
Laboratory Supervisor
Intertek Denmark A/S

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caleb brett

Certificate of Analysis

TEKNOLOGISK INSTITUT
Kongsvang Allé 29
DK-8000 Aarhus C
Danmark

Laboratory Report ID : 20-002441-0-DNK-002-00
Our Reference Number : -

Sample ID	: 3703748 / 20-002441-0-DNK-002-00	**Date Taken**	: 08-Jan-2020
Product	: Benzin	**Drawn by**	: Client
Client Reference	: -	**Date Submitted**	: 08-Jan-2020
Submitted sample		**Date Tested**	: 04-Feb-2020
Representing	: Gasoline BIO		

Method	Test	Spec Limit	Result	Units
ASTM D2699	Research Octane Number (uncorrected)		94.3	
ENISO 5164	Research Octane Number- EN 228 corrected		94.1	

Sampling location : -
Sample container : Glass (1 liter)
Sampling Procedure : Standard

This certificate has been authorised by: Susanne Kristensen on Tuesday, February 4, 2020

Susanne Kristensen
Laboratory Supervisor
Intertek Denmark A/S

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