PROVICE

Market Analysis for Non-road Mobile Machinery Sector

Report from Scandinavian GPP Alliance, 20 March 2017

Author: Tomas Sander Poulsen, Provice

Table of Contents

Abbreviations

CNG/CBG: Compressed Natural Gas/Compressed Biogas
GPP: Green Public Procurement
DME: Dimethyl ether
EV: Electric Vehicles
HVO: Hydrotreated Vegetable Oil
HEV: Hybrid Electric Vehicle
ICE: Internal combustion engine
LNG: Liquefied Natural Gas
NRMM: Non-Road Mobile Machinery
PM: Particulate matter
TCO: Total Cost of Ownership
TRL: Technology Readiness Level

1. Introduction and Aim

Non-Road Mobile Machinery (NRMM) are a wide range of machinery typically used in the construction sector, and in services related to garden and park maintenance in cities.

The regulatory scheme for NRMM constitutes a wide product group regulated with a number of EU-directives and national statutory legal orders defining limit values and terms for emissions, noise, etc. In the EU the primary reference directive is Regulation EC 97/68, the so-called "NRMM regulation", with later applied regulation[1].

From a climate and environmental perspective the challenges with the NRMM sector are pollutant emissions from combustion engines (diesel and gasoline) installed in a wide range of machines that significantly contribute to climate change by emitting carbon dioxide (CO_2) and air pollution in cities by emitting carbon oxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM), causing health hazards. In the EU the NRMM sector is responsible for around 15% of the total NOx emissions and 5% of total PM emissions. The NOx share is expected to increase to up to nearly 20% in 2020, while the PM share is expected to decrease. NRMM is also accountable for roughly 100 million tons of CO2 equivalent emissions annually, corresponding to 2% of the total greenhouse gas emissions in the EU27. For the partnership cities the potential also seems high. For instance in Oslo it is estimated that it is possible to save between 60,000 – 80,000 CO_2 from building and construction machines and non-road freight transport before 2020. In the city of Copenhagen they suggest that CO2 emissions from non-road industrial traffic are around 72,300 tons/year. In the city of Stockholm they find that 19% of all diesel consumption is used for construction machines in the County of Stockholm.

The Scandinavian Green Public Procurement (GPP) Alliance, which includes the city of Copenhagen, Oslo and Stockholm, will further investigate the reduction potential in an NRMM sector that is receiving more and more responsiveness from cities prioritizing aggressive long-term carbon and environmental reduction goals.

This report will look into how climate and environmental developments within the NRMM market can provide use for collaborative non-road procurement between cities in their effort to support reduction goals. One stepping-stone is a market analysis for the NRMM sector on selected non-road machinery defined by the partnership cities. The aim is to offer insight into the dynamics of a special market providing technical status on specific machinery, regarding emission performance, future innovations and technological trends.

[1] Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC.

The report is divided into three major parts:

1. ***Stage norm.*** An overall description of NRMM regulatory work in EU, both today and in the future.
2. ***Results from market analysis.*** Identified technologies, alternative fuels and market trends within the NRMM sector.
3. ***Green public procurement guidelines.*** Preparatory work for the next project phase concerning procurement guidelines and tender criteria for one or more carefully chosen product groups.

It is crucial to note that the market analysis doesn't provide a full picture of all suppliers and manufactures on the Scandinavian market as its main purpose has been to identify market trends towards the greenification of engine technology. The introduction of greener engine technology can have a positive effect on working conditions because of noise level reductions, less vibrations, improved ergonomics etc.. Moreover operating costs can be positively influenced by the introduction of greener technology. Whenever this potential is realized it will be explicated in the market analysis.

2. Method

The market analysis comprises an assessment of the following product categories g:

1. Riding lawnmowers for professional use
2. Large wheel loaders (12-20 tons operating weight)
3. Medium size sweepers (1-2 m^3 capacity is defined as medium by suppliers)
4. Compact tractors for professional use

These product categories have been selected and defined by the Scandinavian GPP Alliance, based on an assessment of the existing volume of NRMM in the partnership cities (the City of Oslo, Stockholm and Copenhagen) and potential for new green market-ready non-road machines. The volume assessment included a unit list from the cities, which forms the basic information for a baseline study.

In appendix 3, a screening of small wheel dumpers is included. Small wheel dumpers may be relevant in combination with wheel loaders at construction work. However, small wheel dumpers are not one of the selected product groups but are included as a supplementary group.

The selected product groups are screened according to the following method and levels of information:

a) Web search and identification of main suppliers (producers and wholesalers) supplying the Scandinavian market within the selected product groups
b) Supplementing phone interviews and mail communication with a number of suppliers (annex 1 provides a list of interviewed stakeholders)

c) Collection of examples of product specifications and technical data sheets for desk assessment
d) Screening of technology level status and future perspective in relation to emission levels and energy sources through dialogue with suppliers

Identification of suppliers and manufactures has been an iterative process based on information from contacted wholesalers and producers in the market. Furthermore the cities have the option to supplement the list with interesting cases relevant to the scope. Through these inputs, the most promising technologies and producers within the selected product categories are covered. The identified suppliers and manufacturers should be considered as interesting stakeholders in the market because of their innovations or as representative of some of the main suppliers. It is not a full list and assessment of all suppliers in the market.

To some extent, technology trends outside the defined product term are mentioned, even through they are not available within the selected product limitation. But the information may be useful on a wider GPP scale.

More focus emphasized the screening of status and development of compliance with emission levels (Stage norm, level 3a, 3b, 4, or 5), the product capability with regard to using renewable energy sources, and the innovation trends determined in relation to the EU definition of technology readiness levels (TRL).

Annex 1 contains a list of persons interviewed.

Annex 2 contains a long-list of relevant producers and suppliers operating in the Scandinavian market and is a useful overview for follow up contact when procurement details and criteria will be determined.

References to interesting articles with more information are made in footnotes to the text.

3. Stage Norm

The stage norm is the EU norm for permittable NRMM emission levels of CO, NOx, HC and particles. [2]

The stage norm levels are usually mentioned in technical product descriptions or product data sheets. In other words they are a useful reference to set GPP minimum levels for NOx and PM emissions. However information on norms are not entirely consistent in the market of NRMM and this issue has to be addressed in GPP tender evaluations. Some producers may convey emission levels in EURO or Tier instead, e.g. in cases where truck engines are used.

[2] In parallel there is the US norm “Tier” and the EU norm “EURO” for on-road vehicles.

Further, the initial survey has heard opinions from various producers on how energy performance levels are stated and monitored and it seems that there is a general lack of clear standards and procedures for how emission and fuel consumption is monitored and documented. This finding indicates a need for tender evaluations that pay special attention to comparable documentation for energy consumption.

The required stage level for new NRMM introduced to the EU market is Stage 3a for NRMM up to 37 kW (50 HK)[3]. For products above 37 kW, Stage 3b shall be complied from 1 January 2013. Stage 4 is introduced in 2014 and reduces the NOx emission threshold to 0,4 g/kW but only for diesel engines above 56 kW. Stage 5 will be introduced from 1 January 2019. The Stage 5 emission threshold requirements for NRMM between 19 kW (25 HK) – 130 kW (177 HK), are as follows:

- 5,0 g/kW CO,
- 4,7 g/kW NOx+HC,
- 0,015 g/kW PM (particulate matter)

The figure below provides an overview of the emissions regulations.

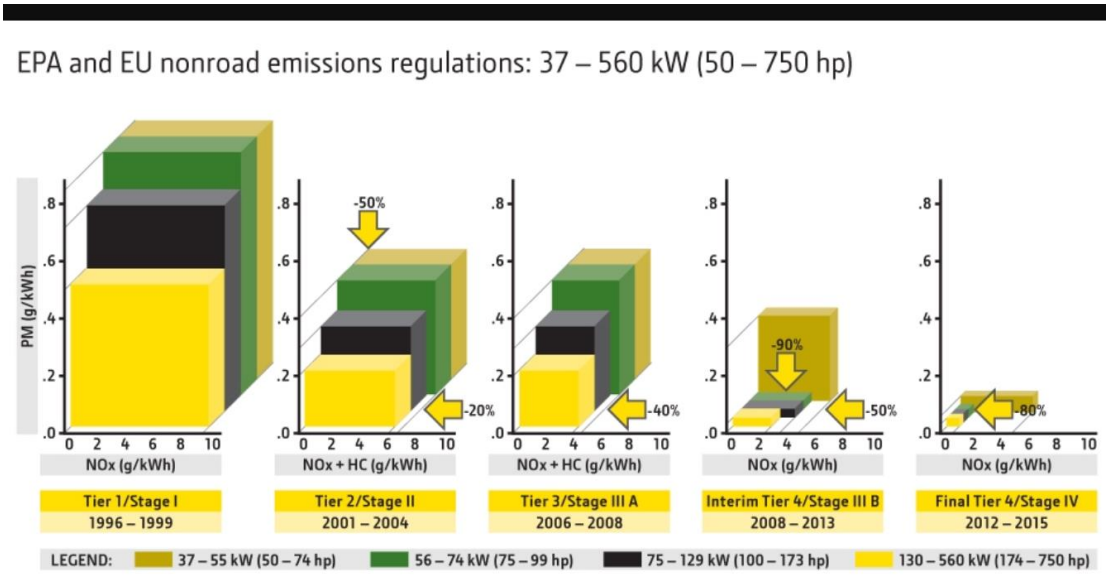

Figure 1: Overview of emissions regulations of NRMM

Main parts of the selected product groups are from 19 kW and above and shall therefore comply with Stage 5 from 2019. The Stage 5 norm will be an extensive improvement in emission reduction of CO, NOx and PM compared to stage 3a, which are the required levels for NRMM from 19-36 kW. However the stage norm has no impact on the CO_2 emissions level.

CO_2 emissions cannot be reduced through filters but are directly influenced by the level of fossil energy consumption. Strategies for reducing CO_2 emission can

[3] 1 kW = 1,36 HK

therefore only be achieved through minimizing fossil energy consumption, or by selecting technologies based on renewable energy (biofuel, biogas) or electricity.

The EU regulation's focus is entirely on air pollution from combustion engines installed in NRMM emitting carbon oxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter. There are no EU regulation or standards in place (or in common use) for CO_2 emissions from NRMM[4].

In Denmark, Norway and Sweden passenger cars have emission norms for CO_2 pr. km but such norms will not be developed for NRMM in DK legislation. This study has not clarified whether N and SE have special national regulations of CO_2 emissions from NRMM, presumed or not, while emission regulation underlies the EU framework.

The table below summarize the timetable for implementation of new Stage norms and Tier norms.

		2010	2011	2012	2013	2014	2015	2016
	Power Rating	Emission Limits in g/kWh						
EU	19 kW < 37 kW	STAGE IIIA HC + Nox = 7,5 PT 0,6						
	37 kW < 56 kW	STAGE IIIA HC + NOx = 4,7 PT 0,4			STAGE IIIB HC + Nox = 4,7 PT = 0,025			
US	19 kW < 37 kW	TIER IV Interim Nox = - NMHC + Nox = 7,5 PT = 0,3			TIER IV NMHC + NO x = 4,7 PT = 0,3			
	37 kW < 56 kW	TIER IV Interim Nox = - NMHC + Nox = 4,7 PT = 0,3						

Emission regulations:

97/68 EC & 2006/105/EC

Table 1: Timetable for implementation of Stage and Tier norms including limit values for HC, NOx and PM (PT)

The actual emission impact from increased stage demands is illustrated in the figure below marking the difference in emission levels for Stage 3a and Stage 3b (black columns). The yellow columns exemplify emissions from a standard and an environmentally friendly model complying with stage 3a and 3b.

[4] The issue concerning CO_2 regulation in Stage/EURO is discussed with emission specialist Katja Asmussen, Danish Environmental Protection Agency which confirms there are no plans so far for including CO_2 in the norms

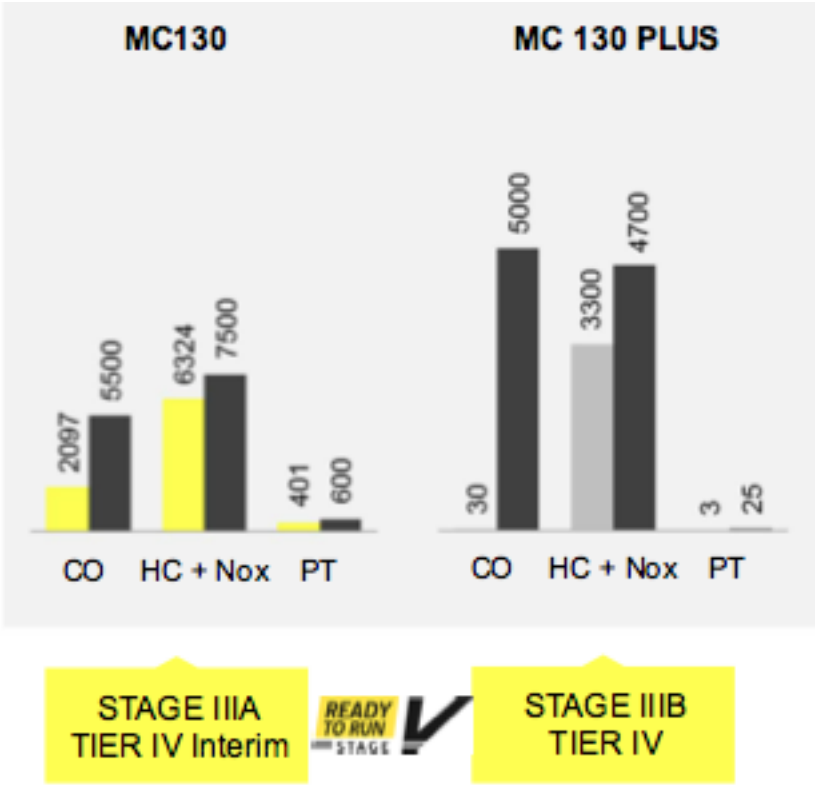

Figure 2: Example of traditional model and environmental plus street sweeper model and the emission level performance (yellow and grey bars) comparing Stage 3a and 3b (black bars).

The regulatory difference of emission levels between Stages 3a and 3b is a 9% reduction of CO, a 37% reduction of HC + NOx and a 96% reduction of particulate matter. These levels stress the theoretical minimum impact of the emission of NOx and PM when upgrading from Stage 3a to Stage 3b. The PM emission is dramatically reduced when upgrading to Stage 3b. With the further upgrade to Stage 5, only PM will decrease further for engines up to 56 kW. NOx, HC and CO will remain the same as at Stage 3b. For engines larger than 56 kW, the NOx will be reduced even more with Stage 5 from 2019.

Cat.	Net Power	Date†	CO	HC	HC+NOx	NOx	PM
	kW		*g/kWh*				
Stage III A							
H	130 ≤ P ≤ 560	2006.01	3.5	-	4.0	-	0.2
I	75 ≤ P < 130	2007.01	5.0	-	4.0	-	0.3
J	37 ≤ P < 75	2008.01	5.0	-	4.7	-	0.4
K	19 ≤ P < 37	2007.01	5.5	-	7.5	-	0.6
Stage III B							
L	130 ≤ P ≤ 560	2011.01	3.5	0.19	-	2.0	0.025
M	75 ≤ P < 130	2012.01	5.0	0.19	-	3.3	0.025
N	56 ≤ P < 75	2012.01	5.0	0.19	-	3.3	0.025
P	37 ≤ P < 56	2013.01	5.0	-	4.7	-	0.025

Figure 3: Comparison of emission standards 3a and 3b[5]

The difference in emission level for the product case comparing Stages 3a and 3b is a decrease of 99% for CO, 48% for HC + NOx and 99% for particulates. This case indicates that it is possible to reduce the regulated air emissions substantially below air emission threshold levels.

As a concluding remark to air emission impact related to the development in stage norm, it should be noted that the essential reduction of NOx and PM is already achieved from upgrade to Stage 3b. NRMM equipment above 37 kW (50 HK) already introduced this level on 1 January 2013. And for NRMM between 19-37 kW, the emission reduction potential for NOx will be achieved no later than 1 January 2019 where Stage 5 is implemented in Denmark and Sweden as EU member countries. It is not investigated whether Stage 5 will be implemented in Norway. The focus for GPP guidelines for the selected NRMM should therefore especially emphasize the potentials for CO_2 emission reductions. This can be achieved through alternative engine technologies with lower CO_2 emissions than diesel, for example electricity and all types of biofuels, or through more energy efficient diesel engine technologies.

[5] https://www.dieselnet.com/standards/eu/nonroad.php#s3

Stage V emission standards for nonroad engines (NRE)

Net Power	Date	CO	HC	NOx	PM	PN
kW		*g/kWh*				*1/kWh*
P < 8	2019	8.00	7.50[a,c]		0.40[b]	-
8 ≤ P < 19	2019	6.60	7.50[a,c]		0.40	-
19 ≤ P < 37	2019	5.00	4.70[a,c]		0.015	1×10^{12}
37 ≤ P < 56	2019	5.00	4.70[a,c]		0.015	1×10^{12}
56 ≤ P < 130	2020	5.00	0.19[c]	0.40	0.015	1×10^{12}
130 ≤ P ≤ 560	2019	3.50	0.19[c]	0.40	0.015	1×10^{12}
P > 560	2019	3.50	0.19[d]	3.50	0.045	-

Figure 4: Stage 5[6]

4. Results from Market Analysis

In the following, the results of the market analysis are presented. The main source is dialogue with stakeholders in the market. Annex 1 contains a full list of contacts for interviews. Annex 2 contains a list of identified suppliers and manufacturers for the selected product categories.

Technology Readiness Levels

Technology Readiness Level (TRL) is used to specify the maturity of the different technologies when identifying machinery for the selected product categories.

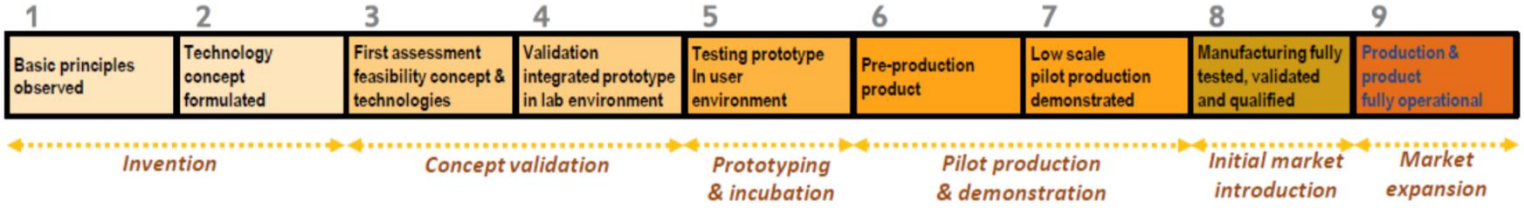

Figure 6: Definition of technology readiness level (TRL)

Most TRL technologies mentioned in the initial market analysis results are at level 8 or 9 which means they are available in the market and introduced at pilot test or

[6] https://www.dieselnet.com/standards/eu/nonroad.php#s3

initial market introduction. Information on earlier stage technologies at concept or prototype level has been difficult to acquire and manufacturers seem unwilling to provide such details. In any case, the market analysis goal has been to identify new market-ready eco-friendly technologies within the NRMM sector for short-term procurement.

Alternative Fuels

To clarify issues regarding the use of alternative fuel in internal combustion engines (ICE) to reduce emissions (in particular CO_2), the following can be mentioned:

- Denmark, Norway and Sweden have different access to biofuels such as biodiesel and biogas and in Denmark, for example, the infrastructure is very poor.
- It is common for standard diesel engines that 7% biodiesel (e.g. FAME) can be blended with the diesel without affecting the guarantee. If the level of biofuel is exceeded, the guarantee will usually be repealed.
- Diesel engines can operate with higher blends of biodiesel such as HVO. Because of quality issues and extended requirements for the emission reduction of PM, supplier guarantees for performance are not usually provided for diesel engines below approx. 55 kW. This may be an issue for dialogue and negotiation in a procurement activity. For large engines (wheel loaders etc.), HVO is applicable to some products; see e.g. Volvo Construction Equipment, which have approved all Volvo machines as HVO-ready.[7]
- None of the producers included in the survey mentioned a particular focus on the alternative biofuel Dimethyl Ether (DME) for further product development. DME is applicable to both diesel and gasoline engines and the benefit is a lower PM that can be produced from CO_2 neutral sources, e.g. biogas. For diesel engines the use of DME will require the modification of fuel injection and control. Furthermore the tank system needs reinforcement and protection against temperature change[8]. It should be subject to particular dialogue in GPP on whether engines can operate with DME.
- Specifications for the use or modification of engines with bio-ethanol and bio-methanol have not been identified for any of the selected product groups[9].
- Hydrogen engines have not been identified for any of the selected product groups.
- Gas engines (CNG, LNG) are a matured technology applied as an alternative in a larger model for compact sweepers and tractors. This is not a technology widely used due to the infrastructure issue mentioned above and problems with range and tank capacity. (Bio)gas engines could, in principle, be an option for Norway and Sweden where the infrastructure for suppliers is expanding and prices are competitive. It has already been introduced for trucks and buses.

[7] https://www.volvoce.com/SiteCollectionDocuments/dealer/volvo_dk/7723_REVY_nr_1_2016_WEB-klar.pdf
[8] Information from David Marc Gurewitsch, City of Copenhagen.
9 David Marc Gurewitsch, City of Copenhagen, mentions that bio-methanol is used widely in China.

- B7 is a standard for 7% blend with biodiesel. When referring to blend conditions in this report, the basis is 100 % regular fossil diesel.
- GTL is a fuel product (Shell) with a reduction potential of 5-38% for NOx and PM.

With regard to HVO biofuel there are some particular benefits to be mentioned. The following text describes points from an analysis of HVO impact when testing in diesel engines[10]:

The hydrotreatment of vegetable oils or animal fats is an alternative process to esterification for producing bio-based diesel fuels. Hydrotreated vegetable oil (HVO) does not have the detrimental effects of ester-type biodiesel fuels, like increased NOx emission, deposit formation, storage stability problems, more rapid aging of engine oil or poor cold properties.

NOx – particulate emission trade-off and NOx – fuel consumption trade-off are studied using different fuel injection timings in a turbocharged air cooled commonrail heavy duty diesel engine. The fuels testedwere sulfur-free diesel fuel, neat HVO, and a 30% HVO + 70% diesel fuel blend.

The study shows that there is potential for optimizing engine settings together with enhanced fuel composition. In principle, biobased diesel fuel component can be used in three ways:

1. To add a portion of bio component into diesel fuels (blending). This is a common approach with ester-type biodiesel fuels (FAME), and the amount is currently limited to maximum 5 vol-% by the EN 590:2004 standard. Higher amounts, like 7%, 10% or even 30%, are considered but they need extra precautions because of fuel stability, engine oil dilution, and deposit formation in fuel injection systems.

2. To blend tens of percentage points of biocomponent into diesel fuels (blending). This is possible with hydrotreated vegetable oils (HVO) without compromising fuel quality, exhaust emissions and engine operation. In fact, the fuel blend will be premium grade since cetane number is increased and aromatic content is decreased, resulting in reduced exhaust emissions and better cold-start performance. These blends are able to meet diesel fuel standards like EN 590 and ASTM D975.

3. To use HVO as a pure fuel in order to reduce exhaust emissions and improve local air quality. This will reduce the emissions of all vehicles concerned, including old high-emitters. To attain the full benefits of the fuel and engine, the fuel injection system may need recalibration due to the lower density and higher cetane number of HVO.

[10] *Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel:* Hannu Aatola, Martti Larmi, Teemu Sarjovaara Helsinki University of Technology Seppo Mikkonen Neste Oil, 2008

The effect of 100% HVO on exhaust emissions compared to sulfur-free EN 590 diesel fuel in heavy duty applications is in the study determined to:

- Particulate mass: 28−46%
- NOx: 7−14%
- CO: 5−78%

As stipulated above, the use of HVO, for example, is applicable to reduce the CO_2 emissions in particular and blends can basically be applied to standard diesel engines, but with some constraints and preconditions. In the initial market analysis the manufacturers contacted had not been able to provide any standardized information on the specific diesel engine tolerances according to use of biofuel (FAME and HVO). Thus, there are examples of blends from 10-100% HVO. With regard to the effect of CO_2 emissions, HVO is not yet fully standardized and the impact on CO_2 emissions vary depending on the source of the vegetable oils used, e.g. the CO_2 profile is different when using palm oil or rapeseed oil.

The concluding remarks for alternative fuels in relation to the selected product groups are that in the case of traditional diesel engines, FAME, HVO and DME can be blended but the guarantee will usually be repealed. Gas (and biogas) is an option in relation to street sweepers. Wheel loaders, compact tractors and lawnmowers running on gas are not identified and suppliers have mentioned a barrier to gas fuel in tractors where long range is a requirement and tank space and infrastructure is limited[11].

The alternative fuels are an efficient action to reduce the CO_2 emission but possible blend features, etc. need to be discussed with suppliers. Issues can include exceeding the cost of procurement of biofuel and service.

[11] John Deer produce construction machines on LPG to the US market. They are not available in EU.

4.1. Wheel loaders (12-20 tonnes weight)

Wheel loaders with a 12-20 ton operating weight are the largest loaders. They are versatile, as they have many uses. Six main producers of large wheel loaders in the Scandinavian market have been identified:

- Volvo
- Komatsu
- Cat
- Liebherr
- Hitachi
- Wacker Neuson

The initial market analysis has been in dialogue with Volvo, Wacker Neuson, Beckmann, Hydrema, Erenfred Petersen and Johs. Møller Maskiner (JMM) in Denmark(suppliers of Thwaites, Cat etc.). John Deer, Cat, Komatsu and Hitachi have been assessed from articles and desk review.

All identified wheel loaders comply with Stage 3b and some models comply with Stage 4, however this only has a marginal influence on the emissions of PM and NOx. With a small exception, all wheel loaders have an engine power above 130 kW. From 2019, these models shall comply with Stage 5.

Technical features and innovation

For large wheel loaders, diesel engines are the standard engine technology. The technological innovation (besides emission reduction through particle filters) focuses on optimizing energy saving related to the operation of the hydraulic. It is, for example, achieved through an electric hybrid solution, where hydraulic pressure is maintained from electricity operating in a separate system independent from the throttle of the diesel engine. A John Deer electric hybrid model has an electric generator that converts horsepower into AC current and also recycles braking energy back into the system to drive hydraulics and reap further fuel savings. It can also be driven as a motor to recycle energy to drive the hydraulics. According to John Deer, they claim their hybrid solution 644K Hybrid Loader can achieve up to 25% lower total energy consumption[12],[13].

Another innovation area is the adaption of software systems to monitor and optimize operation. Hitachi[14], Komatsu[15], Volvo[16] and other brands use telematics in the form of an online service that allows you to wirelessly track your machinery on

[12] https://www.deere.com/en_US/products/equipment/wheel_loaders/644k_hybrid/644k_hybrid.page
[13] http://www.equipmentworld.com/diesel-electric-and-other-hybrid-construction-equipment-are-waging-war-on-wasted-energy/
[14] https://www.hitachicm.com/global/wp-content/uploads/2015/06/ConSite-Leaflet-5B-EN.pdf
[15] http://www.komatsuamerica.com/komtrax
[16] https://www.volvoce.com/united-states/en-us/services/product-services/caretrack/

different parameters, such as operating time, standby time, fuel use, etc. It helps the driver to operate the machine in a way that uses the least amount of fuel for the amount of work done. It also informs the driver if the machine is in standby-mode for excessive amounts of time, which helps save unnecessary fuel use. The data can help the operator maintain the machine, so it operates as smoothly as possible, which significantly increases the lifetime of the machine.

Figure 7 – Technology development – wheel loaders 12-20 tons (operating weight)

For large wheel loaders the technology trend is based on improving energy efficiency from diesel through control systems and electrification of the works hydraulic.

For small wheel loaders, there are models available as full electric models, where both the driving engine and works engine are separate electric motors. For example, Wacker Neuson model WL20e claims to have the following features: 40% lifetime operational savings from reduced energy and maintenance costs, zero direct CO_2 emissions from the vehicle and up to 5 hours' operational time per charge[17]. The investment cost is 20% higher. Also Kramer 5055e is a small 100% electric wheel loader with an operational time of 5 hours per charge and additional investment costs recouped after 2,000 operating hours[18]. The small multi-machine from Weidemann (Hoftrac 1160e) is another example of an electrified wheel loader[19]. In Annex 3, a prototype robot dumper (Volvo electric site) is identified as well.

[17] http://eco.wackerneuson.com/en/home/eco-products/zero-emission/wl20e-electric-wheel-loader/ and http://www.wackerneuson.se/en/products/wheel-loaders/articulated-wheel-loaders/model/wl20e/

18 http://construction.kramer-online.com/en/zero-emission/the-kramer-5055e.html

19http://www.weidemann.de/dk/produkter.html?wm_attachment%5Bgroup%5D=3497&wm_attachment%5Bproduct%5D=392&cHash=fcc768148b46e8f4fd9b76c5ce618768

Because of the functional constraint for large wheel loaders, especially the need for power and flexibility according to operational time, the producers overall sfocus is not on innovating electric driving engines. Still, we see a few electric models evolving in the market concerning smaller wheel loaders.

An interesting cooperative development project happens between Volvo CE and SKANSKA. The project is named "Electric Site" where different electrified and autonomous prototype models are being tested. Volvo CE has announced that the future is electric, but they don't have a promotion date for the new models.

From a GPP perspective a relevant consideration would be to assess the functional needs to the wheel loader, mainly in relation to operational time and proportions of heavy-duty task. If those requirements are of minor importance, small electric wheel loaders may be an option.

The reference list appears on Annex 2 for identified suppliers and manufactures on the Scandinavian market for this product category. 4.2.

Street Sweeping Machine (1-2 m^3)

A large number of producers offer municipal street sweepers. The general range is from 1-8 m^3 storage capacity. In this survey the focus is on street sweepers with 1-2 m^3 storage capacity.

Even though many producers supply the market of municipal street sweepers, it is, to a large extent, based on the same engine technology. The general diesel engine technologies are narrowed down to a few brands dominated by Kubota, Yanmar, Deutz, Hatz, Perkints, VM Motori and Iveco with a relatively slim difference in emission levels and energy consumption features. Beside these, there are also sweepers driven by electrical and Compressed Natural Gas (CNG) .

Examples of street sweeper suppliers with 1-2 m^3 storage capacity are:

- Hako Citymaster 600, 1250, 1600 with Yanmar engines. CM 600 and 1250 comply with Stage 3a, CM 1600 (75 HK) with Stage 3b
- Kaercher NC 130 and 130+ (50 and 66 HK) - Kubota Commonrail engines, Stage 3b
- Nilfisk Cityranger 3500 (Stage 3a), 3570 (Stage 3b)
- Bucher Citycat (EURO 6 for 84 HK model, EURO 6 for smaller models)
- Bucher Citycat 2020 EV (electric)
- Green Machine (electric)
- Dulevo 5000 CNG (this model has 4 m^3 storage but is included because it is an example of a gas engine)

The initial market analysis has been in dialogue with Hako, Bucher, Nilfisk, Karcher, Kumatsu, Svenningsen (supplier of Green Machine) and Helms TMT center

(supplier). Dulevo and Holder Tractors Inc. have been assessed from articles and desk review.

Technical features and innovation

The diesel engines are still the main technology and the size of engines range from an estimated 20-100 HK.

Biodiesel can be added up to 7% for all diesel engines within guarantee. Energy consumption per hour depends on the size of engine but also whether the engine uses *Commonrail* injection technology. Comparing the difference with or without Commonrail, the figures for a 66 HK Kaercher is 2.8 litres/hour in energy consumption with Commonrail and 4-5 litres/hour for engines without Commonrail.

There are only a few electric suction street sweepers in the market. Green Machine, Piquersa and Bucher are manufactures on the market. The Bucher Citycat 2020 model has a 2 m^3 storage capacity. Citycat 2020 is sold and in operation in a number of larger European cities. The operational experience is approx. one year so far but will be accumulated over the coming years. The Green Machine has a 1 m^3 storage capacity. Operational experience is rare so far, but the City of Copenhagen has mentioned poor experience with durability. The Municipality of Frederiksberg (DK) bought one in January 2017 and new operational experience is expected to be available soon. Regarding model BA-360e from Piquersa this is comparable in size with the one from Green Machine.

Based on supplier information from Bucher and Green Machine, the investment cost is higher by an approximate factor of 2-2.5, and the operational cost is reduced by 75% compared to diesel because of low maintenance and energy cost. The electricity consumption per hour is approx. 7 kWh (and daily operation is estimated at 55 kW). A rough estimate indicates that TCO breakeven will not be achieved before at least 8 years of operation.

Producers have focused on the development of electric vehicles and hybrids. The particular combination of hybrids has not been verified, but one producer mentioned rumours of a hybrid between gasoline and electric (Yanmar). Hydrogen has been tested also but is no longer a focus technology. No one mentioned biogas engines or modified engines able to use more than 7% biofuel.

Dulevo has a CNG-driven sweeper and according to them, it is the only one of its kind on the market.

Further development of electric vehicles is recognized as the main lead. Problems to be solved include the high weight, shorter operational ratio (can operate 5-6 hours per charge), increased energy input to fulfil suction functions in larger models, and smaller batteries.

In 2020 it should be expected that all main producers have their own electric models in the market. Especially German and French cities, eg. Berlin and Paris, where *non-emission requirements* are introduced in order to push the technology development of electric models.

The figure below provides an overview of technology development.

Figure 8 – Technology development, suction street sweepers

The reference list appears on Annex 2 for identified suppliers and manufactures on the Scandinavian market for this product category.

4.3. Riding lawnmowers

Riding lawnmowers for professional use are characterized with stronger, more efficient engines based on diesel, improved and more resistant chassis and solid cutters. Basically the cutters are cylinder cutters or rotor cutters. Many producers supply the market for professional riding lawnmowers, however the engine technology is narrowed down to a few engines such as Kubota (diesel), Briggs and Straton or Kawasaki (gasoline) and with a relatively slim difference in emission levels and energy consumption features. The emission levels for diesel engines comply with Stage 3a and a maximum of 7% biofuel can be added within the guarantee. Gasoline engines cannot have biofuel added.

The main suppliers of professional riding lawnmowers identified on the Scandinavian market are:

- Amazone
- Husqvarna
- Jacobsen
- John Deer
- Kubota

- Iseki
- Stihl/Viking
- Shibaura
- Toro

The initial market analysis has been in dialogue with Husqvarna, Jacobsen and Kubota that supply the market with the diesel engines for professional riding lawnmowers (for example Jacobsen uses Kubota engines) and BMI uses HC Petersen (supplier of Kubota and Iseki).

Technical Features and Innovation

The developments within professional mowers focus on improving diesel engines, electric, or developing robotic (driverless) riding models based on electricity (and a few diesel models). Hence, there is also focus on the development of gasoline models for professional use. With regards to diesel, the development follows legal requirements in the Stage regulation (CO, NOx and PM). From 2019, engines above 19 kW shall comply with Stage 5. However most riding lawnmowers are below the 19 kW level which means a more gentle emission requirement.

There are a few electric rotor cutter lawnmowers worth mentioning. Etesia "Bahia electric" is a semi-professional model with 2 hours' operational time (an extra battery can be procured and then total time is 3,5 hour per charge[20]). The lawn mowing output for 2 hours' operation is 2.500 m^2 and has a cutting range of 80 cm. Husqvarna "Rider Battery" is a hobby rider with 1,5 hours' operational time and a cutting range of 85 cm and 500 m^2 [21]. The investment cost for the battery rider is approx. 75% higher. The manufacturer Jacobsen has a larger either 100% electric or hybrid diesel/electric cylinder cutter "Eclipse 322e"[22].
Eclipse is in particular found on golf courts for grass below 25 mm. The range is approx. 20.000 m^2 per charge. Jacobsen emphasizes that this product is not useful for parks or areas with similar grass. Jacobsen note that electric riding lawnmowers with rotor cutters are not expected in the market before 2020 and development depends on the ability to produce smaller lithium batteries. Jacobsen mentioned that they work with hydrogen/electric hybrid at laboratory scale. With respect to cylinder cutter riders, there might be an electric model as a beta version in 2018/2019. The cost for Eclipse 322e cylinder cutter is 400,000 DKK, and the traditional model costs 260,000 DKK.

Beside the few identified electric models and the traditional diesel engine technologies, the market expands with robot lawnmowers based on electricity. Robot mowers are a competitive alternative to diesel riding lawnmowers in some cases. The benefits are low operational/maintenance cost, low emissions, and low operational cost to wages. The new models are also secured against theft through software and alarms. The City of Copenhagen has models in test and mention that aside from the benefits, there are problems with vandalism.

20 http://www.etesia.com/en/products/ride-on-mowers-bahia-m2e.html
[21] http://www.husqvarna.com/dk/produkter/ridere/rider-battery/967187001/
[22] http://www.svenningsens.dk/produkter/golf/graesklippere/greens-klippere/eclipse-322-hybrid

An example of the energy consumption for a diesel lawn rider (Husqvarna/Jonsered: P520, P525 with Kubota motor, diesel D1105) is 17.4 kW per hour. The professional Husqvarna robot lawnmower uses 24 kWh per month. A direct comparison cannot be made while the range of square meter differs, but from an overall perspective the energy consumption from electric robot riders is substantially lower.

Figure 9 below provides an overview of technology development.

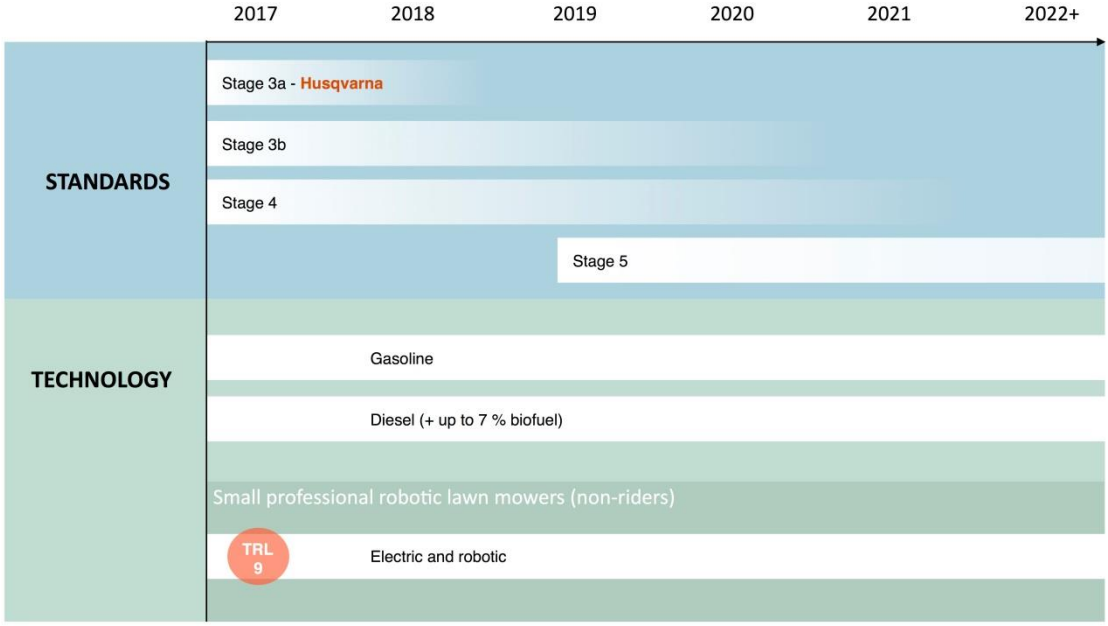

Figure 9 – Technology development – lawn riders

The reference list appears on Annex 2 for identified suppliers and manufactures on the Scandinavian market for this product category.

4.4 Compact tractors

Municipal compact tractors are all diesel engines. Main producers in the market are, for example:

- Iseki – TH series (36 HP)
- Kubota – L series (33-62 HP)
- John Deere – 4M series (44-66 HP)
- New Holland – Boomer easy drive 45D, 54D (45-54 HP)

The initial market analysis included dialogue with Kubota, BMI, HC Petersen (supplier of Kubota and Iseki) and New Holland, Kaercher, Nilfisk and Hako. A desk review included Holder Tractors Inc., which are a tool carrier.

Technical features and innovation

The diesel engine development follows the legal demands from Stage regulation. Compact tractors below 37 kW/50 HK comply with Stage 3a. Compact tractors above 37 kW/50 HK shall comply with 3b. According to New Holland, in the future

small tractors will also be based on diesel. At pilot level New Holland has introduced a gas model (natural gas) for a large tractor model (160-180 HP) but the challenge with gas is limited tank capacity. Gas solutions are therefore not applicable for machines used for intensive operation, for example in the agricultural sector or construction sector[23].

In summary, no innovation or technology trends beside the diesel engine platform have been identified for compact tractors. But for larger traditional tractors, the City of Stockholm, for example, has an prototype of a model operating on biogas where a lawnmower device can be attached.

Compact tractors are multifunctional machines that can be used as tool carriers. For example they can be used as a street suction sweeper or a riding lawn machine if equipped with the right tools. Other alternative products, which in some cases fulfil the functionality of a compact tractor, are small wheel loaders, e.g. Weidemann (eHoftrac) or Wacker Neuson as described earlier. These units are generally three times more expensive in investment cost but they are multifunctional and can exist, for example, in electric versions.

As mentioned previously for some of the other product groups, a maximum of 7% biodiesel can be added within the guarantee. The optimization of energy consumption can be realized through Commonrail injection technology, which generally reduces energy consumption by 30%. .

Figure 10 below provides an overview of technology development.

Figure 10 – Technology development – compact/mini tractors

As illustrated above, the survey has not identified any alternative technologies to diesel to be mentioned in the TRL scale.

The reference list appears on Annex 2 for identified suppliers and manufactures on the Scandinavian market for this product category.

[23] New Holland, Thomas Pedersen

5. Green Public Procurement Guidelines

From the market analysis and the initial market dialogue with suppliers and manufacturers within the NRMM sector, a number of machine types have been identified. Based on the identified machines, recommendations for guidelines or tender criteria will, in the following, provide input for the project's non-road procurement process, which will be enhanced a few steps down the road.

Emission and Energy Consumption Criteria

From 2019 onwards most diesel engines included by the selected product groups shall comply with the Stage 5 norm. Only lawn riders below 19 kW will be exempt. The emission of CO, NOx/HC and particles will therefore be extensively lower than the actual case where Stage 3a are static and decreased emissions will automatically be achieved through implementation of extended particle filters and catalysts. GPP strategic efforts and criteria for reducing PM and NOx from diesel engines seems therefore only relevant in short-term procurement (2017-2018).

Compliance with stage norm emissions is monitored in relation to the particular engine power in kW. Emissions are relative to the size of the engine. If a GPP criterion is determined in relation to stage norm, a maximum emission level per kW is stated. However, total emissions depend on engine size.

Guidelines for GPP of NRMM should therefore include a careful assessment of the engine power needed for a certain function. The energy consumption should be a central indicator when selecting GPP criteria. The difference between e.g. a street sweeper with a 1,300 ccm or 2,000 ccm engine can be, for example, 30-40% lower energy consumption and related emissions. Lower energy consumption through optimized dimensioning is an effective way to reduce the CO_2, NOx and PM emissions, as well as the operational cost.

Possibilities for using blends of biofuels, e.g. HVO or DME in modified diesel engines are probably the most cost effective way to reduce CO_2 emissions from NRMM. Thus, the procurement cost and infrastructure for biofuels are quite different between the cities so operational conditions and business case is not comparable.

Product-Related Green Public Procurement Guidelines

The options for executing GPP vary depending on which NRMM product group is being procured. Overall, the following leads could be explored in more detail to activate reduced emissions from new NRMM equipment in operation.

Wheel loaders 12-20 tons

The developments within wheel loaders are especially focused on energy saving from operation through diesel-electric hybrids and telematic software and control systems for operation. The diesel-electric hybrids claim to reduce energy consumption by 25%. Thus, it is not yet a widespread technology in the market and prices are higher. Only a few brands can provide these hybrids.

More common is the use of telematic control and software systems to optimize engine operation and reduce energy consumption.

GPP guidelines for wheel loaders is recommended to focus on total energy consumption by including telematic monitoring. Further, the development in diesel-electric hybrids, where electrical charge in an alternating current (AV) is used to maintain hydraulic pressure, should be investigated in detail.

Street Sweeping Machine

Two different leads can be applied for street sweepers:

a) low emission and low energy consumption from diesel engines,
b) procurement of electric sweepers.

Ad. A) As mentioned previously, guidelines for GPP should include a careful assessment of the required engine power for a certain function. Correct dimensions according to their functions are an appropriate way to avoid unnecessary emissions and operational costs, because of over-dimensioned equipment. Up to 30-40% reduction in emissions and energy consumption may be achieved per unit by avoiding over-dimensioning.

Further, commonrail or similar direct injection technologies are more energy efficient than traditional engines.

Ad. B) Electric sweepers are more expensive and for now, operational experiences are limited. However, electric models have recently been brought into and used in many European capital cities so more performance documentation will be available in the coming years.

A central issue is lifetime and maintenance cost. An electric model costs approx. 2.5 times more than traditional diesel sweepers. Thus, the operational cost is lower plus emission and noise performance is better.

Many suppliers have focused on development of electric models but only a few suppliers offers electric models. The market is still new and recognized problems include the price/low market demand, operational distance and the increased unit weight for electric models having an impact on the flexibility and requirement to surface.

It is obvious that electric street sweepers in city locations should have high priority when defining GPP guidelines because of the low emission and low noise benefits. But the substantially higher price makes the procurement a political decision because electric street sweepers seem to be less price competitive in the short- and medium-term. The GPP should therefore include an in-depth analysis of TCO from on-going cases, quantification of the low emission benefits to political level and step-wise procurement of electric models for testing.

Riding lawn mowers

The commercial technologies expected in the coming years are mainly based on diesel engines where development follows legal requirement to CO, NOx and PM emissions. From 2019, engines above 19 kW shall comply with Stage 5 and this norm will generally reduce PM and NOx emission extensively. However most riding lawnmowers are below the 19 kW level which means they doesn't comply with stage emission norms. Different types of biodiesel can bee used in blending but producers particular conditions has to be clarified.

A few models with gasoline engines will still be available to the professional segment. If choosing gasoline instead of diesel, it reduces NOx and PM emission but increase CO_2 emission and it is not possible to blend with biofuel. From a GPP perspective diesel should therefore be preferred to gasoline.

John Deer produces a propane gas lawnmower to the US market. Propane fuel reduce especially particulate matter and to some extend NOx. Impacts on CO_2 is considered minor.

Beside the traditional diesel engine technologies the marked is expanding with robot lawnmowers based on electricity. Robot lawnmowers seem to be a competitive alternative to diesel riders in some cases. The benefits are low operational/maintenance cost, low emissions, and low operational cost to wages.

A non-road procurement process will require an initial assessment of areas applicable for robot riders in the cities, while not all tasks can be performed with robots. Suppliers will usually assist in this analysis. A Total Cost of Operation (TCO) perspective will be necessary for evaluations. Beside GPP and emission requirements to CO_2, NOx and PM, noise requirement is an effective criterion to promote electrified non-road machinery.

Compact tractors

The most relevant lead for GPP is a focus on low energy consumption and compliance with Stage 3b (and Stage 5 after 2019). Issues could include automatic engine shut down. Different types of biodiesel can be used in blending but producers' particular conditions have to be clarified.

No alternative technologies are in the pipeline.

For larger tractors, hybrid models on gas/biogas are available, for example New Holland and John Deer. The challenge with using gas in compact tractors seems to mainly be tank capacity versus operational range and infrastructure.

No certain GPP strategies for compact tractors can be proposed, except for a focus on energy consumption per hour. As already mentioned, when using such criteria it should be noted that there is a lack of standards for such monitoring and documentation. That affects reliability and increases uncertainty to supplier information in a GPP.

Multifunctional vehicles can replace compact tractors as an alternative. The technology options for multifunctional vehicles are, to some extent, similar to the technologies for sweepers, thus no electrical or gas driven vehicles are identified.

Political Mobilization for Green Public Procurement

The context for public procurement is generally to achieve savings through the principle of "best value for money". In practice it influences the implementation of GPP, especially where alternative and more environmentally friendly technologies, for example EL, are available but cost more. The general experience is that strong political support is needed if GPP is to be successful. In relation to the forecast for improved GPP of NRMM in the Scandinavian GPP alliance, the relevance of political involvement and support should be stressed, especially in relation to:

- Procurement of electric street sweepers
- Procurement of electric robot lawn riders

These two procurement options will probably need a tender formulation where the decision to procure electric vehicles is already in place. Otherwise a comparable procurement will be difficult, while "best value for money" in the EL case requires TCO evaluation and a positive evaluation of environmental performance.

An efficient way to push the market and determine political preference is via direct city regulations with non-emission requirements as practiced in Germany, for example. There, since 2014 construction machinery which is used on construction sites has to fulfil emission standard IIIB/IIIA (IIIA for machines <37KW). This corresponds to the current EU standard prescribed for new machinery. Older construction machinery has to be equipped with a particulate filter. The city of Berlin has, among other things, a funding programme to incentivise modernisation of engines[24].

There is a similar regulation in UK, where only registered NRMM (complying with low emissions) are allowed to operate in the city zone districts. A best practice guide for construction and demolition, with recommendations on how to reduce dust and soot emissions from construction and demolition work, was published in 2006 and substantially updated in 2014. It now includes a Low Emission Zone (LEZ) for non-road mobile machinery, which was introduced in 2015. The LEZ requires construction machinery between 37 kW and 560 kW to meet at least Euro regulation IIIA when working in Greater London and IIIB when working in central London or Canary Wharf [25].

[24] http://sootfreecities.eu/city
[25] https://www.london.gov.uk/priorities/planning/publications/the-control-of-dust-and-emissions-during-construction-and

References and links

1. Example of NRMM emission regulation in UK cities: http://www.dft.gov.uk/vca/other/non-road-mobile-mach.asp:

2. UK NRMM register for London ”low emission zones”: http://nrmm.london/nrmm/how-use/data-entry:

3. EU information on NRMM : https://ec.europa.eu/growth/sectors/automotive/environment-protection/non-road-mobile-machinery_en

4. Directive 2014/0268 regulation of emission from NRMM: http://eur-lex.europa.eu/legal-content/DA/TXT/PDF/?uri=CELEX:52014PC0581&from=EN

5. NRMM report from Danish Environmental Protection Agency: http://www2.mst.dk/Udgiv/publikationer/2013/08/978-87-93026-46-9.pdf

6. Report on emissions from NRMM in DK Cities, DCE/Aarhus University: http://www.dmu.dk/Pub/SR65.pdf

Annex 1 – List of interview contacts

Wheel loaders and dumpers

- Volvo entreprenør + 45 70 22 27 28, Lars Kristiansen, Product specialist. Has no dumpers below 25 tonnes. Main supplier of wheel loaders
- Wacker Neuson Denmark 70 22 92 00, Bjørn Nivel. Has small wheel loader on electric. Has no dumpers below 25 tonnes
- JMM (Supplier of Bergmann), Simon Nielsen, +45 21 48 69 17 (Product manager JMM/Stenos, Ole Klitgaard, Lene Nørgaard , sales agent.
- Hydrema, +45 98 37 13 33. Jørgen Sørensen (support), Allan Mølgaard fra Marketing. amo@hydrema.com
- Erenfred Pedersen (Supplier of Thwaites) +45 70 26 77 22. Jørgen Olsen

Street Sweeping machine

- Hako Denmark. Jesper Jensen, sales agent, +45 61 20 76 73, Jan Andersen (CEO) +45 65 38 11 63, ja@hako.dk
- Frederiksberg Kommune, Frederiksberg gade og vejservice. Kenneth Bruun. + 45 28 98 46 12, kebr01@frederiksberg.dk, Claus Pedersen +45 28 98 43 15 (operational experience with electric sweepers)
- BMI (supplier). Jan Bjørklund, CEO + 45 36709945
- Svenningsen (Supplier of Green Machine) Lars Petersen, +45 40 10 66 60
- Helms TMT-centret (Supplier for Bucher). Svend Dreyer, +45 60 11 63 30
- Nilfisk Outdoor street sweepers, Erling Enevoldsen +45 40 29 49 54

Lawn riders

- Husqvarna/Jonsered. Keld Sørensen, teknisk afdeling, +45 70 26 47 70,
- Jacob Konnerup (robot riders +45 20 58 90 05 Jacob.konnerup@husquarnagroup.com
- BMI (supplier). Jan Bjørklund, CEO + 45 36709945
- Kubota motors. Lars Wolff
- Svenningsen (Supplier of Green Machine) Lars Petersen, +45 40 10 66 60
- HC Petersen Danmark/Nordic (supplier of Iseki). Martin Hansen, +45 76 73 11 17
- Jacobsen, Boye Thomsen, Salgschef, +45 40 30 12 12

Mini tractors

- BMI (supplier). Jan Bjørklund, CEO + 45 36709945
- Kubota motors. Lars Wolff
- New Holland, Thomas Pedersen +45 61220671
- Svenningsen (Supplier of Green Kubota) Lars Petersen, +45 40 10 66 60
- HC Petersen Danmark/Nordic (supplier of Iseki). Martin Hansen, +45 76 73 11 17

Annex 2 – Reference list for identified suppliers and manufactures

Annex 2 contains lists of relevant producers and suppliers for the selected product categories in the Scandinavian market. For each product category identified models for the initial market analysis is listed with an overview of emission norm compliance and eventually alternative technologies such as Internal Combustion Engine (ICE), Hybrid Electric Vehicle (HEV), Electric Vehicle (EV) etc. Furthermore, internet links to suppliers or manufacturers is included whenever possible.

It should be mentioned that the list is based on the preliminary screening of websites and contact with suppliers or manufacturers of the particular product category. The lists shall not be perceived as a complete list including all suppliers and manufacturers on the market, as the list instead should reflect the broadness of the technologies available on the market right now or new upcoming technologies in the near future.

Wheel Loaders (12 – 20 tonnes)

Product	Models	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Terex	**TL210 (12,5 ton)**	119		N/A	N/A	N/A	Internal combustion engine (ICE)	Common Rail	http://www.terex.com/construction/en/products/loaders/compact-wheel-loaders/index.htm
	TL260 (14,4 ton)	128		N/A	N/A	N/A	ICE	Common Rail	
	TL310 (17,6 ton)	149		N/A	N/A	N/A	ICE	Common Rail	
CAT	926M	114			4		ICE		http://www.cat.com/en_US/products/new/equipment/wheel-loaders.html
	930M	122			4		ICE		
	938M	140			4		ICE		
	950 GC	168			4		ICE		
	950M (four versions)	171 or 185			3a and 4		ICE		
Hitachi	ZW140-5	113		N/A	N/A	N/A	ICE		https://www.hitachicm.eu/machinery/wheel-loaders/
	ZW180/ZW180-6	128		N/A	N/A	N/A	ICE		
	ZW220/ZW220-5A/ZW220-6	164/144/149		N/A	N/A	N/A	ICE		

Wheel Loaders (12 – 20 tonnes)

Product	Models	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Hitachi	ZW220HYB-5 (unclear if sold in EU)						Hybrid Electric Vehicle (HEV)		https://www.hitachicm.eu/press-center/hitachi-unveils-hybrid-wheel-loader-at-intermat/
	ZW250	179		N/A	N/A	N/A	ICE		
Liebherr	L526	103			4		ICE		https://www.liebherr.com/en/dnk/products/construction-machines/earthmoving/wheel-loaders/wheel-loaders.html
	L538	114			4		ICE		
	L546	123			4		ICE		
	L550 XPower	143			4		ICE		
	L556 XPower	168			4		ICE		
John Deer (John Deere construction equipment is only sold in the US)	644K, 944K Hybrid	400				4	HEV		http://www.deere.com/en_US/products/equipment/wheel_loaders/944k_hybrid/944k_hybrid.page ?
Komatsu	WA250PZ-6	104			3a		ICE		https://www.komatsu.eu/en/wheel-loaders/wheel-loaders

Wheel Loaders (12 – 20 tonnes)

Product	Models	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Komatsu	WA270-7/WA270-8	115			3b/4		ICE		
	WA320-8/WA320-7	127			4/3b		ICE		
	WA380-7/WA380-8	143			3b/4		ICE		
Hydrema					4		ICE		https://www.hydrema.dk/
Volvo	L250H	296/402			2		ICE	Eco-pedal	https://www.volvoce.com/-/media/volvoce/global/products/wheel-loaders/wheel-loaders/brochures/l250h/brochure_l250h_t2_en_30_20047151_c.pdf?v=OCgzPw
Wacker Neuson	WL20e						Electric Vehicle (EV)		http://www.wackerneuson.se/en/products/wheel-loaders/articulated-wheel-loaders/model/wl20e/
Weide-mann	eHoftrac						EV		http://www.weidemann.de/dk/virksomheder/innovation/ehoftrac.html
Kramer	5055e						EV		http://construction.kramer-online.com/en/discover-more/news/view/article/79/Electric-wheel-loader-5055e-wins-technology-award-in-Sweden.html

Street Suction Sweepers (1-2m^3)

Producer	Models	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Aebi Schmidt	Swingo 200 +			6			ICE		https://www.aebi-schmidt.com/en/products/street-cleaning
Ausa	B 200 H iLink			5			ICE		http://www.ausa.com/productsfamily/cleaning/#morep
Boschung	S3			N/A	N/A		ICE	S2 is advertized as having low fuel consumption: http://urban-sweeper.com/en/consumption-calculator	http://boschungscandinavia.com/town-city/street-cleaning
	S2			5	3b		ICE		
	Pony P3			5			ICE		
	Pony P4			N/A	N/A		ICE		
Brodd	YESS			5			ICE		http://www.broddsweden.com/en/yess-sweeper/
Holder Tractors Inc	X 30	19,7	N/A	N/A	N/A		ICE	Holder PowerDrive	http://www.holdertractors.com/homepage/
	C 250/270/350/370	37-49	N/A	N/A	N/A		ICE		
	C 480	56	N/A	N/A	N/A		ICE		
	C 992/ S 1090	68	N/A	N/A	N/A		ICE		

Street Suction Sweepers (1-2m^3)

Producer	Models	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Johnston Sweepers	C101	N/A					ICE		http://www.johnstonsweepers.com/media/documentation/johnston-sweepers-br-18226.pdf
	C201	58, 55, 62			3a/3b		ICE		
	C401 (4 m3)	N/A		6			ICE	Common Rail	
Mathieu	MC 210	62	2300	6			ICE	Adjustable sweeping speeds save 20 % fuel	http://en.mathieu.fayat.com
	MC120 WASHER (not sweeper)	62	2300	5			Biodiesel (percentage is unclear)		
Ravo	5 iSeries (4 m3)	104	2200	5 and 6		3	ICE		http://ravo.fayat.com/content/download/4631/29228/file/RAVO%205%20iSeries.pdf

Street Suction Sweepers

Producer	Models	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Tenax	Electra 1.0 (small)	5					EV		http://www.tenaxinternational.com/en/street-sweepers-tenax/
	Electra 2.0 (small)	9					EV		
	CleanAir 3.0	56		N/A	N/A	N/A	ICE		http://www.tenaxinternational.com/en/suction-street-sweeper-cleanair-3/
Tennant	Sentinel	74		N/A	N/A	N/A	ICE		http://www.tennantco.com/am-en/equipment/outdoor/high-performance-rider-sweeper/sentinel
Tymco	All models are small CNG powered trucks. See link for more info.						CNG		https://www.tymco.com/environment/alternative-fuel-sweepers.htm
Vitra	2067	50	2800		3b	4	ICE		http://www.lindholdt-maskiner.dk/vitra-2037/
	2045	38	3000		3a		ICE		
	2037	25	3000		3a		ICE		

Street Suction Sweepers (1-2m^3)

Producer	Models	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Green Machine	500ze						EV		http://www.greenmachines.com/gm5ze/
	636						ICE		http://www.greenmachines.com/wp-content/uploads/2016/07/636_TECHNICAL_SPEC_EN.pdf
Bucher Schorling	CityCat 2020ev	N/A					EV		http://www.citycat2020ev.com/index_en.html
Piquersa	BA-360e						EV		http://www.piquersa.es/images/productos/pdf/barredoras/ba360e_cat.pdf
Dulevo	5000 CNG						CNG		http://www.dulevo.com/machines/5000zero.html
Brock (have a single electric model)	SL 140 ECO						ICE		http://www.brock-kehrtechnik.de/en/
Hako									http://www.hako.dk/produkter/gadefejemaskiner
Kaercher									https://www.kaercher.com/dk/professionel/redskabsbaerere-og-feje-sugemaskiner/feje-sugemaskiner.html
Nilfisk									https://www.nilfisk.com/en/products/Pages/Outdoor/Suction-sweeper/group.aspx

Riding Lawn Movers

Producer	Model	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Stihl/Viking	MT 4097 SX, 4112 S, 5097 C og 6127						ICE		http://www.stihl.dk/VIKING-et-komplet-sortiment/Havetraktorer/1830/VIKING-havetraktorer.aspx
Husqvarna	P 524, 520D og 525D				3a	Kubota og Kawasaki	EV (Robot)		http://www.husqvarna.com/dk/produkter/pro-ridere/#ProductCategoryListingHeader
	Rider Battery						EV		http://www.husqvarna.com/dk/produkter/ridere/rider-battery/967187001/
Stiga	Park 120 og 540 og Park Pro 740						EV (Robot)		http://www.stiga.dk/produkter/stiga_dk/ridere/park.html
Etesia	Bahia Electric						EV		http://www.etesia.com/en/products/ride-on-mowers-bahia-m2e.html
Jacobsen	Eclipse 322						EV	Operating time 3,5 h	
Amazone	Profihopper zDrive	18		N/A	N/A	N/A	ICE		http://www.amazone.net/99.asp
	Profihopper iDrive	18		N/A	N/A	N/A	ICE		
	Profihopper 4WDi	18		N/A	N/A	N/A	ICE		

Riding Lawn Movers

Producer	Model	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Wiper	Yard 101-301						EV (robot)		http://www.wiperpremium.nu/yard-101/
Belrobotics	Parcmow/Bigmow						EV (robot)		https://www.belrobotics.com/en-gb
Ferris	5100Z, 3200Z, 2600Z, 2100Z, 700Z, 600Z, F210Z, F160								https://www.ferrismowers.eu/
John Deere									https://www.deere.dk/da_DK/products/equipment/greens_mowers/walk_behind_and_riding_greens_mowers.page?
Jacobsen									http://www.jacobsen.com/mp653-xc
Massey Ferguson									http://www.masseyferguson.dk/Havetraktorer.aspx
Ransomes									http://www.jacobsen.com/mp653-xc
Stiga									http://www.stiga.dk/produkter/stiga_dk/ridere/park.html
Toro									https://www.toro.com/en/homeowner/riding-mowers
Ventrec									https://www.ventrac.com
Kubota									http://www.kubota.com/product/GroupMowers.aspx
Nilfisk									https://www.nilfisk.com/en/products/Pages/Outdoor/Riding-lawn-mowers/group.aspx

Compact Tractors

Producer	Model	kW	RPM	EURO Norm	Stage Norm	Tier	Powertrain	Special Features	Learn more
Iseki	TH series				3a/3b		ICE		http://www.iseki.com.au/
John Deere	4M series				3b		ICE		https://www.deere.dk/da_DK/docs/html/brochures/publication.html?id=1e4fcaa8#44
New Holland	BOOMER 45D, 54D EasyDrive				3b		ICE		http://agriculture1.newholland.com/eu/da-dk
Kubota	L-series				3a/3b		ICE		http://www.kubota.com/product/LSeries.aspx
Carraro							ICE		http://www.antoniocarraro.it/en
Mitsubishi							ICE		http://www.vsttillers.com/product/tractor/mitsubishi-shakti-mt-180d-tractor#/0
Shibaura							ICE		http://www.shibaura.com/
Yanmar							ICE		http://www.yanmartractor.com
New Holland							ICE		http://agriculture1.newholland.com/eu/da-dk
Holder Tractors Inc							ICE		http://www.holdertractors.com/homepage/

Annex 3 – Small dumpers

Dumpers with a capacity of 12-20 tonnes are small dumpers and available products in this range are few. Three Scandinavian producers of small dumpers are identified:

- Bergmann - model 2090 and 3012
- Hydrema 912, 922
- Thwaites, 10 tonnes

The range of products and suppliers increase extensively when requesting dumpers larger than 20 tonnes capacity. For larger dumpers, most construction brands have dumpers, e.g. Volvo, CAT, Komatsu, Wacker Neuman etc.

The identified dumpers are all based on diesel engines. The emission level complies with the legislation defined in the EU Directive for NRMM emission. None of the identified suppliers consider development of alternative engines, e.g. electric, gas or hybrids.

Technical features and innovation

With regard emission levels, all suppliers shall be able to meet stage 5 in 2019 or 2020, depending on the net power of the machine. This will be achieved through particle filters and catalyst on existing diesel engine platform.

Innovation in hybrids is not in focus because it doubles the prizes.

It is a general feature that biofuel can be added up to 7% in diesel engines without affecting the guaranty. None of the engines are innovated to exceed a higher blend than 7%.

Further, *Ad-Blue* is also used in both dumpers, as in wheel loaders. Automatic engine stop after e.g. 60 seconds is also a feature in some models.

For larger engines (more than 25 tonnes) innovation in engines also include hybrids combining HVO diesel (produced from waste). The development is at prototype level. However the case is strongly demanded on future availability of HVO diesel, which is uncertain

Driverless, or autonomous, construction equipment is on the rise. Volvo has already made a fully autonomous wheel loader, but semi-autonomous machines have also been identified. As of now these machines help the operator work more efficiently. In the future the fully autonomous machines will operate more efficiently than a skilled operator. The environmental benefits to this is less fuel consumption for the amount of work done and time savings due to more efficient working patterns around the construction site. This technology exists in a prototype (Volvo) and is assumed ready to market in 6-8 years if there is a market demand.

Electric dumpers are generally not a considered technology for dumper engines because of the functional constraints with high-energy input and hydraulic systems.

Figure 6 below provides an overview of technology development.

Figure 6 – Technology development – dumpers 10-20 tonnes

Concluding remarks for small dumpers
The most relevant lead for GPP in relation to small dumpers is focus on low energy consumption and compliance with Stage 3b (and Stage 5 after 2019). Amending issues could be automatic shot down of engine. For diesel engines max. 7% biofuel can be added.

No alternative technologies are in pipeline for small-size dumpers in a short-term and mid-term perspective. In a long-term perspective (6-8 years), robot dumpers (based on electricity) may be available but the technology development is only at prototype stage.

For larger dumpers above 25 tonnes capacity, a few hydrid models are available. Thus, the prizes for hybrid models are considerable higher than traditional dumpers.

No certain GPP strategies for dumpers seems relevant to propose, except from focus on energy consumption per hour. But using such criteria it should be noticed there is a lack of standards for such monitoring and documentation. That affects reliability and increase uncertainty to supplier information in a GPP.