# BIOMETHANE FUELLED TRACTOR – OPERATION EXPERIENCES AND EMISSION BEHAVIOUR

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ABSTRACT: The use of biomethane as fuel for agricultural machinery with dual-fuel technology contributes to climate protection and ensures safe fuel supply. So far, hardly any newer operational experiences are known. The aim of the project, funded by the Bavarian Ministry of Economic Affairs and Media, Energy and Technology, was to investigate practicability for daily use and emission behaviour of a Valtra N101 prototype tractor (exhaust stage IIIA). The retro-fitted dual-fuel technology allows simultaneously use of biomethane or natural gas and diesel as ignition fuel. During the field test over 590 operating hours, the tractor showed overall high reliability. On average, the operating range in dual-fuel mode with one complete filling of the gas tanks was about 11.5 hours. On the tractor test stand a significant improvement of the exhaust emissions could be observed, when the gas ECU had been changed by the manufacturer. For dual-fuel operation, nitrogen oxides ($NO_x$) are lower, whereas carbon monoxide (CO), hydrocarbons (HC) and particulate matter emissions (PM) are higher compared to solely diesel operation. In particular, HC emissions exceed the proposed limiting value, submitted by the European Commission. This is due to incomplete methane combustion and insufficient conversion by the exhaust after-treatment-system. A big potential for optimisation is expected by adjusting the operating point-specific gas-diesel ratio and improving exhaust gas after-treatment.
Keywords: biofuel, methane, agriculture, engine, emissions, operation and maintenance

## 1 INTRODUCTION

Regionally produced biofuels contribute to reduce greenhouse gas (GHG) emissions and increase security of fuel and food supply. This is particularly relevant for the agricultural sector, since agriculture is on one hand a considerable source of GHG emissions and on the other hand, agricultural production is seriously affected by climate change effects. Besides process optimisation, diesel fuel consumption of agricultural machines has to be lowered significantly. To substitute fossil diesel fuel, biofuels are promising sustainable alternatives. Presently available biofuels are mainly biodiesel, pure vegetable oil and biomethane.

Biomethane is known as upgraded biogas. In Germany biomethane has to fulfill DIN 51624 [2] or draft DIN EN 16723-2 [3] for compressed natural gas (CNG) or biomethane, respectively. According to FNR (2015) [8] 98,000 vehicles run on CNG in Germany. There are 900 CNG filling stations, 150 of them offering 100 % biomethane and more than 300 biomethane-CNG mixtures. By using biomethane, GHG reduction rates of 73 to 82 % can be achieved in comparison to fossil fuel, according to default value specified in the EU renewable energy directive [7]. Additionally, biomethane has environmental benefits, such as soil and water protection in particular when used in environmental sensitive areas.

It has been shown, that biodiesel and vegetable oil fuel are suitable alternative fuels for farm machinery [4, 14]. However, for the usage of biomethane as fuel for contemporary agricultural machinery, only little experiences are available.

Within the Swedish MEKA project from 2012 to 2015 [11], three dual-fuel Valtra tractors were investigated, two of them from the first and one from the second generation. “Operational tests show that the performance of dual fuel tractor was satisfactory.” “The first generation of Valtra biogas tractor had substantial methane emissions from the engine.” However, “Development to reduce methane emissions in the next generation has been successful…” Finally it is stated: “The test results have led to the conclusion that the technology has potential, but it is not yet fully mature. Further investigations are needed to obtain better knowledge regarding emissions… Another important area to watch is the ageing of methane catalysts…”

Research on agricultural machines with monovalent fuelled gas engines is conducted at University of Rostock in co-operation with engine manufacturer Deutz AG [13].

Open questions remain especially for the simultaneous use of two fuels (dual-fuel operation). Dual-fuel operation is suspected to affect reliability, practicability in every day's use, performance, fuel consumption and exhaust gas emissions. For latter no legal framework has been defined, yet. A proposal of the European Commission suggests to follow emission regulation for diesel tractors and to introduce limiting values for relevant emission components. Main deviation to diesel regulations regards to the limiting value of hydrocarbons (HC) by including a power related factor and the average relation of share of fuels (gaseous and liquid) during the test cycle.

## 2 PURPOSE

The purpose of this work is to investigate a dual-fuel tractor, compatible for biomethane and diesel fuel at a tractor test stand and in the field for some period.

At the test stand the influence of the operation modes dual-fuel and pure diesel on emissions should be investigated. Therefore the exhaust components nitrogen oxides ($NO_x$), hydrocarbons (HC), carbon monoxide (CO) and particulate matter (PM) should be measured recurrently. If appropriate, measures for optimisation of the dual-fuel technology should be deduced.

Besides that, the tractor should be operated in field under practice conditions to ascertain operation behaviour and - if needed - to identify need for action.

## 3 APPROACH

Subject of investigation is a small-series produced, biomethane compatible tractor of the type Valtra N101 HiTech (see Fig. 1).

**Figure 1:** Dual-fuel tractor Valtra N101 HiTech for bio-methane and diesel operation

The biomethane tractor is powered by a dual-fuel engine, in which gaseous fuel (biomethane) and liquid fuel (diesel) is being burnt simultaneously. Additionally, solely diesel operation is possible, too.

The tractor is equipped with an engine of the type AGCO Sisu Power 44CTA of exhaust stage IIIA (for diesel, since there is no legislation for dual-fuel, yet) featuring a common rail injection system and internal exhaust gas re-circulation. Technical data of the tractor are displayed in Tab. I.

**Table I:** Technical data of dual-fuel tractor for field and test stand investigation (after [15])

| Tractor type | Valtra N101 HiTech |
|---|---|
| Engine type | AGCO Sisu Power 44CTA |
| Number of cylinders | 4 |
| Cylinder capacity | 4,397 cm³ |
| Nominal load (diesel mode) | 81 kW / 110 PS |
| Injection system | common rail |
| Year of manufacture | 2012 |
| Exhaust stage | IIIA |
| Number of gas tanks | 3 |
| Gas reserve/diesel equivalent | 200 l (at 200 bar)/40 l |
| Transmission | power shift |

The original diesel tractor was retrofitted with dual-fuel technology under supervision of the manufacturer Valtra. The engine can be operated simultaneously with diesel and biomethane in alternating shares, depending on the engine operating point. The regulation is induced by the gas engine control unit (gas ECU) and realised by a reducing throttle in the intake air stream. The share of gas to the aggregated fuel energy content is called gas energy ratio (GER). During retrofitting an oxidation catalyst was installed to minimise methane emissions.

Field tests are conducted on a state owned test farm in Bavaria. During the field test period relevant parameters of the tractor are monitored by continuous electronic data collection, machine diary notes and operator interviews.

The limited exhaust gas components carbon monoxide (CO), nitrogen oxides ($NO_x$), hydrocarbons (HC) and particulate matter (PM) are measured on a test stand in accordance to directive ISO 8178 [1, 9], applying the Non-Road-Steady-Cycle (NRSC), which is also known as C1-Cycle. The test cycle comprises four power phases (100 %, 75 %, 50 % and 10 % of nominal power) at nominal speed, three power phases (100 %, 75 % and 50 % of nominal power) at intermediate speed and idle.

Emissions of the eight phases are added up by using special weighting factors. The values are related to work at tractor's power-take-off (PTO). Results are evaluated by using limiting values of emission stage IIIA for 100 % diesel operation (CO = 5,0 g/kWh, PM = 0,3 g/kWh and $NO_x$ + HC = 4,0 g/kWh) as well as suggested limiting values according to the proposal of the European Commission [5, 6] for dual-fuel operation (CO = 5,0 g/kWh, PM = 0,3 g/kWh, $NO_x$ = 3,81 g/kWh and HC = 0,7 g/kWh).

In addition, performance and fuel consumption measurements are carried out. Measurements are conducted in both dual-fuel and solely diesel operation. Test stand set-up is described in Fig. 2. A comprehensive description of the tractor test stand is given in [4, 14].

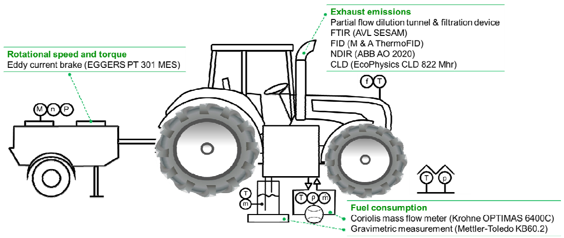


**Figure 2:** Scheme of tractor test stand set-up

## 4 RESULTS

### 4.1 Field test

The field test of the Valtra tractor began in June 2014. Until March 2016 the tractor proved full suitability in everyday use for some 590 operating hours. 140 hours of them were run on the tractor test stand. The tractor was usually operated in dual-fuel mode. When the gas storage tank was empty, the operation mode was automatically switched to 100 % diesel operation and work could be proceeded with solely diesel fuel. Intermediate gas fillings at the filling station, which was 6 km away from the test farm was not rated to be pratical due to work organisation reasons. Predominant types of use of the tractor were transport, mowing and test stand trials that account in total for some 81 % of the entire operation time (see Fig. 3). Further tractor uses include rotary harrow, cultivator, swath, fertiliser spreader, plough, field sprayer and others.

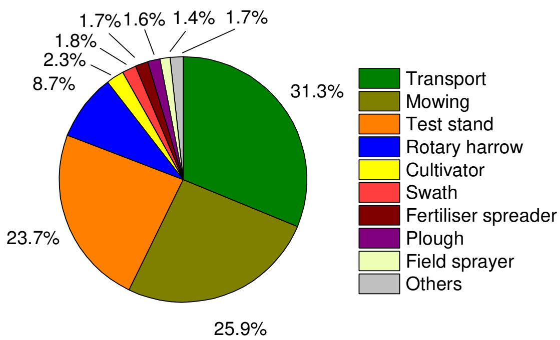


**Figure 3:** Types of use of the tractor Valtra N101 during test operation (Status: 620 operation hours, March 2016)

Based on the documented consumption of diesel and CNG, it is obvious that depending on the type of work and its specific engine load profile, significantly different gas energy ratios (GER) were noticed. For mowing with some 44 % the highest mean GER was reached. GER during transport was 15 % and 22 % at test stand operation. Over the entire operation time an average GER of 28 % was calculated. Stated values for GER are related to dual-fuel operation only and hence do not include 100 % diesel operation modes. Compared to stationary pilot injection engines, where GER of 90 % are achieved, dynamic operation of tractors hampers such high ratios.

To assess GER within the engine operation map of the Valtra, besides the eight test phases of the NRSC additionally further 78 different test phases were evaluated. Fig. 4 shows that for high rotational speed (1800 to 2100 $min^{-1}$) and low torque (< 130 Nm) as well as for medium speed (1400 to 1600 $min^{-1}$) and torque lower 250 Nm the highest GER with maximum values up to 80 % appears. High GER are aspired to achieve high GHG emission avoidance and cost reduction. On the other hand, factors such as methane emissions or engine knocking are limiting very high GER.

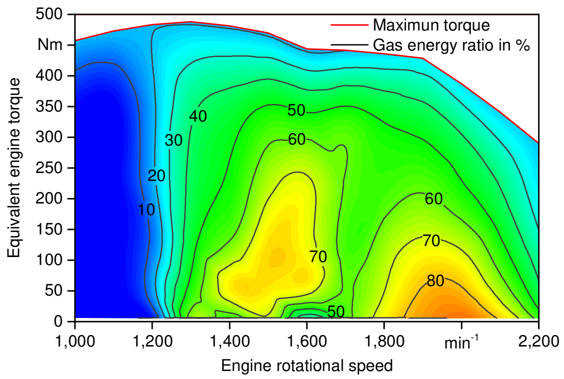


**Figure 4:** Gas energy ratio distribution within engine map of the dual-fuel tractor Valtra N101 HiTech

Operator questionnaires show that the dual-fuel tractor with biomethane is overall seen positively. Initial safety concerns due to the use of gaseous fuel could be eliminated over project time. According to the operator no losses in terms of operation behaviour need to be accepted apart from additional fuel filling procedures. For the Valtra every 11.5 operating hours within the field test a filling of the on-board gas storage tanks was necessary with a span between 4 and 26 hours. Limited operating range was the main point of criticism of the dual-fuel mode.

Average fuel consumption over all 590 operating hours was 7 l/h diesel and 2 kg/h CNG. In total 4292 l of diesel fuel and 1087 kg CNG was consumed. CNG which was used in the field test is composed of 50 % bio-methane calculatory. This relates to 1.66 t GHG saving (default value according to EU RED [7]) without considering additional GHG emissions by methane emissions at tailpipe.

4.2 Tractor test stand

Specific emissions of nitrogen oxides ($NO_x$), carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) for dual-fuel mode was measured at 250 and 550 operating hours. Results are displayed in Fig. 5.

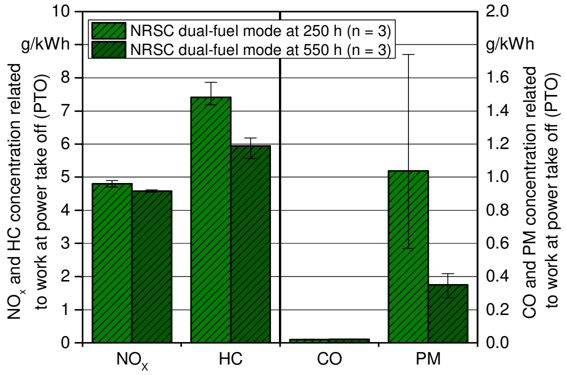


**Figure 5:** Exhaust gas emissions for C1-Cycle according to ISO 8178 for dual-fuel operation at 250 and 550 operating hours of the Valtra N101 HiTech

Interpretation of results need to consider, that test cycle values at tractor test stand are related to performed work at tractor power-take-off (PTO) rather than to work at crankshaft, which is customary for engine certification. This difference results in 20 to 30 % higher values for specific emissions, when related to PTO work. Reasons therefore are losses through transmission and various drives of the entire tractor system.

Between the two measurements at 250 and 550 h the gas ECU was changed. The altered parameters of the gas ECU had positive effects on specific $NO_x$-, HC- and PM-emissions. For $NO_x$-emissions only little, for HC- and PM-emissions significant reduction was achieved. Especially PM-emissions could be decreased by 66 %. CO-emissions stayed almost at the same very low level. The results show a high level of effectiveness through applied optimisation of the gas related engine control unit.

At 550 operating hours a comparison of emission values between dual-fuel and diesel mode was conducted. As displayed in Fig. 6, dual-fuel mode shows higher concentrations of HC, CO and PM whereas $NO_x$-emissions were lower than during 100 % diesel operation.

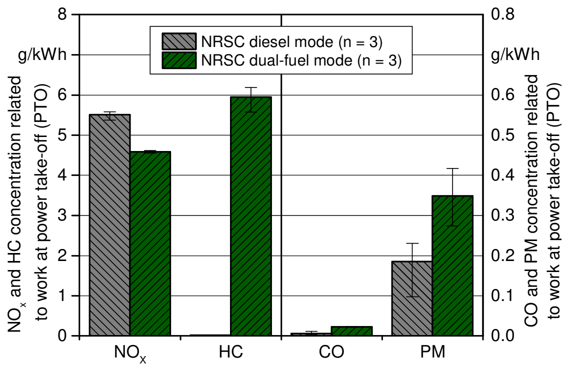


**Figure 6:** Exhaust gas emissions for C1-Cycle according to ISO 8178 for dual-fuel and diesel operation of the tractor Valtra N101 HiTech

Lower $NO_x$-emissions can be attributed to lower injected diesel amount and higher heat capacity of added gas-air-mixture (lower combustion temperature) [10, 12]. For PM emissions also a decrease compared to diesel operation was expected [10], due to lower diesel and higher gas amount. However, during dual-fuel mode of the Valtra tractor higher PM-emissions were observed. This is because of local lacks of oxygen during combustion, also evident by low lambda values close to one at intermediate speed.

For diesel operation emission limits of exhaust stage IIIA for CO (5.0 g/kWh) and PM (0.3 g/kWh) are fulfilled easily under consideration of 20 to 30 % higher concentrations for PTO related values due to losses in transmission and engine-auxiliary items. The same applies for dual-fuel mode despite higher absolute emissions. For diesel operation the crucial cumulative concentration for $NO_x$ plus HC, again under consideration of differences between PTO and crankshaft related values is near the limit of 4.0 g/kWh. For dual-fuel operation instead, this – only for diesel operation legal - limit applied for type approval, would be exceeded. It has to be considered that so far no emission limiting values for dual-fuel tractors are in force. If the results for dual-fuel mode are compared to suggested limiting values of the draft of the European Commission [5, 6] for $NO_x$ (3.81 g/kWh) and for HC (0.7 g/kWh) $NO_x$ is lower than the limit whereas HC is significant higher. Causes for high HC are unburnt methane, mainly during low load operation as well as poor HC reduction in the exhaust gas after-treatment system at low temperatures. Measures for improvements include constructive modifications of the exhaust gas system (engine proximity, catalytic coating), optimisation of gas energy ratio and intake air throttling.

Presently the test operation of prototype tractor Valtra N101 is being continued for further practice experiences (Fig. 7).

**Figure 7:** Prototype Valtra N101 Hi Tech dual-fuel tractor in practice field test.

## 5 CONCLUSIONS

Results of this research prove reliable operation of the dual-fuel tractor Valtra N101 in practice. Neither malfunctions nor damages that could be attributed to dual-fuel operation did occur within 590 operating hours of the study. Staff that was operating the tractor has an overall positive attitude. However, operating range in dual-fuel mode might be one hurdle in everyday use. A gas filling station nearby is an important precondition.

Neither performance nor fuel consumption showed any change during the investigated period. Specific emissions in dual-fuel mode could be reduced significantly by change of gas ECU settings. Further optimisation potential is suspected.

Comparative measurements between dual-fuel and diesel operation showed for all monitored exhaust components except $NO_x$ higher concentrations for dual-fuel. Especially HC-emissions designated as methane slip need to be lowered in future dual-fuel concepts with implementation of advanced exhaust standards. There is a great potential for reducing HC-emissions through optimisation of gas-diesel ratio for different load points and oxidation catalyst optimisation. The results of this study are widely in agreement with the findings of the MEKA project [11] in Sweden. There, HC-emissions could be lowered enormously between the first and second generation dual-fuel Valtra.

With further development of dual-fuel tractors and improvement of gas supply, biomethane could be another sustainable fuel option besides biodiesel and vegetable oil fuel for agriculture.

## 6 ACKNOWLEDGEMENT

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## 7 REFERENCES

[1] Deutsches Institut für Normung e.V. (DIN) (1996): DIN EN ISO 8178-4: Hubkolben-Verbrennungs-motoren, Abgasmessung - Teil 4: Prüfzyklen für ver-schiedene Motorverwendungen; Dezember 1996. Berlin: Beuth-Verlag, pag. 14.
[2] Deutsches Institut für Normung e.V. (DIN) (2008): DIN 51624: Kraftstoffe für Kraftfahrzeuge - Erdgas - Anforderungen und Prüfverfahren. Berlin: Beuth-Verlag, pag. 21.
[3] Deutsches Institut für Normung e.V. (DIN) (2014): DIN EN 16723-2:2014-06 – Entwurf. Erdgas und Biomethan zur Verwendung im Transportwesen und Biomethan zur Einspeisung ins Erdgasnetz – Teil 2: Festlegung für Kraftstoffe für Kraftfahrzeuge. Berlin: Beuth-Verlag, pag. 23.
[4] P. Emberger, K. Thuneke, E. Remmele (2013): Pflanzenöltaugliche Traktoren der Abgasstufe IIIA. Prüfstandsuntersuchungen und Feldeinsatz auf Be-trieben der Bayerischen Landesanstalt für Landwirt-schaft. Straubing: Technologie- und Förderzentrum (TFZ). Berichte aus dem TFZ, Nr. 32, pag. 125.
[5] Europäische Kommission (2014): Anhänge des Vorschlags für eine Verordnung des europäischen Parlaments und des Rates über die Anforderungen in Bezug auf die Emissionsgrenzwerte und die Typgenehmigung für Verbrennungsmotoren für nicht für den Straßenverkehr bestimmte mobile Maschinen und Geräte. Annexes 1 to 6. Europäische Kommission (Hrsg.). Brüssel, pag. 24.
[6] Europäische Kommission (2014): Vorschlag für eine Verordnung des Europäischen Parlaments und des Rates über die Anforderungen in Bezug auf die Emissionsgrenzwerte und die Typgenehmigung für Verbrennungsmotoren für nicht für den Straßen-verkehr bestimmte mobile Maschinen und Geräte;

2014/0268 (COD). Europäische Kommission (Hrsg.). Brüssel, pag. 62.
[7] Europäisches Parlament; Rat der Europäischen Union (2009): Richtlinie 2009/28/EG des Europäischen Parlaments und des Rates vom 23. April 2009 zur Förderung der Nutzung von Energie aus erneuerbaren Quellen. Amtsblatt der Europäischen Union, Nr. L 140, pag. 16-62.
[8] Fachagentur Nachwachsende Rohstoffe e.V. (FNR) (2015): Basisdaten Bioenergie Deutschland 2015. Festbrennstoffe, Biokraftstoffe, Biogas. Gülzow: Fachagentur Nachwachsende Rohstoffe e. V. (FNR), pag. 30.
[9] International Organisation for Standardization (ISO) (2006): ISO 8178-1: Reciprocating internal combustion engines - Exhaust emission measurement - Part 1: Test-bed measurement of gaseous and particulate exhaust emissions Second edition 2006-09-15. Geneve, Switzerland: International Organization for Standardization (ISO), pag. 126.
[10] G. A. Karim (2015): Dual-fuel diesel engines: CRC Press, pag. 295.
[11] LINDVALL, E. E.; TÖRNQUIST, S.; ENGHAG, O.; LUNDSTRÖM, E. (2016): Biogas Operation in Non-Road Machinery. Final Report from the Government Commission. E. E. LINDVALL (Hrsg.). Jönköping: Jordbruksverket; Metandiesel Efter Konvertering av Arbetsmaskinger (MEKA). Report, Nr. 2015:23, 68 Seiten, ISBN 1102-3007
[12] R. G. Papagiannakis, D. T. Hountalas (2003): Experimental investigation concerning the effect of natural gas percentage on performance and emissions of a DI dual fuel diesel engine. Applied Thermal Engineering, Jg. 23, Nr. 3, pag. 353–365.
[13] S. Prehn, V. Wichmann, M. Kaspera, T. D. Lassak, H. Harndorf (2015): Entwicklung und Untersuchung eines Gasmotors für Landmaschinen – Phase 1. Abschlussbericht, Rostock: Fachbereich Maschinenbau und Schiffstechnik, Lehrstuhl für Kolbenmaschinen und Verbrennungsmotoren, pag. 80.
[14] K. Thuneke, T. Gassner, P. Emberger, E. Remmele (2009): Untersuchungen zum Einsatz rapsölbetriebener Traktoren beim Lehr-, Versuchs- und Fachzentrum für Ökologischen Landbau und Tierhaltung Kringell. Berichte aus dem TFZ, Nr. 17. Straubing: Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ), pag. 177.
[15] Valtra Inc. (2014): Research for the future – Valtra biogas tractor. Available at: http://www.valtra.com/downloads/VALTRA_BIOGAS_EN.pdf.