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Assessment on the availability of technology allowing vehicles of categories T2, T4.1 and C2 to fulfil Stage IV emission limits.

Final Report

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Executive Summary

The study assesses the technical readiness of narrow track and high clearance tractors (T2, C2 and T4.1) to meet the European Commission’s pollutant emission Stage IV for non-road mobile machinery (NRMM) engines. Directive 2003/37/EC specifies the criteria for the T2, C2 and T4.1 vehicle categories, which are designed for operation in extremely restricted spaces, for example in orchards or on fruit and vine crops.

The project comprised a desk based study and involved close cooperation with pertinent stakeholders, including visits to an engine manufacturer, a tractor manufacturer, an agricultural show and observations of rigid and articulated tractors in action between narrow rows on hillside vineyards. A stakeholder meeting was held in Brussels, followed by further telephone conferences to clarify information raised. An in-depth analysis of the current and forthcoming emission legislation was performed and a stocktake of the industry structure and design choices made and being made for preceding emission Stages.

In Europe, the total fleet size in 2013 is estimated to be 358,859 for T2, 56,331 for C2, and 8,250 for T4.1. With 21,750 T2, 3,400 C2 and 500 T4.1 new tractors sold in Europe annually.

Many technologies to abate the NOx emissions were identified on a variety of vehicles including tractors of comparable engine type. One technology was identified which can fully meet the Stage IV requirements and is widely used. The key concern was the placement of the emission after treatment technologies on the vehicles. The T2 and C2 tractors are exceptionally narrow; as are the lower parts of T4.1 tractors, but all require high manoeuvrability to navigate the narrow spaced crops, and a good field of view. A detailed analysis evaluated the feasibility of fitting additional technologies to the vehicles. The practicality with regards to whether the vehicles would achieve the required emission criteria for Stage IV (would the technologies work) and would the operational performance be adversely affected (would the tractor still be fit-for-purpose) were considered.

This assessment concluded that it is technically feasible to implement the new pollutant emission Stage IV, for T2, C2 and T4.1 categories of tractors within the timescales available and with some, however minimal, changes to the current farming methods employed.

For rigid T2, articulated T2 and C2 vehicles there are three to four viable locations. Each has different potential advantages. Of the viable locations identified, the fitment will affect either mid-mounted implement usage, change the fields of view and/or alter the turning radius. Therefore, the manufacturers are likely to use their understanding of their user's needs to choose the most appropriate. Or offer multiple optional fitment locations that a customer could select depending on their specific needs. For T4.1 there are very different design considerations, however it would appear that the space on or around the ROPS behind the operators cab, offers considerable scope to site EAT hardware on T4.1 vehicles.

Given shortcomings of current technologies, it is not foreseen that there will be a technology in the short-term that can be applied without at least some level of penalty. Nevertheless, with the relatively large number of tractor producers, there is a competitive pressure from the tractor manufacturing customers to the engine and abatement manufacturers to promote the development of new technologies including those which reduce the size, complexity and cost of components as well as reduce their impact on usability.

It has, however, been recognised that there are commercial reasons for not producing Stage IV compliant vehicles, specifically the relatively short time difference between introducing Stage IV and the following Stage V. This time difference is shorter than the usual Research and Development time afforded for a new model. To counter this, as Stage IV and V engines of the relevant power ranges are begin developed, the tractor manufacturers can liaise more closely from the early stages of their tractor design. The

aim of this collaboration would be to develop complete powertrains, including the after treatment systems, to allow a so-called engine or powertrain 'family' approach to be used for type approval. This would reduce the time and costs associated with the design, development and certification.

An environmental assessment used the fleet size, replacement rate, average annual usage, and duty cycles to calculate the potential benefit of the emission stage. The environmental assessment found that if Stage IV was not attained in 2019, then approximately 7,000 tonnes of additional NOx emissions would be emitted for the year 2021 and approximately 16,400 tonnes of additional NOx emissions for the year 2025. The increase in additional NOx emissions in 2025 compared to 2021 is associated with the greater proportion of vehicles that could have met Stage IV criterion if it was introduced in 2019.

When assessed as a cumulative value, the non-introduction of Stage IV emission limits in 2019 would have cumulatively generated 14,000 tonnes of NOx by 2021 and this would have reached 65,500 tonnes by 2025. The heavier than air NOx will disperse in a relatively small area, meaning that the vine-growers themselves and the rural towns and villages in and around them will take the majority of the burden from the additional NOx pollution.

Moreover, while the year's emissions for 2021 present a 1.6% increase in this sector, or 0.08% of the entire EU28, the 2025 emissions will represent a 3.4% increase in the sector and by applying the emission reductions agreed in the Gothenburg 2020 target, the proportion becomes 0.32% against the entire EU28's yearly emissions.

1 Introduction

The study assesses the technical readiness of narrow and high clearance tractors (T2, C2 and T4.1) to meet the European Commission's pollutant emission Stage IV for non-road mobile machinery (NRMM) engines.

1.1 Background

Due to specific concerns raised by stakeholders the tractors within category T2, C2 and T4.1 (as defined by Directive 2003/37/EC) were granted three years derogation on the Stage IIIB and IV emission limits.

Stage IV covers a reduction of NOx for engines between 56 and 560 kW, these are engine categories Q and R (Section 3.1.1, Table 11). The preceding Stage IIIB covered engines between 37 and 560 kW. The T2, C2 and T4.1categories of tractor usually have engine powers not more than 130 kW (Section 2.5). Therefore, the study concentrated on tractors fitted with category R engines.

These tractors are designed for operation in extremely restricted spaces, for example between closely spaced fruit, orchard and vine crops, therefore driving as compact a design as possible while still permitting them to perform energy intensive farming functions. T2 and C2 tractors are exceptionally narrow to fit between the crops and are called narrow track tractors (NTT), while T4.1 tractors travel over the crops on narrow wheeled legs and are termed high clearance tractors (HCT). This narrow or high design gives some of these vehicles a high centre of gravity (CofG) and therefore potential stability issues. Further details on their design and use are given in Section 2.

Directive 2011/87/EU amending Directive 2000/25/EC, Article 4, details the dates of application and changes to that timetable for the specific engine categories granted by said derogation (Table 1, and Annex 2 for further details).

Table 1: Timescales from Directive 2000/25/EC (as amended up to 18/11/2011), stage IIIB dates passed are highlighted in green, and dates upcoming are in blue, stage IV dates upcoming are in orange.

Stage	Engine category	MS granting of EC type approval (article 2)	With derogation (article 9)	MS prohibition for sales of non-compliant engines (article 3)	With derogation (article 9)
IIIB	L	After 31 December 2009	after 31 December 2012	after 31 December 2010	after 31 December 2013
	M & N	after 31 December 2010	after 31 December 2013	after 31 December 2011	after 31 December 2014
	P	after 31 December 2011	after 31 December 2014	after 31 December 2012	after 31 December 2015
IV	Q	after 31 December 2012	after 31 December 2015	after 31 December 2013	after 31 December 2016
	R	after 30 September 2013	after 30 September 2016	after 30 September 2014	after 30 September 2017

In addition to the derogation, EU legislation also permits two further provisions which must be considered when describing the available timescales for developing appropriate technologies; a sell off provision and flexibility for old stock.

Figure 1 shows the extent of the extension available to manufacturers between the IIIA and IIIB stages. Overall Stage IIIB vehicles are not required on the market until mid-2017.

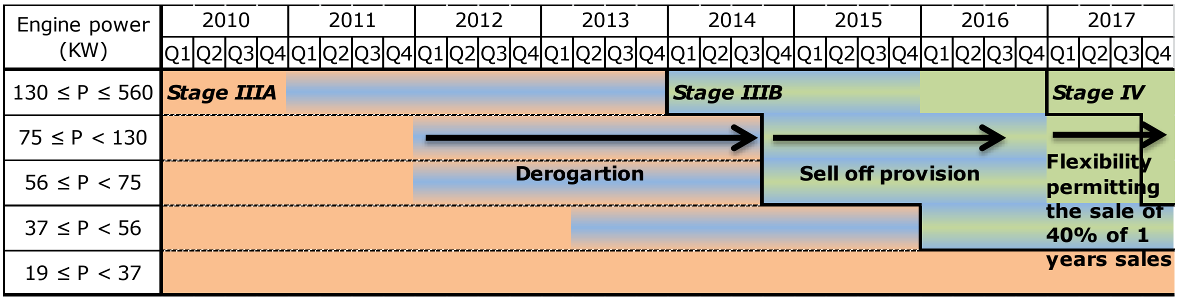

Figure 1: Chart showing the allowable sale of Stage IIIA engines, the coloured areas indicate the provision types, the black lines represent the MS prohibition for sale of non-compliant engines.

(Copyright TRL)

Stage IV is permitted up to a three year derogation, two year sell off provision and a reduced 20% flexibility. Performing the same calculation as was done for Stage IIIB for stage IV, suggests that Stage IV NTT and HCT vehicles will be entering into service during 2019.

1.2 Approach

The study has analysed the vehicles and their emission abatement technologies separately, followed by a consolidation of the results.

Section 2 contains the in-depth analysis of the T2, C2 and T4.1 vehicles. Including their design characteristics, an assessment of their operating environment, the roles performed, energy requirements, usage, and duty cycles (engine load for a given task and time performing that role through a given year).

In parallel an assessment of technologies used to abate the emissions covered by Stage IV was performed (Section 3), as well as a summary of the emissions mitigated by this stage. The section begins by presenting the current technologies used in the preceding emission stages, current technologies, and an assessment of similar engines which have not been afforded the derogation. This continues with abatement methods used in other sectors or which are under development.

Furthermore, the Stage V requirements (which are to follow Stage IV from 2021) were kept in mind, because it is preferable that the technologies identified as promising for Stage IV are also compatible with the next emission step's design needs.

In addition, data was collected to perform an environmental assessment and an assessment of the industry sector. The environmental assessment took the data collected in Section 2 on usage, the emission stage implementation dates as well as the vehicles' longevity to quantify the potential benefit of reduced NOx emissions for these specific vehicles. An assessment of the tractor and engine manufacturer industries provided an understanding of their development processes, as well as a gauge of their ability to meet the emission stage, in regards to development capabilities and timescales (Section 2.4).

The project has been a desk based study and has involved close cooperation with pertinent stakeholders, including consulting with engine and tractor manufacturers. Further information was obtained from agricultural shows and visits to observe rigid and articulated tractors in action. This included real life demonstrations of various tractors operating between narrow rows of crops on hillside vineyards. A stakeholder meeting was conducted in Brussels attended by key representatives, including tractor and engine manufacturers. This was followed by telephone conference calls to clarify information raised. An in-depth analysis of the current and forthcoming emission legislation was performed and a stocktake of the industry structure and design choices made and being made for preceding emission Stages.

Overall this study assumes that given the timescales available, entire new tractor models could be developed and designs adjusted to accommodate any additional equipment.

2 Overview of the tractor characteristics (Task 1)

This section provides a comprehensive review of the different types of narrow tractor pertinent to the new emission standards. Data from this section feeds into the Assessment of the technical requirements for compliance with Stage IV (Task 2) in Section 4 as well as the Environmental impact (Task 4) in section 5. For each vehicle category as well as the analysis of the industry sector, a summary is provided in Section 2.5.

During the 20th century, the desire to increase agricultural productivity and reduce labour inputs resulted in increasing levels of mechanisation, often addressing applications which had previously relied upon hand labour and/or draught animal power. Such trends encouraged the development of special-purpose tractors, these frequently being modified versions of standard production models. This process of market-led evolution resulted in the development of T2, C2 and T4.1 tractors as we know them today.

2.1 Category T2: Narrow-track wheeled tractors

2.1.1 T2 tractors: Design characteristics

T2 tractors and the other tractor categories considered by this study are defined by the EU type-approval procedure for agricultural and forestry tractors. This procedure and the associated vehicle definitions are currently specified by Directive 2003/37/EC. This will be repealed from 1 January 2016 by the Regulation (EU) No 167/2013. The definitions used for the T2 vehicle category within both documents are identical, namely:-

> *"… Wheeled tractors with a minimum track width of less than 1150 mm, with an unladen mass, in running order, of more than 600 kg, with a ground clearance of not more than 600 mm. If the height of the centre of gravity of the tractor (measured in relation to the ground) divided by the average minimum track for each axle exceeds 0.90, the maximum design speed shall be restricted to 30 km/h"*

Within the industry, T2 tractors are usually referred to as Narrow-Track Tractors (NTT) and are primarily intended for use in applications which require a vehicle of limited overall width. These are often areas of semi-permanent cropping where moderately-tall (> 1 m high) plants are grown in a rectilinear arrangement and tractors are required to travel between each crop row on a regular basis, to perform crop treatment and harvesting operations (Figure 2). Typical examples found within the EU and worldwide include vineyards, orchards, field-scale soft fruit (e.g. raspberries, blackcurrants) and hops.

Figure 2: NTT performing crop treatment operation in a vineyard

(Copyright New Holland)

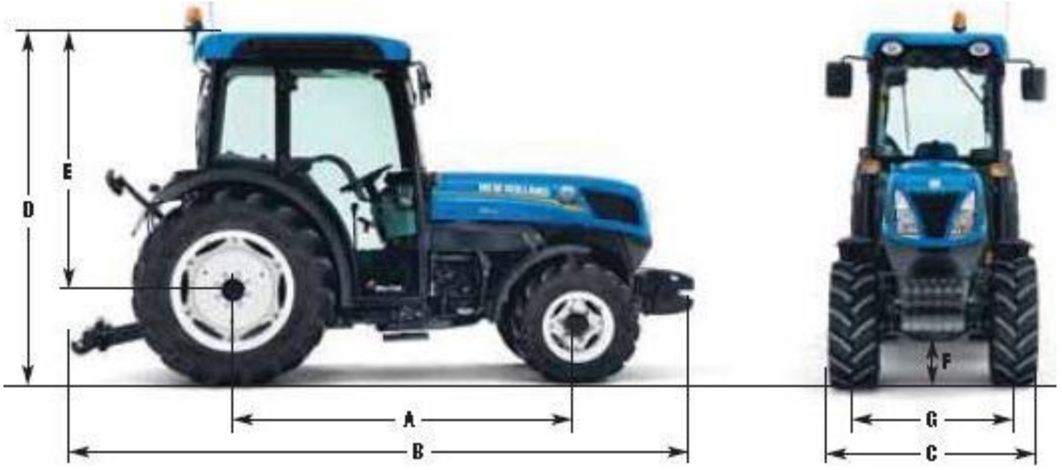

Figure 3: Principal dimensions of a rigid-chassis NTT

A – wheelbase
B – overall length
C – overall width
D – overall height
F – ground clearance
G – track width

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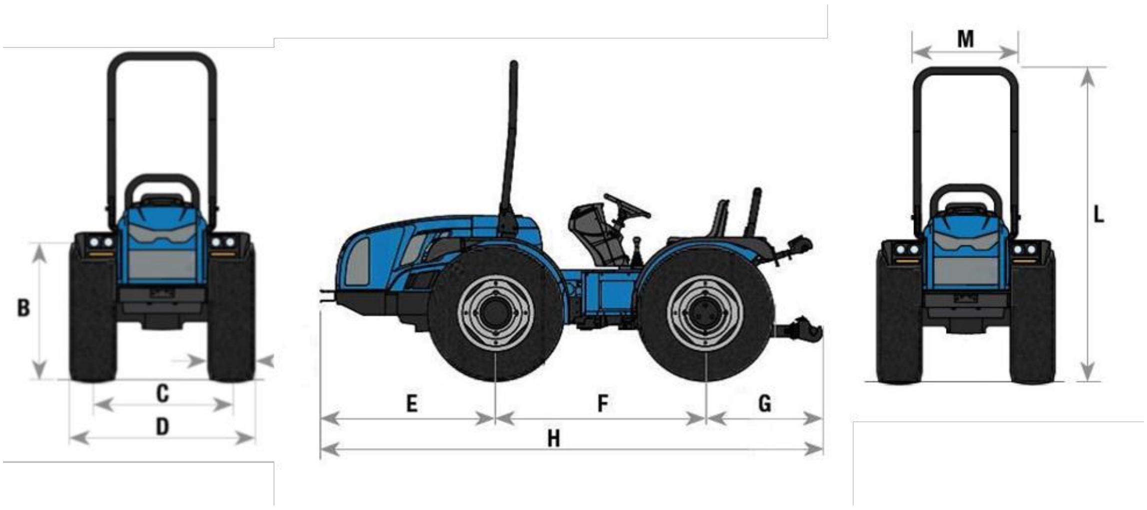

Figure 4: Principal dimensions of an articulated-chassis NTT

F – wheelbase
H – overall length
D – overall width
L – overall height
C – track width
A – tyre section width

(Copyright CEMA)

Figure 3 illustrates the principal dimensions of a typical, rigid-chassis NTT, while Figure 4 depicts the other common NTT variant where steering is effected by means of a centrally-articulated chassis. This may in some instances also be supplemented by a conventionally-steered front axle to further enhance manoeuvrability. It should be noted that, in either case the T2 tractor definition focusses primarily upon the track width of the vehicle, namely the lateral distance between tyre centrelines, rather than the overall width. However, in practice it is the minimum overall width, not the minimum track width, which determines the suitability of a given tractor for use in a width-restricted application. Also the minimum track width is dependent both upon vehicle design and the particular tyre size(s) (section widths) fitted: a range of alternative tyre sizes are normally offered.

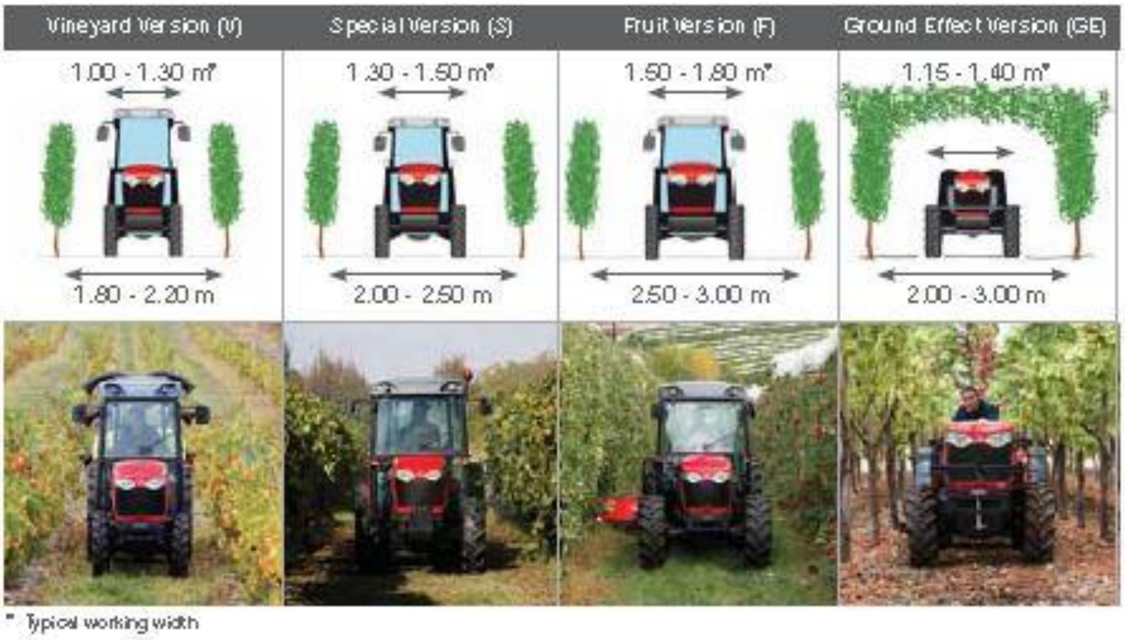

Figure 5: Typical (width) variants of NTT

(Copyright AGCO)

Most manufacturers produce a range of NTTs, both in terms of engine power rating and overall width: customer selection is largely based upon the crop growing system and crop row spacing employed. Typically up to four width-based variants of rigid chassis NTTs are produced by the major tractor manufacturers, as shown in Figure 5. They are intended primarily for the generic applications outlined in Table 2.

Table 2: Overall widths and typical operating environments of NTT variants

NTT Variant	Typical Overall Width (m)	Comments / Typical Operational Use
Vineyard	1.0 – 1.3	Ultra-narrow for narrow row spacing vineyards
Special / Wide Vineyard	1.3 – 1.5	Wider-spaced vineyards
Fruit / Orchard	1.5 – 1.8	Orchards and field-scale soft fruit
Low Orchard	1.15 – 1.4	Orchards and other applications where height is limited

To comply with the category T2 type-approval definition, the tractor's track width must be less than 1150 mm. However, virtually all tractors are fitted with adjustable wheel rim and centre assemblies which may be configured to provide a range of wheel track width settings. Consequently, if fitted with tyres of sufficiently narrow section width, it is possible for all the NTT variants described in Figure 5 and Table 2 to be configured to comply with the category T2 definition, even though in practice their overall widths may, in many cases, be substantially greater than 1150 mm. Figure 5 provides an example of a NTT with the maximum overall or working width of 1800 mm.

2.1.2 T2 tractors: Fleet size

The T2 Narrow-Track Tractors (NTT) population may be split into two distinct components, namely:-

- Specialist narrow-width tractors for vineyard and orchard applications

- Compact / small utility tractors

The specialist (vineyard / orchard) tractors typically have an engine power up to 75 kW engine power, whereas the compact / small utility tractors generally fall in the 15 – 45 kW range, the majority being below 37 kW.

Industry input to previous studies relating to this subject (JRC, 2008 and EC, 2011) estimated that, in 2005, approximately 25,000 T2 NTTs were sold within in the EU15. Slightly more than 10,000 of these vehicles fell in the >56 kW engine power category of specific interest for Stage IV engine emission requirements. However, no information was provided regarding the T2 tractor population split outlined above, but information presented in the JRC study alluded to its existence. Whilst other information received by that study estimated annual T2 sales of 30,000 units within the EU15 in 2005, one source quoted a total of 14,000 specialist (NTT) tractors sold in 2004.

For this assessment, CEMA[1] provided estimated sales data for T2 tractors in 2013 for the EU28, summarised in Table 3. This information suggests that nearly 22,000 T2 tractors were sold and the ≥56 kW engine power sector accounted for virtually 50% of the sales in the EU28. This corresponds with the information presented in previous studies (JRC, 2008 and EC, 2011). The differences in sales estimates between 2005 and 2013 fall in line with stakeholder feedback, which suggests average tractor engine power levels have increased slightly and unit sales have followed a gradual decreasing trend.

Table 3: Estimated sales of T2 tractors - EU28 (2013)

Engine Power Range (kW)	Articulated Chassis	Rigid Chassis	Total T2	
			Units	Percentage of Total
< 19 kW	0	330	330	1.5
19 ≤ P <37 kW	3300	2810	6110	28.1
37 ≤ P <56 kW	1500	3012	4512	20.7
≥ 56 kW	1800	8997	10797	49.6
Total	6600	15149	21749	-

(Data courtesy CEMA)

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[1] European Committee of Association of Manufacturers of Agricultural Machinery

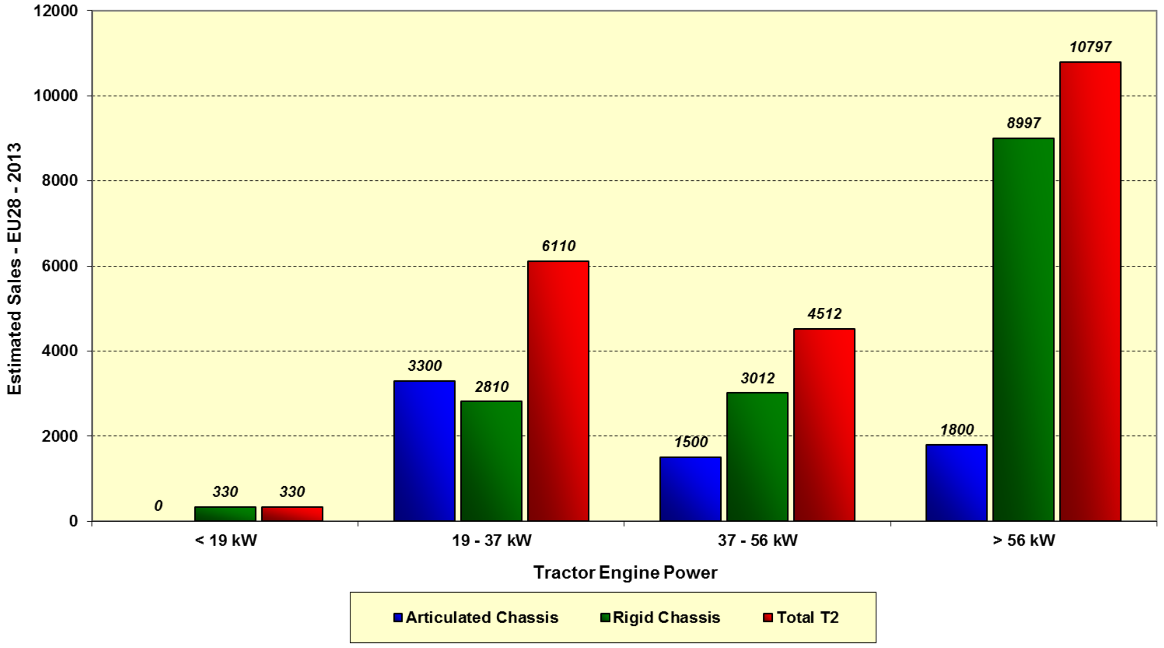

Figure 6: Estimated sales breakdown of T2 tractors - EU28 – 2013

(Data courtesy CEMA)

During 2013, total sales of rigid-chassis T2 vehicles outnumbered those of articulated-chassis types by 70%:30%, but this trend was particularly evident in the ≥56 kW sector where rigid-chassis models accounted for 83% of sales. That is not to suggest that articulated-chassis T2 tractors are not of consequence, but rather that, at present, they have a stronger (relative) presence in the 19 – 37 kW and 37 – 56 kW power ranges (Figure 6). In 2013 approximately 73% of articulated-chassis T2 sales were of <56 kW engine power, but we have been informed by the manufacturers that this is reducing in response to increasing demand for ≥56 kW NTTs of high manoeuvrability.

It has not been possible to obtain specific data regarding sales volumes of Compact / Utility T2 tractors, because this sub-sector is not defined separately by the industry: however estimation is possible based upon the following reasoning. It is known, both from the extent of NTT manufacturers' product ranges and their own reports of market characteristics, that the vast majority of vineyard / orchard rigid-chassis NTTs currently sold with the EU are of ≥56 kW engine power: indeed very few models of <56 kW are offered. This suggests that the majority of the ~6000 rigid-chassis NTTs of <56 kW are in fact Compact / Utility tractors rather than specialist Vineyard / Orchard variants; meaning that Compact / Utility models potentially represent up to 40% of the rigid-chassis NTT market. In comparison, the majority of articulated-chassis T2 tractors are used for specialist vineyard / orchard purposes and, in any case, their design features and associated engineering constraints remain common, irrespective of their eventual use.

2.1.3 T2 tractors: Use requirements and operations

Whilst an entire (vineyard / orchard) NTT model range may share the same engine and transmission design, different front and rear axle assemblies are installed to obtain the minimum overall width demanded by the specific application. In the case of ultra-narrow vineyard tractors, a very narrow operator's cab is also required (if fitted). The restricted height of certain orchard growing systems may even preclude the fitting of a cab or require it to be of a limited height.

Vineyard and orchard NTTs are produced both in rigid and articulated chassis configurations (Figure 3 and Figure 4). Articulated-chassis NTTs are generally of lower engine power, typically falling in the 20 – 50 kW range. Virtually all vineyard / orchard NTTs feature four-wheel drive (4wd).

Figure 7: Compact / utility T2 tractors intended for general use

(Copyright New Holland & Kubota)

In addition to tractors intended for vineyard and orchard use, many other compact / small utility tractors also fall within the T2 category. Whilst not specifically designed for limited-overall width operating environments, their dimensions enable type-approval as T2 vehicles. These tractors are typically used for a wide variety of purposes, including amenity turf-care, general estate maintenance, municipal (park / garden) maintenance, field-scale and glasshouse horticulture, and by hobby farmers for paddock maintenance and general farming activities (Figure 7). Whilst certain of these applications require narrow-width tractors, the majority do not, rather the vehicles are classified as T2 types by default. In comparison with specialist vineyard and orchard T2 vehicles, these compact / utility T2 tractors are generally of lower engine power, typically falling in the 15 – 45 kW range, with the majority being exempted from Stage IV requirements because they are below 37 kW. Otherwise, in the main, they share the constructional features and design characteristics of larger / wider (orchard) rigid-chassis T2 tractors and even some larger T1 category vehicles.

T2 tractors incorporate very similar features to those found on larger, conventional (T1 category) tractors. A hydraulically-controlled 3-point (3pt) mechanical linkage and a mechanical Power Take Off (P.T.O.) shaft are located at the rear of the chassis, for the attachment and, where necessary, powering of implements. External hydraulic couplings are also sited at the rear to provide hydraulic power to implements which require it. Manoeuvrability (small turning circle) is an important attribute, primarily to enable tight end-of-row turns in the limited headland space typical of many older vineyards. Articulated-chassis NTTs are usually more manoeuvrable than rigid-chassis versions, although specific front axle designs are available for each type, to further enhance manoeuvrability.

Vineyard and Orchard T2 tractors usually have a higher technical specification than Compact / Utility variants and so usually provide the option of a front-mounted 3pt linkage, P.T.O. and front and/or mid-mounted external hydraulic outlets (Figure 8 and Figure 9). These facilities support the front-mounted equipment, which is popular for vine maintenance operations (e.g. mechanical leaf trimming, pruning and wire-lifting: Figure 2, Figure 10 and Figure 12). The relatively low power requirement of such equipment and the need to precisely-control its lateral and vertical position relative to the crop rows, results in it usually being powered hydraulically from the external outlets. By comparison, certain rear-mounted or trailed implements, e.g. air-assisted sprayers for agrochemical application in vineyards or orchards (Figure 13), can have a very high power requirement, necessitating mechanical power supply from the rear P.T.O.

Figure 8: Typical, modern, rigid-chassis T2 vineyard tractor

(Copyright AGCO)

Figure 9: Mid-mounted external hydraulic couplings on a rigid-chassis T2 tractor

(Copyright TRL)

Figure 10: Front-mounted crop treatment machinery mounted on T2 vineyard tractors

(Copyright AGCO)

Figure 11: Mid-mounted intra-row weeding and disc ridging tools

(Copyright Clemens)

Historically, certain implements for crop treatment operations within vineyards were mid-mounted on the tractor, between the front and rear axles. This location affords good visibility of the implement in work, encourages precise positioning and can permit simultaneous operation with front or (more likely) rear-mounted implements. Whilst mid-mounted implements are still available (Figure 11), the increasing power, complexity and limited space upon modern T2 tractors complicates their installation. To achieve adequate productivity, most of such tools are installed in (left and right-hand) pairs to treat two rows during each pass. The need for precise location and control of such tools often requires mid-mounted implements be fitted with remote sensing and actuation systems, to automatically-adjust the position of each tool relative to the tractor and the crop row being treated. Such arrangements reduce strain upon the operator and permit faster working: however, they also permit such tools to be mounted either on the front or the rear of the tractor without detriment to their function, as precise control by the operator is no longer a fundamental requirement.

The structural capability of modern NTTs above approximately 50 kW, particularly rigid-chassis designs, encourages the installation of front-mounted implements (Figure 2, Figure 10 and Figure 12). These implements not only provide the benefit of good operator visibility and consequent accurate control, but also enable ready adjustment of tool height, lateral position and, importantly, the position about the vehicle’s longitudinal axis as the tractor passes along the crop row. As shown by Figure 12, this capability is vital on side-sloping ground to ensure the tool(s) remain in the correct orientation relative to the crop rows. This degree of adjustment would be very difficult if not impossible to achieve with mid-mounted implements due to interference with the vehicle structure.

Figure 12: Front-mounted twin-row vine leaf trimmer hydraulically powered from tractor rear-mounted external couplings. Note adjustment of implement orientation relative to tractor chassis to compensate for sloping ground (lower right)

(Copyright TRL)

Table 4 and Table 5 assume that the T2 tractor(s) will participate in every operation within the vineyard. In an increasing number of instances, specialist self-propelled machines are used for crop harvesting. These may also then be re-configured to perform spraying and other operations during the remainder of the year, to improve their utilisation and help spread the greater financial investment they represent for the grower.

The typical annual usage of a T2 vineyard / orchard tractor has been suggested by manufacturers to be approximately 500 hours per annum (p.a.)[2], compared with 700-1,000 hours p.a. or more for a standard (T1) agricultural tractor. However, information gained from a number of franchised tractor dealers in the United Kingdom suggests that frontline T2 vineyard / orchard tractors employed on crop spraying duties in fruit orchards will frequently accumulate 1,000 operating hours p.a., equivalent to that of a well-utilised T1 tractor.

Given the variety of crops and agronomic systems in which NTTs are likely to be used across EU member states, this degree of variation in annual usage is to be expected. Whilst approximately 500 hours p.a. may be typical of vineyard usage, utilisation in orchards would appear to be more intensive. In the light of these data, an average annual usage of 600-700 hours may be considered reasonable for environmental impact calculation purposes.

Table 4: Typical seasonal distribution of operations in a mechanised vineyard

Season	Operation	Intensity of Use	Tractor Power Requirement
Spring	Wire lifting	Low	Low
	Spraying	Moderate / High	Moderate / High
	Weeding	Moderate	Moderate
	Leaf Trimming	Moderate	Low
Summer	Spraying	High	Moderate / High
	Leaf Trimming	Moderate	Low
	Grass Mowing	Moderate	Moderate
Autumn	Harvesting	Moderate / High	Moderate
	Crop transport	Moderate / High	Moderate
	Fertilising	Moderate	Moderate
Winter	Pre-pruning	Low	Moderate
	Pruning	Low	Moderate

Table 5: Typical T2 vineyard/orchard tractor activities and associated duty cycles

	Spraying	Transport (trailer)	Soil Treatment	Crop Maintenance	Irrigation	Harvesting
Time Spent (%)	55	5	15	15	5	5
Power Requirement (%)	80-90	40-50	60-70	20-30	70-80	80-90
Season						
Spring	x	-	x	x	x	-
Summer	x	-	x	x	x	x
Autumn	-	x	x	x	-	x
Winter	-	x	-	x	-	-

(Data courtesy CEMA)

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[2] CEMA data (2014).

Figure 13: Air-assisted sprayer applying agrochemicals and mowing in an orchard

(Copyright AGCO)

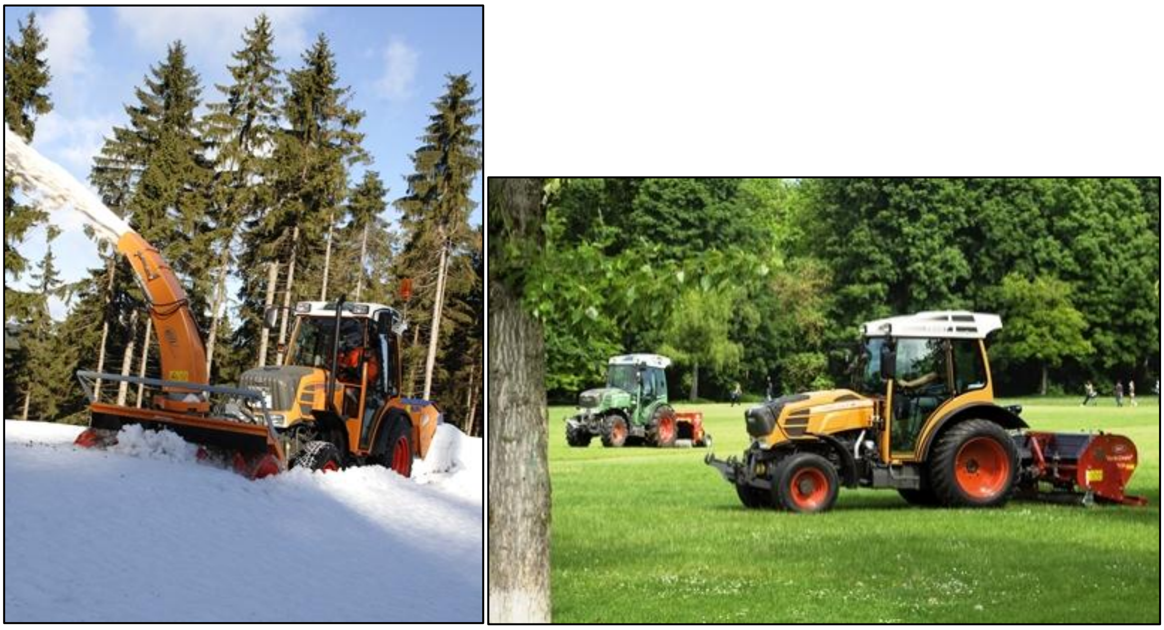

Figure 14: T2 vineyard / orchard tractors in use in municipal applications

(Copyright AGCO)

A number of large, global tractor manufacturers source their specialist (vineyard and orchard) T2 vehicles from a small number of dedicated manufacturers who specialise in the design and production of such vehicles.

Manufacturers of specialist T2 tractors also market their vehicles for use in other applications, frequently cited examples being amenity turf-care and municipal (park / garden) maintenance (Figure 14). Light-duty, restricted-space forestry operations are other limited applications.

However, specialist (vineyard and orchard) NTTs are disproportionately-costly vehicles when compared with compact / utility T2 or conventional (T1) tractors of equivalent engine power. Consequently, unless a specific operational application demands a vehicle of limited overall width, it is usually more cost-effective to utilise a compact / utility T2 or standard-width tractor. Additionally, the greater available space within the operator's cab of the latter machines, and consequent improved level of comfort, is another factor in their favour. So whilst narrow-width T2 tractors can be used for municipal applications, frequently their specialist attributes are not required.

Certain T2 manufacturers have developed specialist vehicles for municipal applications, as derivatives of their T2 products. However, these feature load-carrying platforms, reverse driving position and spacious operator cabs; they are sold in relatively small numbers and, given that they are not agricultural tractors, are outside the scope of this study.

Such compact / utility T2 tractors, whilst perhaps less powerful than certain specialist (vineyard / orchard) T2 tractors, are considerably less expensive. Consequently they are often preferred by users who do not require the combined extreme limited-width and high engine power package offered by specialist vineyard / orchard T2 tractors. In most cases these compact / utility T2 tractors fall below the 56 kW engine power thresholds for Stage IV engine emissions requirements, effectively removing them from the scope of this study. However, their presence in the marketplace is a significant factor with respect to total T2 vehicle sales data (Section 2.1.2): additionally, in time as technologies mature, it is likely that such vehicles will be required to comply with Stage V engine emission requirements.

2.1.4 Summary

Regarding T2 tractors in relation to future engine emissions requirements, the EU28 2013 T2 sales data suggests that approximately 11,000 (≥56 kW) vehicles, or approximately 50% of total T2 tractors sold, would be affected by Stage IV. According to current data, approximately 70% of these vehicles would be rigid-chassis tractors.

With regard to potential fleet size, industry stakeholders have suggested the typical annual usage of a T2 vineyard tractor to be approximately 500 hours per year compared with 700 - 1,000 hours per year or more for a standard (T1) agricultural tractor. However, reliable information from other sources has indicated that annual T2 usage within intensive orchards may frequently reach 1,000 hours each year. In the light of these data and accepting regional variations in machine use, an average annual usage of 600 - 700 hours may be considered a reasonable estimate. Industry stakeholders[1] have estimated the average first life / frontline use lifespan of a T2 to be 5000 – 6000 hours, after which the vehicle would be transferred to less demanding work and annual usage, would decrease significantly. These predictions appear reasonable and would suggest a T2 first life / frontline lifespan of 7 – 10 years, followed by up to a further 15 – 20 years in a secondary role. Given that the service life of modern tractor diesel engines is usually in excess of 8,000 – 10,000 operating hours, such extended lifespans (albeit at much reduced annual usage intensities) are feasible. However, it should be remembered that many other factors in addition to age and accumulated operating hours, can contribute to a business choosing to renew a given tractor.

Contrary to the information presented in previous studies (JRC, 2008), the use of specialist vineyard/orchard T2 tractors is by no means exclusive to the EU. In addition to the EU, such vehicles are widely used in every major wine growing region of the world, e.g. USA, Australia, New Zealand, South Africa and South America. The narrow row-width vineyard systems employed in many of these regions and the consequent utilisation of specialist T2 tractors is no less common than within the EU (Franson, 2008). A small proportion of T2 tractors are used in municipal applications, e.g. amenity turf-care, park / garden maintenance and snow clearance, but industry stakeholders estimate such uses account for no more than 5 – 10% of T2 vehicle sales.

Compact/utility T2 tractors are produced and marketed by all the major global tractor manufacturers and a number of smaller companies, but are frequently constructed outside the EU. A large proportion of these vehicles are also sourced from manufacturers in the Far East and India, such vehicles being characteristically-suited to indigenous agricultures of those regions.

2.2 Category C2: Narrow-track track-laying tractors

2.2.1 C2 Tractors: Design characteristics

Category C vehicles are defined by the EU type-approval procedure for agricultural and forestry tractors as track-laying tractors. This category is further divided into numbered sub-categories, by analogy with those of Category T (wheeled tractors). Therefore a C2 tractor is, in essence, a track-laying equivalent of a T2 wheeled narrow-track tractor and they are primarily favoured for use in vineyards and orchards on steeply-sloping terrain, where adequate traction and vehicle stability may be issues.

Generally, Category C track-laying or ‘crawlers’ tractors feature a single endless steel or rubber track unit fitted on either side of the engine / transmission / vehicle chassis (Figure 15). The vehicle is both propelled by the track units and skid-steered by varying their relative speed, either hydraulically or by a mechanical system of individual clutches and brakes.

A slight modification has recently been made to the track-laying tractor definition found within EU tractor type-approval legislation:-

- Current type-approval text (Directive 2003/37/EC) states:-
  "Track-laying tractors that are propelled and steered by endless tracks ……"
- Forthcoming type-approval text (Regulation (EU) No 167/2013) states:-
  "Track-laying tractors propelled by endless tracks or by a combination of wheels and endless tracks ……"

This modification means that wheeled tractors which are fitted with track units to replace the wheels, on either one or both axles (Figure 16), in the future fall within the C type category. However, at present such vehicles are relatively few in number, but this modification of the type definition may have implications, should any particular derogation be granted to specific C category vehicles in the future.

Figure 15: Typical examples of Category C2 tractors

(Copyright Yanmar & Same Deutz-Fahr)

The specific design characteristics of C2 'crawler' tractors and the principal vehicle dimensions are illustrated by Figure 17. To correspond with the T2 narrow-track wheeled tractor category, the minimum track width of a C2 tractor must be less than 1150 mm and the mass be greater than 600 kg.

Figure 16: Full-track (left) and half-track (right) conversions of wheeled T2 tractors

(Copyright Antonio Carraro & Kubota)

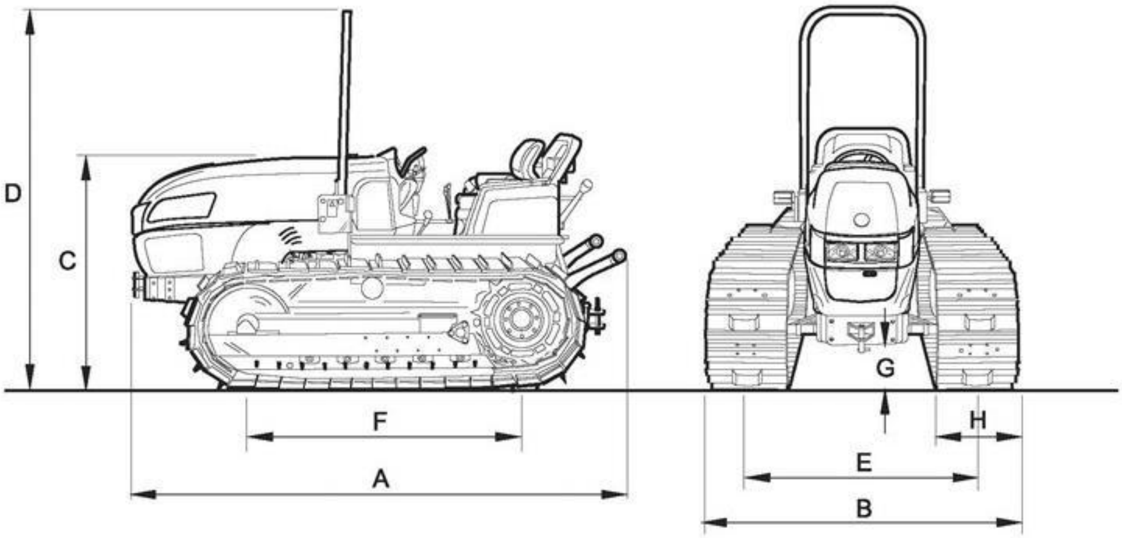

Figure 17: Principal dimensions of a Category C track-laying / crawler tractor

A – overall length;
B – overall width
C – bonnet height
D – overall height
E - track width
F - wheelbase
G – ground clearance
H – track shoe width

(Copyright Argo Tractors)

The small / medium power track-laying tractor market sector is unique in a number of ways. Although some examples originate from the Far East, the majority are produced by a small number of Italian manufacturers (e.g. Argo, CNH and SDF – Section 2.4), Northern Italy being one of the main areas worldwide where such vehicles are used. These machines employ the same engine variants as their wheeled counterparts, typical power levels being in the range 50 – 75 kW. They also usually share a similar general powertrain configuration to T2 tractors, in so much as the engine and associated cooling packages are mounted centrally, at the front of the vehicle. Drive then passes rearwards down the vehicle centreline, via a multi-ratio transmission to the rigidly-mounted rear axle. This component differs from that of wheeled tractors in that it contains individual steering clutch and brake systems for both left and right-hand sides. These permit the drive to either axle end to be disengaged or the respective half-shaft held stationary: the application by the operator of this action, proportionately, to either the left or right sides of the vehicle, effecting directional control. Sprockets attached to the rear axle ends transfer drive to the steel or rubber track units which run forwards on either side of the engine / transmission / vehicle chassis (Figure 15 and Figure 17).

The vehicles are produced in both 'standard width' (C1) and 'narrow width' (C2) configurations, but share powertrain components: the 'narrow' configuration being engineered by fitting the track units with narrow width track shoes and installing the track units as close as possible to the sides of the engine / transmission. This has the effect of severely limiting space in these locations. For reasons of minimising overall width and height, C2 tractors are rarely fitted with operator cabs: instead foldable rollover protective structures (ROPS) are fitted to enable vehicle use in areas of restricted headroom (e.g. orchards).

As in the case of T2 tractors, the dimension of consequence to the C2 tractor user is the overall width of the vehicle, not the minimum track width. However, unlike wheeled tractors, few track-laying tractors offer user-adjustable track width settings: consequently the machine remains in the same configuration throughout its life as when it left the factory. C2 tractors are offered at the time of manufacture with track shoes of alternative widths (e.g. 310 or 360 mm), but in practice the dimensional variations resulting from these options are small.

In common with wheeled tractors, C2 tractors are fitted with a hydraulically-controlled 3-point (3pt) mechanical linkage and a mechanical power take off (P.T.O.) shaft at the rear of the chassis: external hydraulic couplings are also sited at this location. Some manufacturers offer the option of front-mounted 3pt linkage systems, but front-mounted P.T.O. systems, whilst offered, are not as popular as on wheeled (T2) tractors.

Whilst wheeled T2 tractors are often used with front-mounted implements, primarily to improve driver visibility and enable more precise implement control in restricted areas, the skid-steering characteristics of a track-laying tractor do not permit extremely small steering corrections and precise directional control. The resulting angular movements of the vehicle during steering corrections tend to be amplified into larger lateral movements of front-mounted implements. For these reasons, rear-mounted and/or trailed implements are more commonly used with track-laying tractors.

2.2.2 C2 tractors: Fleet size

C2 tractors are marketed in a limited number of EU member states and, as commented above, are used for a very limited range of applications. Markets identified by industry stakeholders include Italy (middle and south), Spain, Portugal and Greece. Worldwide production of true C2 vehicles (Figure 15) as opposed to track-unit conversions of T2 wheeled vehicles (Figure 16), is concentrated in northern Italy and involves a very small number of companies (e.g. Argo, CNH and SDF –Section 2.4), although limited numbers are produced elsewhere (e.g. Far East and Eastern Europe). Italy is the largest market within the EU for these machines.

Anecdotal information provided by one Italian C1 / C2 crawler tractor manufacturer suggested their own annual production amounted to 300 – 500 units, the majority of which were supplied to the home market; but this quantity included both 'narrow' (C2) and 'standard-width' (C1) models. However, the major industry stakeholder (CEMA) has estimated that in 2013, approx. 3,414 C2 tractors were marketed within the EU28. This does seem to be a large number of units for a relatively specialist vehicle which is used in relatively few Member States, but CEMA has verified the data with the three manufacturers mentioned above. Apparently 2013 was a particularly good year for C2 sales and volumes may reduce slightly in subsequent years, but it is predicted that any reduction will not be substantial.

2.2.3 C2 tractors: Operational uses

C2 narrow-track crawlers are almost exclusively used in vineyards and orchards, performing a similar range of in-field operations to those undertaken by wheeled T2 narrow-track tractors (Section 2.1.2). However, whilst the greater ground contact area provided by the vehicle's tracks enables track-laying tractors to develop higher levels of tractive effort than wheeled tractors, the absence of any form of compliant suspension severely limits their maximum forward speed (typically ≤ 12 km/h).

Consequently, whilst the additional track-soil grip and inherent low centre of gravity makes C2 tractors very well-suited to performing operations in steeply-sloping vineyards and orchards, their slow speed and unsuitability for on-road use makes them unsuited for transport applications. These attributes also restrict their adaptability and market appeal. C2 tractors therefore remain very specialist machines.

2.2.4 Summary

In general C2 tractors can be used on slopes that T2 and T4.1 tractors cannot. This is not only because they are tracked, but also their low CofG. They are used in the hilly agricultural regions of France, Italy, Portugal and Spain. Due to their design they are not permitted to be used for road transport.

Regarding annual usage, typical lifespan and consequent likely fleet size, C2 manufacturers estimate annual usage of these vehicles to be 350 – 650 hours per year, reflecting their somewhat less versatile nature compared to a wheeled T2. Corresponding lifespan is estimated to be, on average, 16 years with a typical range of 10 – 20 years, depending upon the customer. Initial data suggesting European sales of approximately 500 new C2 tractors per year was obtained, however subsequent data for 2013 suggested 3,414, the likely fleet size is considered further in Section 5. The total fleet size estimated to be 56,331.

2.3 Category T4.1: High-clearance wheeled tractors

2.3.1 T4.1 tractors: Design characteristics

T4.1 or High-Clearance Tractors (HCTs) fall within the EU type-approval category of 'special purpose wheeled tractors'. They incorporate raised chassis to enable them to straddle and travel along the rows of tall growing crops (> 1 m high) such as vines, olives, field-scale soft fruit, sugar cane, tobacco and many others.

High-clearance tractors are an established vehicle type: specialist conversions of standard wheeled or track-laying tractors have been produced in relatively small numbers for special applications ever since conventional tractors became widely used in agriculture. However, as levels of agricultural mechanisation and labour costs have increased, so has the demand for productive, efficient specialist vehicles, tailored to suit the requirements of specific applications. In the case of T4.1 HCTs within the EU, the key operating environment is vineyards with narrow-spaced rows (0.9 – 1.5 m). HCTs are designed to carry and/or power implements / tools mounted on the front or rear, between the front and rear wheels, or even on a load-carrying platform above the crop rows. These attached implements will operate both on the row(s) being straddled and also on part / all of the immediately-adjacent crop rows.

Although the general characteristics of HCTs are defined by the current type-approval text (Directive 2003/37/EC), no approval criteria are specified. The vast majority of these machines are produced by a small number of French manufacturers. Issues regarding HCT safety (slope stability and operator rollover protection) resulted in the introduction of rigorous national type-approval requirements for HCTs marketed in France. To address the shortfall of 2003/37/EC, the forthcoming EU type-approval Regulation (EU) 167/2013 has adopted technical elements of the French national requirements. It defines T4.1 high-clearance tractors as:-

> *"… tractors designed for working with high-growing crops, such as vines. They feature a raised chassis or section of chassis, enabling them to advance in parallel with the crop with left and right wheels on either side of one or more rows of crop. They are intended for carrying or operating tools which may be fitted at the front, between the axles, at the rear or on a platform. When the tractor is in working position the ground clearance perpendicular to the crop rows*

> *exceeds 1000 mm. Where the height of the centre of gravity of the tractor (measured in relation to the ground), using the tyres normally fitted, divided by the average minimum track of all the axles exceeds 0.90, the maximum design speed shall not exceed 30 km/h"*

Vehicle manoeuvrability and slope stability are both important characteristics of HCTs, because the narrow-row vineyards which utilise these machines are typically planted on sloping sites and, to maximise productivity, headlands and field margins are of limited size. Whilst the majority of HCT incorporate four-wheel drive, most only feature front axle (as opposed to front and rear axle) steering.

Unlike conventional tractors, which usually utilise the structural properties of the engine and transmission casings to form the vehicle chassis, modern T4.1 tractors are constructed on a framework principle. This approach, together with the use of hydrostatic drivelines to the driving wheels, permits a large degree of flexibility with regard both to vehicle configuration and component location. Consequently in the case of one or two-row straddle HCTs (two or three-row treatment), it is feasible for the power unit to be located above the crop / vehicle main frame, either behind the operator's cab or side-mounted in line with the left or right-hand wheels (Figure 18 and Figure 19).

Alternatively, for two-row straddle (three-row treatment) machines, the engine may be located below the main frame in a centrally-mounted nacelle, designed to pass between the two crop rows being straddled (Figure 20). This has the advantage of lowering the machine's centre of gravity and improving slope stability. Apparently, designs of this type are increasing in popularity to the point where they represent the majority of HCTs variants currently sold (Section 2.3.3). More complex HCT models even offer adjustable wheel track widths (by hydraulic adjustment of the chassis width), to suit different crop row widths (Figure 20).

The majority of T4.1 high-clearance tractors fall in the 70 – 110 kW engine power range, but larger machines, designed to accept harvesting equipment in place of other attached implements used during the year, offer higher engine power levels, some approaching 140 kW. However, care is needed to differentiate between T4.1 high-clearance tractors and dedicated, self-propelled grape / olive harvesting machines (Section 2.3.2).

It should be emphasized that specialised variants of T4.1 high-clearance tractors are also produced in alternative formats (e.g. 3-wheel as opposed to 4-wheel), albeit in small numbers, to suit specific customer requirements. Due to the considerable design flexibility permitted by the generic method of HCT construction, packaging of both the powerplant and any exhaust after-treatment components should perhaps be less challenging than in the case of T2 or C2 tractors, where available space is more restricted (Section 4).

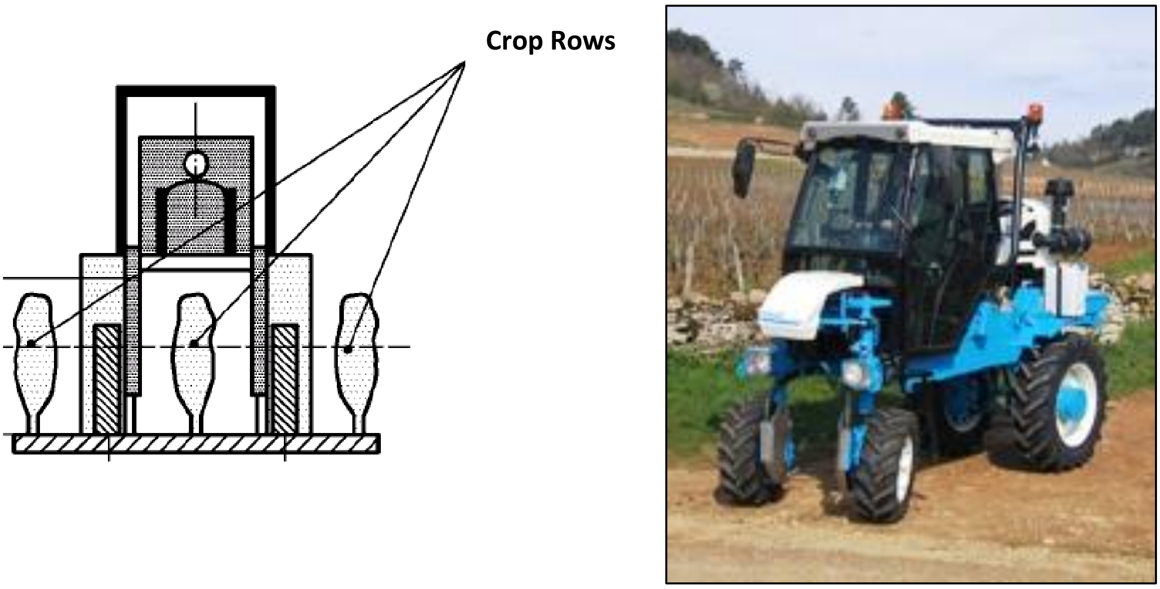

Figure 18: T4.1 high-clearance tractor designed to straddle a single crop row

(Copyright IRSTEA & Bobard)

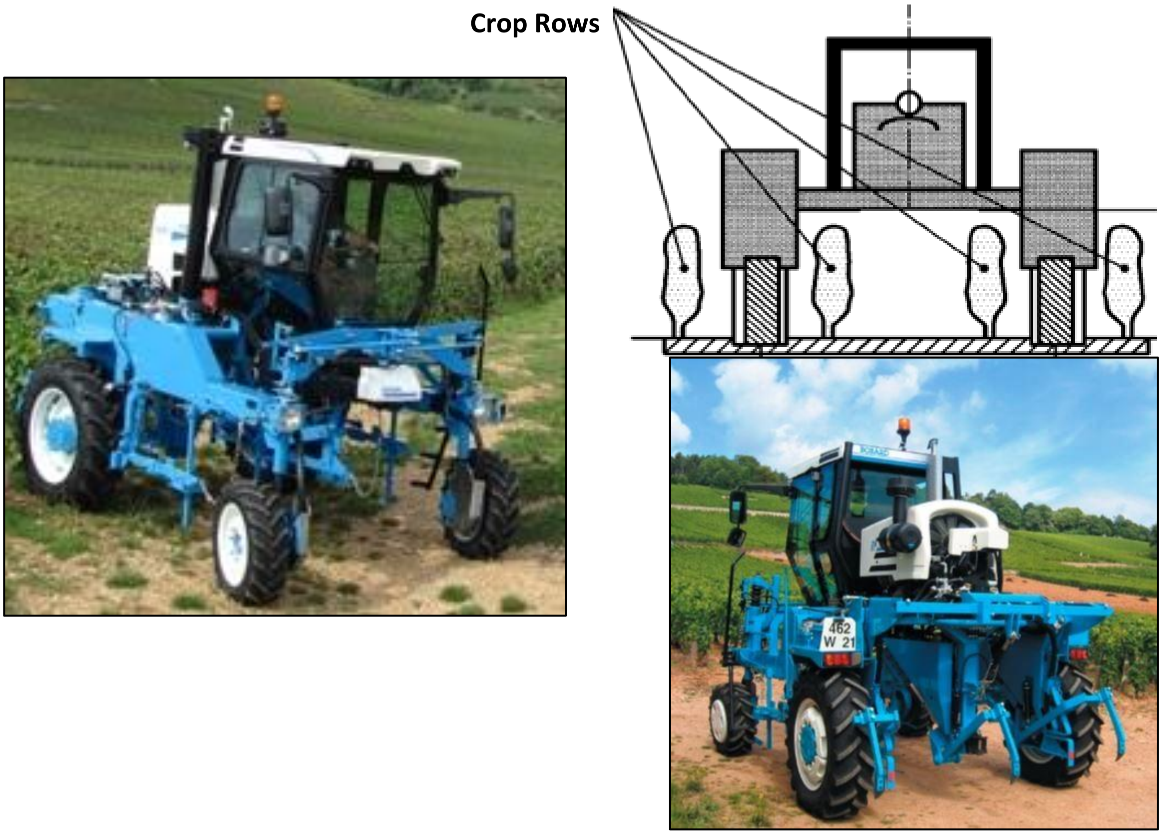

Figure 19: T4.1 high-clearance tractors designed to straddle two crop rows

(Copyright IRSTEA & Bobard)

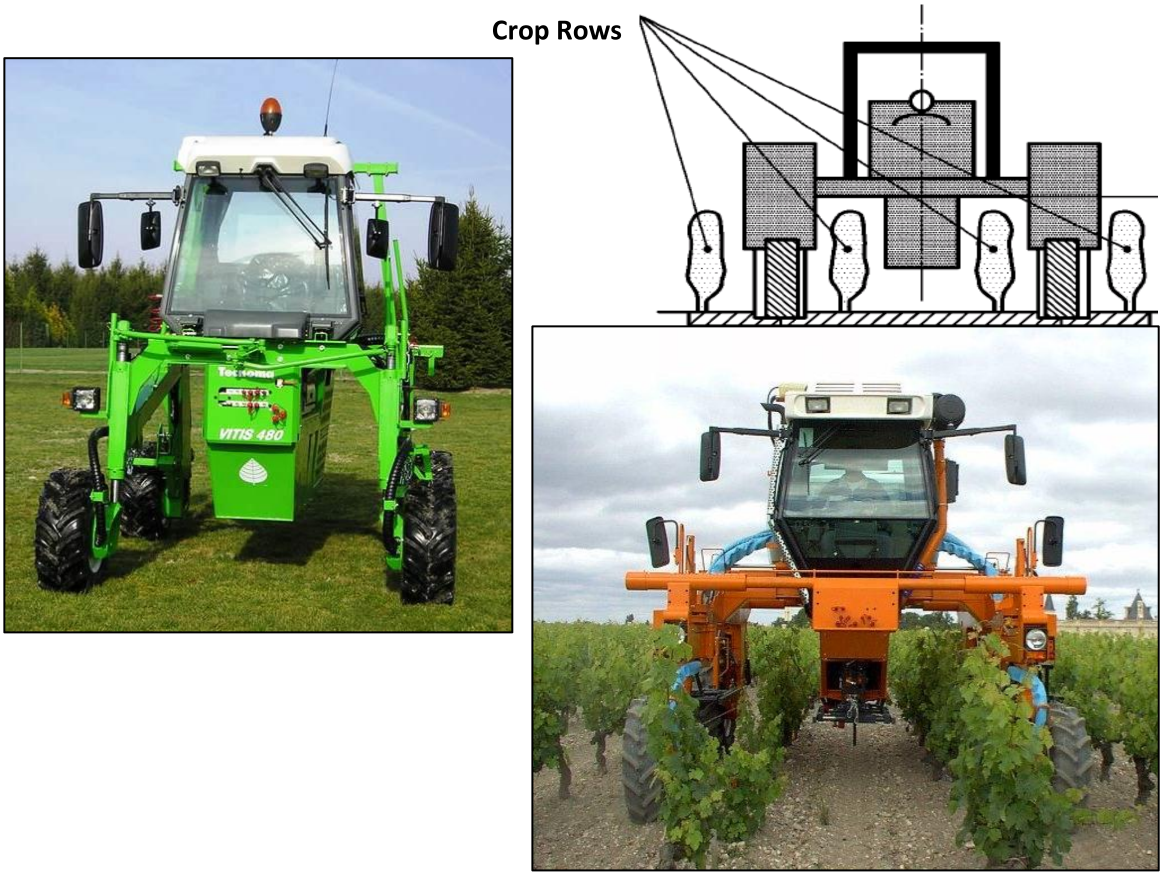

Figure 20: T4.1 high-clearance tractors designed to straddle two crops rows, fitted with a low-slung, centrally-mounted engine

(Copyright Tecnoma & FREMA)

2.3.2 T4.1 tractors: Fleet size

T4.1 high-clearance tractors (HCTs) are almost exclusively manufactured in France by a small number of generally small companies (≤ 5). Even the inclusion of manufacturers of self-propelled grape harvesters, who also are mainly located in France and in certain instances also produce T4.1 tractors, does not bring the total number of manufacturers to 10 (Section2.4).

France remains the primary marketplace for these vehicles, accounting for approximately 95% of HCT production[3], but they are also penetrating other wine-growing regions, both within the EU and worldwide (e.g. northern Italy, USA, South America, Australia and New Zealand). Indeed, as levels of vineyard mechanisation increase, there appears to be a general trend in most wine growing regions towards narrower row spacing, primarily to improve crop yield. Such growing systems are only feasible with over-the-row T4.1 tractors and associated equipment (Morris, 2000 and Franson, 2008).

Previous studies (ARCADIS, 2010) have estimated the total annual market for T4.1 high-clearance tractors to be approximately 500 to 600 units per year. The T4.1 manufacturers consulted by that study commented that volume sales were gradually reducing, but that machine complexity and capability was increasing. This mirrors the trend in other specialist self-propelled agricultural vehicles, where man-machine productivity is enhanced, but at the expense of overall unit sales volumes. The manufacturers consulted also estimated the economic lifetime of a T4.1 HCT to be 7 –

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[3] AXEMA data (2014)

10 years, beyond which annual maintenance / repair costs were likely to increase significantly.

The French agricultural machinery manufacturers' trade association (AXEMA) provided updated estimates of these data. Current sales of new T4.1 tractors within the EU are estimated to be approximately 500 units p.a., of which ~25% are of 1-row straddle design and the remaining ~75% are 2-row straddle types, the latter having gained popularity both because of their improved slope stability characteristics and their capacity for higher (multiple-row) productivity. Interestingly, 2-row straddle machines with a centrally-mounted, low-slung engine (Figure 20 and Figure 21) now account for 60% of total T4.1 sales, primarily due to their further enhanced stability characteristics over other 2-row HCT designs. Those 2-row machines with higher-mounted engines (e.g. above the load platform – Figure 19) only represent 15% of annual sales.

AXEMA estimate that T4.1 annual usage varies from 200 hours p.a. (small farms) up to 1000 hours p.a. (contractors and large vineyards / wineries): however, smaller farms currently account for a majority of vehicle sales and so average annual use across the T4.1 fleet would probably be approximately 400 hours p.a.

As concluded by the previous study (ARCADIS, 2010), machine frontline operating life is likely to be approximately 7-10 years[4], depending of course upon annual usage levels. However, it is apparently common for machines to subsequently experience a second life (at reduced annual usage levels), of up to 10 years. This may either be on the same farm or upon a smaller farm which inherently imposes lower annual usage upon its equipment.

2.3.3 T4.1 tractors: Operational uses

Within the EU, T4.1 high-clearance tractors (HCTs) are primarily used for all operations within vineyards with very narrow row spacing (e.g. 0.9 – 1.5 m). As illustrated by Figure 5, ultra-narrow T2 tractors (and their C2 counterparts) can operate between vine rows of ≥ 1.8 m spacing, but narrower row spacing requires a vehicle which can straddle the rows and operate above the crop. Such cultural trends and consequent demand for HCTs originated in the Bordeaux, Bourgogne and Champagne regions of France, but are now being adopted by other intensive wine growing areas outside the EU (Morris, 2000 and Franson, 2008). The side-slope stability of an appropriately-designed HCT is claimed to be superior to an ultra-narrow T2 tractor and therefore is better-suited to operating in vineyards located on slopes.

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[4] AXEMA data (2014)

Figure 21: Two-row T4.1 crop spraying in a narrow-row vineyard

(Copyright Tecnoma)

Small numbers of HCTs are used in other crops, but the vast majority are used for vineyard operations. These include those operations outlined within Table 4 and Table 5, such as wire-lifting, agrochemical application (spraying), fertiliser application, light-duty inter-row cultivation, vine trimming, leaf removal, pre-pruning and pruning. As shown in Table 3, the most intensive of all these operations during the growing season is crop spraying (Figure 21). As mentioned in Section 2.3.1, certain higher-powered HCTs also accept grape harvesting equipment, but this operation is frequently performed by other dedicated self-propelled machines or, in the high-quality vineyards which often favour narrow row spacing and therefore use HCTs, by hand. In such instances an HCT is frequently used to transport baskets of harvested grapes (on its rear load platform) to the roadside, for trans-shipment and transport to the winery.

It is important to recognise that not every high-clearance, straddle-row agricultural vehicle which operates in a vineyard is necessarily a T4.1 high-clearance tractor. Self-propelled grape harvesters and certain types of specialist self-propelled sprayer may appear to be of similar design and construction to HCTs, but these machines do not fall within the T4.1 type-approval category. Self-propelled grape-harvesting machines are becoming increasingly popular and are an integral component of a fully-mechanised vineyard. These machines straddle the crop rows and mechanically harvest and clean the crop, before transferring it in bulk for transport from the vineyard. Not surprisingly, given their common operating environment, the generic construction of self-propelled grape harvesters is extremely similar to that of T4.1 high-clearance tractors (Figure 22). To further complicate the issue, in order to improve their utilisation throughout the season and help justify their substantial unit cost, many grape harvesters are designed so the harvesting equipment modules may be removed and substituted with other equipment for crop spraying, trimming, pre-pruning or other dedicated crop treatment purposes (Figure 23). The machines have in effect, evolved into multi-purpose tool carriers. Certain T4.1 models are also designed to perform the same multi-purpose tool carrier (and harvester) functions.

Figure 22: Typical self-propelled grape harvesters

(Copyright New Holland & Pellenc)

Figure 23: Self-propelled grape harvester with demountable harvesting equipment. Harvesting unit fitted (left) and removed (right) to accept other equipment

(Copyright New Holland)

Arguably it is possible for a self-propelled grape harvester of modular construction (Figure 23) when fitted with appropriate attachments, to perform a similar range of tasks to a T4.1 high-clearance tractor. Larger vineyard enterprises may conceivably be able to justify examples of both vehicle types, but this is an issue of the mechanisation system employed rather than of vehicle design. It is claimed that self-propelled grape harvesters are generally of larger dimensions than T4.1s and are therefore unsuited to operation within narrow row-spacing vineyards. This may be the case in certain instances but, as previously mentioned, certain T4.1s are offered which will straddle either one or two crop rows (down to 0.9 – 1.0 m spacing), and accept normal vineyard implements and also harvesting equipment. Such vehicles are of comparable wheelbase (and therefore of comparable manoeuvrability) to other T4.1s, although it is not known whether their slope stability characteristics would enable them to operate on steeply-sloping vineyards.

Regarding this particular investigation, a consequence of this technological progress is as follows. A self-propelled grape harvester or self-propelled sprayer is categorised within the EU as a self-propelled agricultural machine or Non-Road Mobile Machine (NRMM). As such the power units installed in these machines must in theory comply with the exhaust emissions requirements stipulated by current EU Legislation (Directive 97/68/EC): they do not qualify for the derogation currently applied to T4.1 high-clearance tractors (Directive 2011/87/EU). However, given the similarity in design, construction and operational application between self-propelled grape harvesters and high-clearance tractors, it may be questioned that, if the former can accommodate engines featuring the latest exhaust gas emissions technology, why not can vehicles of the T4.1 type? Closer examination of this issue has shown that, in fact, many self-propelled grape harvesters still utilise Stage IIIA-compliant engines, rather than those meeting the most recent emissions requirements. Nonetheless, it seems likely that a great deal more space is available to accommodate exhaust gas after-treatment equipment on T4.1 tractors than in the case of either C2 or T2 vehicles. This issue is discussed in more details in Section 4.4.

2.3.4 Summary

T4.1 or High-Clearance Tractors (HCTs) straddle one or more rows of crops, traveling >1 m over the crop. The total fleet size is estimated to be 8,250 (EU28, 2013) with 500 new T4.1 tractors sold in Europe annually. It is estimated that ~25% of the population above straddle 1-row, with the remaining ~75% straddle 2-rows. The vehicles typically work with crop row widths of 0.9 – 1.5 m. Crop planting methods excepted, they can be used in the same locations (gradient, tasks, etc.) as T2 tractors. Conversely, due to their design they are not permitted to be used for road transport.

Typical power levels range between 70 – 110 kW, although some reach +130 kW. Implements are mounted between the rows, in the front of a low slung engine and/or mounted. T4.1 tractors have an estimated annual usage of 200 – 1,000 hours, average 400 hours, with a first life usage (high intensity) between 7 - 10 years, and a second life usage of up to 10 years.

2.4 Industry structure

The World tractor market is dominated by a relatively small number of companies, many of which are global operations in terms of design and production facilities (Table 6). Many of these manufacturers market product across a number of brand names and, with the partial exception of Kubota, manufacture and/or market product across the entire T1 tractor power range (e.g. 30 – 200 kW). Most of these companies also market rigid-chassis vineyard / orchard T2 tractors (Table 7) while, as discussed in Section 2.1, a number (e.g. Claas, Massey Ferguson and John Deere) co-engineer their T2 products in association with an Italian manufacturer which specialises in the design and production of such vehicles (Agritalia). Note none of the tables in the Section are exhaustive lists of the sector's manufacturers, but aims to include the vast majority of the organisations.

Table 6: Global tractor manufacturers and associated brands

Parent Company / Manufacturer	Product Brand
AGCO	Fendt
	Massey Ferguson
	Valtra
Argo Tractors	Landini
	McCormick
	Valpadana
Claas	Claas
CNH Industrial	Case-IH
	New Holland
John Deere	John Deere
Kubota	Kubota

Parent Company / Manufacturer	Product Brand
Same Deutz-Fahr (SDF)	Deutz-Fahr
	Hurlimann
	Lamborghini
	Same

Whilst a very small number of global manufacturers produce C2 track-laying tractors, (Table 9) only one, (Argo Tractors) currently produces articulated-chassis T2 vehicles. The manufacture of these specialist (vineyard / orchard) T2 vehicles remains the preserve of a limited number of smaller manufacturers (Table 8), the majority of which are located in Italy.

Table 7: Manufacturers and product brands of rigid-chassis T2 tractors

Parent Company / Manufacturer	Product Brand	Engine Supplier / Manufacturer	Comments
AGCO	Fendt	AGCO Power (SISU)	Vehicle built in-house
	Massey Ferguson		Produced by Agritalia
Argo Tractors	Landini	Perkins** / FPT*	Same product platform – different brands
	McCormick		
Carraro (Agritalia)	Carraro	FPT	-
Claas	Claas	FPT	Produced by Agritalia
CNH Industrial	Case-IH	FPT	Same product platform – different brands
	New Holland		
John Deere	John Deere	FPT (Stage IIIB)	Produced by Agritalia
Kubota	Kubota	Kubota	-
Same Deutz-Fahr (SDF)	Deutz-Fahr	SDF (Stage IIIB)	Same product platform – different brands
	Hurlimann		
	Lamborghini		
	Same		
Sauerberger	Sauerberger	John Deere	Minor manufacturer

Note: * -FPT = Fiat Powertrain Technologies (IVECO Engine Group)

** -This Perkins engine shares a common engineering platform with the FPT F5C engine used in many other rigid-chassis T2 tractors

Table 8: Manufacturers and product brands of articulated-chassis T2 tractors

Parent Company / Manufacturer	Product Brand	Engine Supplier / Manufacturer	Comments
Agromehanika	Agromehanika	Lombardini	-
Argo Tractors	Valpadana	Cummins / John Deere / Yanmar	-
Antonio Carraro	Antonio Carraro	Deutz / Kubota / V.M. Motori / Yanmar	-
BCS	BCS	V.M. Motori	Largely common product platforms – different brands
	Ferrari		
	Pasquali		
Goldoni	Goldoni	V. M. Motori	-

Parent Company / Manufacturer	Product Brand	Engine Supplier / Manufacturer	Comments
Holder	Holder	Deutz	Also supplies dedicated products for municipal use

Regarding the engines which currently power T2 and C2 tractors, a number of manufacturers (e.g. AGCO, CNH Industrial, SDF and Yanmar) utilise power plants produced by other divisions of their parent companies (e.g. AGCO Power, Fiat Powertrain Technologies (FPT), Fahr Motion and Yanmar). FPT and Yanmar engines are also utilised by other T2 manufacturers. Table 7 indicates that FPT engines, or rather a single engine family within the FPT product range (and its derivatives marketed by Perkins) are the most commonly-used power plants in rigid-chassis T2 tractors. The same powerplant is also currently found in CNH and Argo C2 track-laying tractors (Table 9). This is not surprising as C2 tractors typically utilise a high proportion of powertrain components from in-house rigid-chassis T2 vehicles in order to reduce production costs of these low-volume machines.

Consequently, if rigid-chassis T2 tractors and C2 tractors continue to source engines from their existing suppliers over the next 2-4 years, it may be suggested that the ease with which these vehicles can satisfy future (Stage IV) emission requirements will be heavily-dependent upon developments in engine technology and consequent product availability from a very small number of diesel engine manufacturers. Given that individual off-highway diesel engine product families are typically expected to have a useful product life in the marketplace of at least 15 years, vehicle manufacturers are somewhat dependent upon engine manufacturers maintaining product development at an adequate pace. However, engine manufacturers are only too aware of the demands of forthcoming exhaust emissions legislation and the need to offer compliant products to their customers. In the majority of cases the same engine manufacturers are making compliant products for other vehicles which need to meet Stage IV or equivalent testing.

A greater diversity of powerplant manufacturers supply the articulated-chassis T2 tractor market (Table 8). This is in part a consequence of the wider power range covered by such vehicles (e.g. ~19 – 75 kW) compared with rigid-chassis (vineyard/orchard) T2s, the majority of which are of > 56 kW engine power (Section 2.1). All manufacturers of articulated-chassis T2s source their engines from external suppliers, Deutz, Yanmar and V.M. Motori (part of the Fiat Group) being the most common.

It can be debated whether or not it is advantageous for a tractor manufacturer to be able to source power plants from another division within its parent company. In practice, within large global corporations, different divisions operate as separate business units. Indeed such in-house engine manufacturers must actively court external customers and supply product to other (competitor) tractor manufacturers in order to ensure economic survival. Tractors manufacturing divisions within large corporate groups may perhaps recognise the advantages likely to result from engaging with the (in-house) engine manufacturer at an earlier stage in the vehicle development process, so that certain (perhaps bespoke) engineering requirements may be considered. This aspect is potentially of increasing importance as engine emission requirements become more demanding and the consequent complexity of exhaust gas after treatment systems increases and perhaps should be given greater consideration by manufacturers who produce diverse designs of tractor in relatively small volumes.

Table 9: Manufacturers and product brands of C2 track-laying tractors

Parent Company / Manufacturer	Product Brand	Engine Supplier / Manufacturer	Comments
Argo Tractors	Landini	Perkins[**] / FPT[*]	Same product platform – different brands
	McCormick		

Parent Company / Manufacturer	Product Brand	Engine Supplier / Manufacturer	Comments
CNH Industrial	Case-IH	FPT	Same product platform – different brands
	New Holland		
Same Deutz-Fahr (SDF)	Deutz-Fahr	Deutz (Stage IIIA) / SDF (Stage IIIB)	Same product platform – different brands
	Same		
Yanmar	Yanmar	Yanmar	-

Note: * - FPT = Fiat Powertrain Technologies (IVECO Engine Group)

** -This Perkins engine shares a common engineering platform with the FPT F5C engine used in CNH C2 tractors and many other rigid-chassis T2 tractors

As discussed in Section 2.3.1, T4.1 high-clearance tractors (HCTs) are manufactured by a small number of generally small companies (Table 10). Even the inclusion of manufacturers of self-propelled grape harvesters, certain of whose products can (with adaptation) perform certain of the functions of a T4.1, does not bring the total number of manufacturers to 10.

T4.1 tractors are constructed on a structural framework principle and utilise hydrostatic drivelines to the driving wheels (Section 2.3.1): these features combine to permit a large degree of flexibility with regard both to vehicle configuration and component location. This flexibility reduces restrictions in choice of power plant which, in all instances, are sourced from dedicated engine manufacturers (Table 10). The typical power ranges of T4.1 tractors (primarily 70 – 110 kW, but up to ~140 kW) means that the engines fitted to these vehicles are not usually from the same product families as those found in T2 and C2 tractors.

Table 10: Manufacturers and product brands of T4.1 high-clearance tractors

Parent Company / Manufacturer	Product Brand	Engine Supplier / Manufacturer	Comments
Bobard	Bobard	Perkins	Extensive range of different vehicle models / designs
Excel Group	Tecnoma (Preciculture)	Deutz	Extensive range of different vehicle models / designs
Frema	Frema	Not known	Extensive range of different vehicle models / designs + scope for bespoke designs
Same Deutz-Fahr (SDF)	Gregoire	Perkins / Deutz	Produces both T4.1s and S.P. grape harvesters
Manufacturers of S.P. grape harvesters			
CNH Industrial	Braud	FPT	Manufacturers of S.P. grape harvesters, NOT T4.1s. But harvesting units can be demounted and replaced with other vineyard implements
Pellenc	Pellenc	John Deere	

2.5 Summary

T2 tractors comprise of two distinct sub-types, rigid and articulated chassis. The former being similar in shape to conventional T1 category tractors, while the latter are generally designed to be shorter to travel under overhanging crops.

- The total fleet size is estimated to be 358,859 (EU28, 2013)
- 21,750 new T2 tractors are sold in Europe annually
- Approximately 50% have engines of ≥56 kW
- They are less than 1150 mm wide and weigh over 600 kg
- Implements may be rear, front or mid mounted
- Estimated annual usage of 300 - 1200 hours. The average being 650 hours
- First life usage (high intensity) between 7 - 10 years
- Second life of 15 - 20 years

C2 tractors are both narrow and tracked; they are able to traverse the steepest terrain of the three categories.

- The total fleet size in is estimated to be 56,331 (EU28, 2013)
- 3,400 new C2 tractors are sold in Europe annually
- Typical power levels range between 50 – 75 kW
- They are less than 1150 mm wide and weigh over 600 kg
- Implements are typically either rear mounted or pulled
- Estimated annual usage of 350 – 650 hours
- Average lifespan of 16 years, ranging from 10 – 20 years

T4.1 or High-Clearance Tractors (HCTs) straddle one or more rows of crops, traveling >1m over the crop

- The total fleet size is estimated to be 8,250 (EU28, 2013)
- 500 new HCT tractors are sold in Europe annually
- Typical power levels range between 70 – 110 kW, although some reach +130 kW
- Approximately 25% straddle 1-row remaining; approximately 75% straddle 2-rows
- Work with crop row widths of 0.9 – 1.5 m
- Implements are mounted between the rows, in the front of a low slung engine and/or mounted
- Estimated annual usage of 200 – 1,000 hours, average 400 hours
- First life usage (high intensity) between 7 - 10 years,
- Second life up to 10 years

The section on the industry structure found that engines and tractors are generally produced by separate companies. However, these companies can sometimes be of the same overall group. T2 narrow tractors are the most popular of the three categories under consideration with 14 companies that produce the tractors incorporating many brands. Four narrow and tracked C2 category tractors have been identified, most of which also make T2 tractors. Seven T4.1 high clearance tractor manufacturers have been identified, the majority of which are specialists in this sector. Further details of the industry structure are given in Section 2.4.

3 Assessment of technology solutions (Task 3)

This section details the technical solutions both in use and in development that are used to meet the previous and upcoming emission stages.

At the time of the granting of the original derogation (by Directive 2011/87/EU) for the engines used in category T2, C2 and T4.1 tractors, a limited number of potential exhaust after-treatment (EAT) technologies had been identified by manufacturers of off-highway engines. However, it was recognised that without further development, these specific technologies might not be suitable for installation upon Narrow Track Tractors (NTTs), due to the packaging constraints imposed by the design characteristics of these vehicles and their restricted space.

Tractor manufacturers typically buy engines as complete solutions from a small number of manufactures (note these are sometimes subsidiaries of the same group). These engines can be developed and type-approved separately from the vehicles, under Directive 2000/25/EC of the European Parliament and of the Council. Emission abatement equipment (which can include multiple configurations of EAT technologies and exhaust pipework) forms an integral part of any given engine's type approval.

To understand the criteria used in selecting appropriate emission abatement strategies an overview of the emission limits is essential.

3.1 Emissions

3.1.1 Engines and emission limits

An engine for use in Non-Road Mobile Machinery (NRMM) is categorised by both the engine power and emission stage: Table 11 correlates the engine power against the associated emission stage. Where a category (letter code) is not specified for an engine power in a subsequent stage the previous stage remains applicable

Table 11: Relevant engine power range categorisation for emission stages (2000/25/EC as amended) (Stage V draft regulation)

Engine power (kW)	Stage I	Stage II	Stage IIIA	Stage IIIB	Stage IV	*Stage V*
130 ≤ 560	A	E	H	**L**	**Q**	*NRE-#-6*
75 ≤ 130	B	F	I	**M**	**R**	*NRE-#-5*
56 ≤ 75	C	G	J	**N**		
37 ≤ 56				**P**	←	*NRE-#-4*
18/19 ≤ 37	-	D	K	←	←	*NRE-#-3*
18/19	-	(18 ≤ P)	(19 ≤ P)	←	←	*NRE-#-2/1*

The emission targets for the vehicles are defined as "Engines for use in other applications than propulsion of inland waterway vessels, locomotives and railcars". Directive 97/68/EC, Article 9 details the timetable for implementation of the relevant emission targets. Annex I of the directive shows the targets for Stages IIIA, IIIB and IV, as emissions of: carbon monoxide, hydrocarbons, oxides of nitrogen or the sum of hydrocarbons and oxides of nitrogen and the emissions of particulates (mass) as g/kWh. These are shown in Annex 2, Table 28 of this report. In addition, the draft values for Stage V from the draft regulation are shown at the end of the table, at the time of writing this was still being reviewed by the European Parliament, therefore the values it contains as well as the implementation dates could change.

Stage V (draft) changes the measurement of particulates, both reducing the limit for particulate mass, but also adding the requirement to measure particle number for engines with power ranging from 37 to 560 kW. All other emission limits (CO, HC, and NOx) remain unchanged.

3.1.2 Emission generation

Tractors are predominately fitted with diesel engines. Diesel engines have an open throttle and typically run with a lean mixture (i.e. with excess oxygen in the combustion chamber). In comparison, a petrol engine would have a throttled intake and operate under stoichiometric conditions most of the time (i.e. the exact amount of fuel and oxygen to ensure the complete usage of both during combustion). In diesel engines, the fuel is injected directly into the combustion chamber, where the amount of fuel and the timing (relative to top dead centre on the compression stroke) affects the power available and also the resulting emissions.

Although the diesel exhaust emissions will consist of a variety of pollutants, the two regulated emissions relevant to the study are oxides of nitrogen (NOx) and particulate matter (PM), which are covered by Stage IV and IIIB & V respectively.

- NOx is a mixture of nitric oxide (NO) and nitrogen dioxide (NO2), which is created when combustion occurs in the presence of nitrogen. High temperatures and high concentration of excess oxygen increase the levels of NOx generated. Reduction of NOx is the target of the Stage IV emission limits.
- PM, also known as soot, consists of small particulates and/or liquid droplets. Low temperatures increase the emissions of PM. These can be reduced by combustion under high temperatures. PM reduction is implemented in Stages IIIB and V.

NOx and PM emissions can be both related to respiratory problems. The European Environment Agency states for NOx that:

> *"NO_X contributes to acid deposition and eutrophication which in turn can lead to potential changes occurring in soil and water quality. The subsequent impacts of acid deposition can be significant, including adverse effects on aquatic ecosystems in rivers and lakes and damage to forests, crops and other vegetation."*
>
> *"It is NO_2 that is associated with adverse affects on human health, as at high concentrations it can cause inflammation of the airways. NO_2 also contributes to the formation of secondary particulate aerosols and tropospheric ozone (O_3) in the atmosphere - both are important air pollutants due to their adverse impacts on human health. NOx is therefore linked both directly and indirectly to effects on human health." (European Environment Agency, 2013)*

And for PM that:

> *"In recent years scientific evidence has been strengthened by many epidemiological studies that indicate there is an association between long and short-term exposure to fine particulate matter[5] and various serious health impacts. Fine particles have adverse effects on human health and can be responsible for and/or contribute to a number of respiratory problems."*
>
> *"A large fraction of the urban population is exposed to levels of fine particulate matter in excess of limit values set for the protection of human health. There have been a number of recent policy initiatives that aim to control particulate concentrations and thus protect human health." (European Environment Agency, 2014)*

There is generally a trade-off between NOx and PM emissions, where low combustion temperatures results in lower emissions of NOx but higher emissions of PM. High combustion temperatures cause the opposite effect.

In addition, the fuel consumption will be of interest to the end user because it affects running costs and the CO_2 emissions, which are linked to fuel consumption and are relevant to the reduction of greenhouse gas contribution.

---

[5] Fine particles in this context refer to primary particulate matter (PM2.5 and PM10) and emissions of secondary particulate matter precursors (NOX, SO2 and NH3).

Primary PM2.5 and PM10 refers to fine particles (defined as having diameter of 2.5 μm or 10 μm or less, respectively) emitted directly to the atmosphere.

Secondary particulate matter precursors are pollutants that are partly transformed into particles by photo-chemical reactions in the atmosphere.

3.2 Current technologies (Task 3.1)

Since 2011, tractor manufacturers have introduced a variety of EAT solutions to enable their vehicles to meet Stage IIIB exhaust emission requirements. These have either supplemented the developments in engine technology which enabled compliance with Stage IIIA requirements or form part of a new engine platform for use in the following emission stages. The latter include, but not limited to:

- turbocharging and intercooling;
- high-pressure common rail (HPCR) fuel injection systems;
- electronic control of fuel injection quantity and timing (ECU);
- cooled, external exhaust gas recirculation (C-EGR); and

These technologies are detailed below, including further developments that may be beneficial for the NTTs to meet Stage IV.

Note, all of these technologies are not limited to tractors, but are used on other NRMM, LD and HD vehicles. However they will have differences in characteristics such as size and flow rate to match the needs of a given engine and its applicable emission legislation.

3.2.1 Engine aspiration (Turbo charging)

A turbocharger forces extra air into the combustion chamber which increases the engine's efficiency and power. The differing pressure within a turbo charged engine also changes the emission generating characteristics of the engine. Namely reducing the CO creation (Figure 24), but increased heat within a cylinder increases NOx creation.

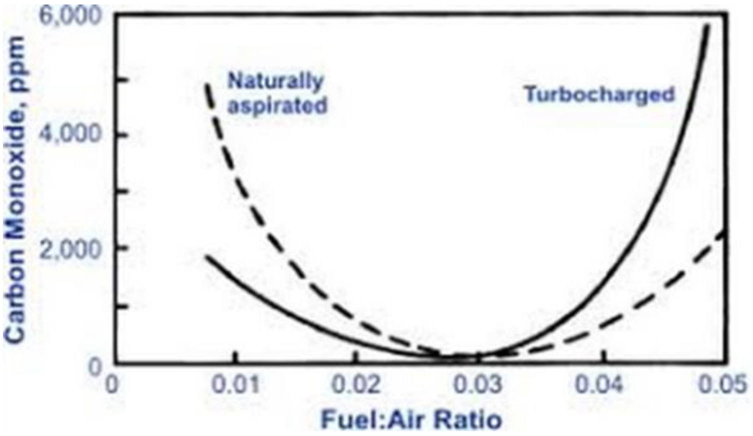

Figure 24: Change to CO emission with aspiration (reproduced from Emission Formation in Diesel Engines (Magdi K. Khair, Hannu Jääskeläinen)

The majority of diesel engines used for tractive power in operation today are fitted with a turbocharger.

The turbocharger is driven by a turbine powered by the engine's exhaust gas, recovering energy from the exhaust that would otherwise be lost. However, the size of the turbocharger needs to be carefully selected for the engine size and the expected duty-cycle. A large turbocharger will generate more power from the engine. However, it will take more heat and pressure from the exhaust to spin the turbine. This can result in turbo lag, defined as the time required to change the power output in response to a throttle change. A small turbocharger will react and begin spinning more quickly reducing turbo lag, but it will not have the same performance at higher power demands, possibly restricting the airflow. A number of advanced options are now established technology solutions to deal with this:

- Two stage turbochargers consist of one small and one large turbo charger. The small turbocharger is used at low engine speeds to reduce turbo lag. At high engine speeds the larger turbo is used, providing the higher power. The turbochargers are generally arranged in series, with a bypass valve regulating the exhaust flow to each.

- Variable geometry turbochargers (VGT) use movable vanes to adjust air flow through the turbine. This results in the optimal sized turbo throughout the engine revolution range.

Although there are potential space savings to be made, some stakeholders stated that VGT is not considered viable for these vehicles. However, VGT is fitted to NRMM engines ≥56kW by some engine and tractor manufacturers for Stage IIIB. (John Deere, 2010) (Tina Grady, 2010)

3.2.2 High pressure common rail (HPCR)

The droplet size injected into the engines cylinder greatly effects the creation of PM and HC. By electronically controlling the injection of fuel, using high pressure common rail, greater control is afforded, permitting a reduction in HC emissions.

The move from mechanical injection to HPCR (1,000 bar) occurred in previous emissions stages. Current developments to reduce PM emissions include increasing the injection pressures to 2,000 - 3,000 bar, together with adapted air flow and strengthening of relevant parts of the engine, this can reduce the particulate mass to a level which negates the need for a DPF, although additional abatement is still required to control the smaller partials covered by Stage V.

HPCR circulates unused fuel back into the tank. This takes heat from the engine, supplementing the cooling system, but requiring careful design of the tank (Figure 35).

3.2.3 Electronic control unit (ECU)

An ECU permits many of the electronic engine systems and abatement systems to function as efficiently as possible (fuel injection, reductant injection, NOx measurement etc.).

The move to electronic control occurred in previous emissions stages. Advances in tuning the engine greatly assist the reduction of emission.

3.2.4 Exhaust Gas Recirculation (EGR)

EGR is the introduction of exhaust gas into the combustion mix. The effect is to dilute the air/fuel mix available within the combustion chamber, resulting in a lower combustion temperature. Lower temperatures reduce the formation of NO_x but can cause an increase in the emissions of particulate matter.

There are a number of methods available to the engine designer:

- Internal EGR – this occurs within the combustion chamber/exhaust manifold interface, set by the timing of the closing of the exhaust valve. Following the completion of the exhaust stroke, the exhaust valve remains open during the start on the induction stroke, causing some of the exhaust in the exhaust manifold to be drawn back into the combustion chamber. As there is no additional control over this, the amount of EGR that occurs is generally kept low.
- External EGR – some of the exhaust is directed through a pipe from the exhaust manifold back into the inlet manifold. This can be controlled by a solenoid valve to turn EGR on only under idle conditions. External EGR requires additional space around the engine.
- Cooled EGR – as per external EGR, but the recirculated exhaust gases pass through a cooler before re-entering the engine. This provides a further reduction in the combustion temperature. The exhaust cooling is performed with a water heat exchanger using the engines coolant; therefore either an increase in air flow and/or radiator size is required.

The amount of recirculation occurring can be adjusted by engine design to produce the desired results. EGR can however lead to reduced power levels and to increased fuel consumption. Also, additional devices will be required to deal with the increase PM emissions.

EGR has been around for many years on both light-duty and heavy-duty engines. It is used in some manufacturer's emission abatement strategy, but the packaging size and location as well as the increased PM generation must be considered.

3.2.5 Catalyst technologies

Catalytic emission abatement systems use a material layered on or impregnated into a substrate. The material under the correct conditions assists encouraging a chemical reaction (AECC, 2014).

For a given catalyst there is an optimal temperature range in which it functions. The catalyst has to be heated by the engine exhaust flowing through it before it begins working, the so called 'light up' or 'light off' temperature.

All catalyst substrates need to be tailored for the application, i.e. the engine type, exhaust volume produced, duty cycle and exhaust temperature. This is done by appropriately selecting the amount of active compositions in the surface or pores of the substrate, the porosity of the substrate, the surface area, adjusting distance to and between given substrates and insulation around and leading to the substrate.

3.2.6 Diesel oxidation catalyst (DOC)

A diesel oxidation catalyst promotes the oxidations of several of the exhaust components. These are oxidised using oxygen, which is present in the diesel exhaust, in the presence of a catalyst. The components include:

- Carbon monoxide (CO), forms carbon dioxide (CO_2)
- Hydrocarbon (HC), oxidised to CO_2 and water
- Soluble organic fraction (SOF) of particulate matter (PM)

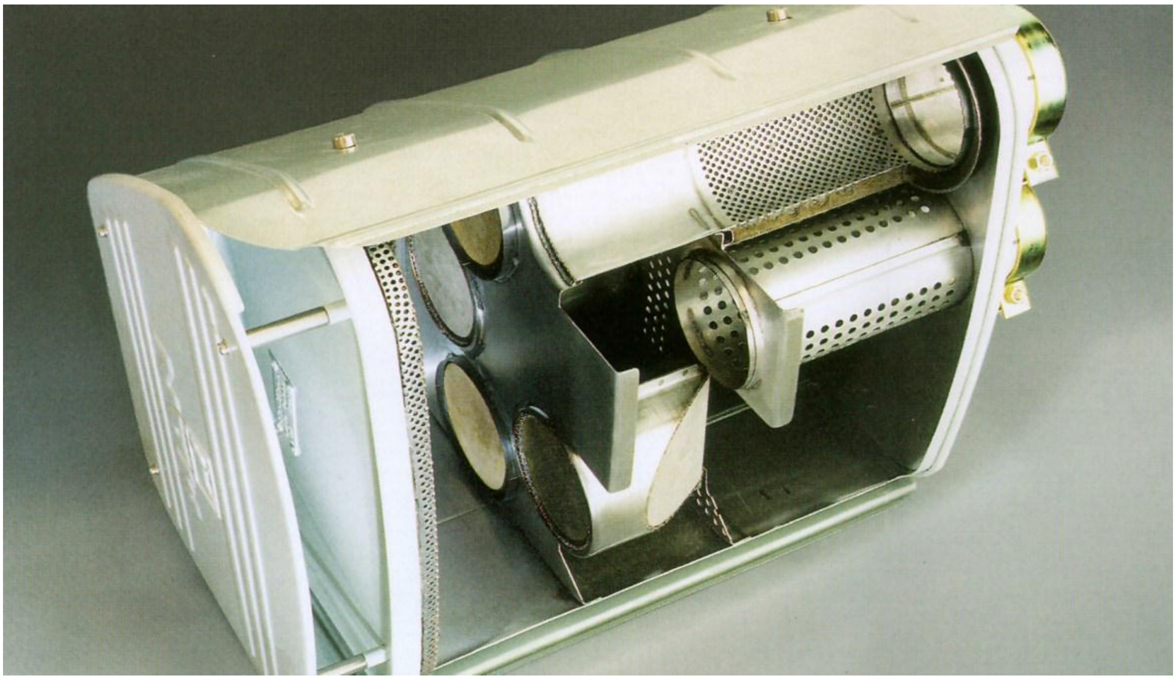

Figure 25: Opened can showing the cylindrical Diesel Oxidation Catalysts (DOC)

(Copyright AECC, MAN)

Some proportion of particulate matter consists of droplets of hydrocarbons, therefore a DOC also partially assists in the reduction PM and PN which is especially relevant to the Stage V limits.

In addition to targeting regulated pollutants, a DOC can also control several non-regulated HC species as well as reducing the odour of the exhaust.

The disadvantage of DOCs when used on their own is that they might increase the emissions of the NO_2 fraction of NOx, due to the oxidation of NO. However, this may prove to be a benefit when used prior to a DPF or SCR, by helping regeneration in the former and enhancing the performance of the latter.

Figure 26: Tractor industry development to reduce DOC size (A4 paper for scale)

Key	Left	Substrate 3.1 litre	Engine capacity 3.8 litre
	Right	Substrate 4.1 litre	Engine capacity 3.6 litre

In response to the upcoming requirements for Stage IIIB, the tractor, engine and catalyst industries have produced a DOC significantly reduced in size (Figure 26). This assists the EAT to be fitted within the bonnet above the engine, sacrificing less space needed for other engine peripherals.

3.2.7 Diesel particulate filter (DPF)

A diesel particulate filter is a device to remove the particulate matter from the exhaust gas of a diesel engine. They generally consist of some form of filter material which traps the particles as the exhaust flows through it. They can be full flow (i.e. all of the exhaust passes through the filter material) or partial flow (only part of the exhaust is filtered, the rest by-passes the filter unaffected).

The use of a DPF has been chosen by some manufacturers in their current emission abetment strategy, although not indispensable. To meet any PN limits in Stage V, however, it is accepted that DPF of some form is essential.

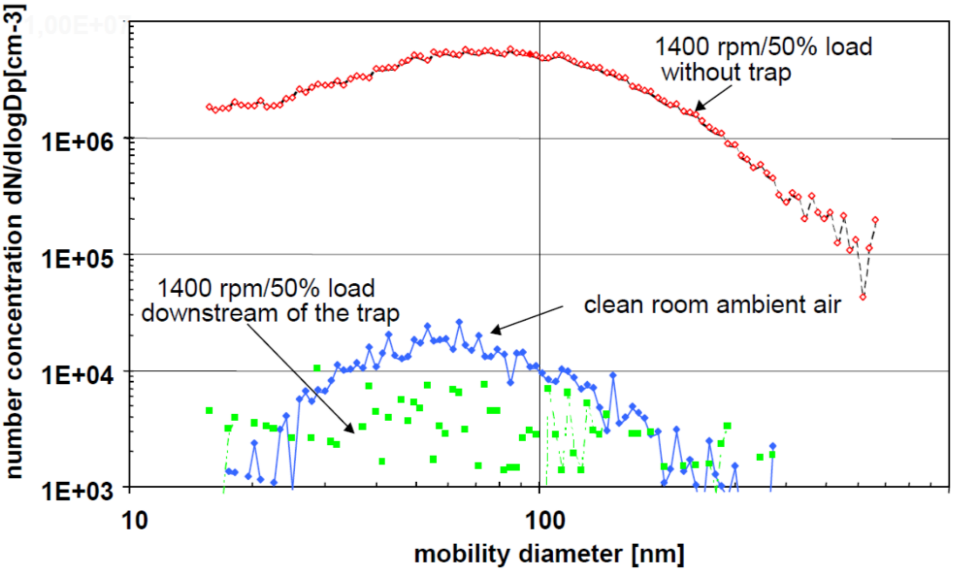

Figure 27: Particulate number reduction through the use of a full flow DPF

(Copyright AECC, Measurement by Matter Engineering Ingenieurschule Biel)

The majority of modern factory fit DPFs are full flow filters. During use, soot will accumulate on the filter, increasing the back pressure in the exhaust. To allow continued efficient operation, this accumulated soot needs to be regularly removed. There are a number of ways to achieve this, including:

- By regeneration, where the soot is burned off by increasing the exhaust temperature. Diesel particulate burns at about 600 °C, so this temperature needs to be maintained for generation period (i.e. a period of high engine load needs to be sustained).
- Late fuel injection (Engine controller)
- Fuel injection during the exhaust stroke (Engine controller)
- Changing the load on the engine through control of the inlet airflow
- Electrical heating elements (high electrical energy use)
- An alternative to on-board regeneration is to remove the DPF from the vehicle to be processed externally, using electrical systems or another heat source, though this is often impractical and is not a common solution.
- The addition of a fuel borne catalyst, which reduces the combustion temperature of the particulate from 600 °C down to 350-450 °C. This requires a small additional tank to hold additive, plus the associated plumbing, but this is more energy efficient. The fuel borne catalyst also becomes trapped in the filter, in newer types the DPF is designed with this in mind, reducing the additive needed.
- Catalysed Diesel Particulate Filters (C-DPF) have a coating on the porous filter walls which assists in removal of the particulates, reducing the temperature for regeneration, but regeneration is still required (DieselNet, 2005).
- Continuous Regeneration DPF (CR-DPF or CRT) utilises NO_2 to assist in burning the PM trapped on the filter continuously. It comprises of two stages with an NO to NO_2 catalyst preceding the DPF. This system does not require additional energy (heat or fuel). Low sulphur fuel must be used. This system outputs NO which must still be controlled separately.

Due to the increased exhaust out temperate at regeneration, tractors include a user activated control within the cab to delay the process until they can take the vehicle away from crops or dry flammable material.

An example of a DPF fitted to a tractor (Category T1) is illustrated in Figure 28. The DPF in this case is approximately 400mm long and 200mm diameter, fitted to a 3.4 litre, 4 cylinder engine developing 76 kW.

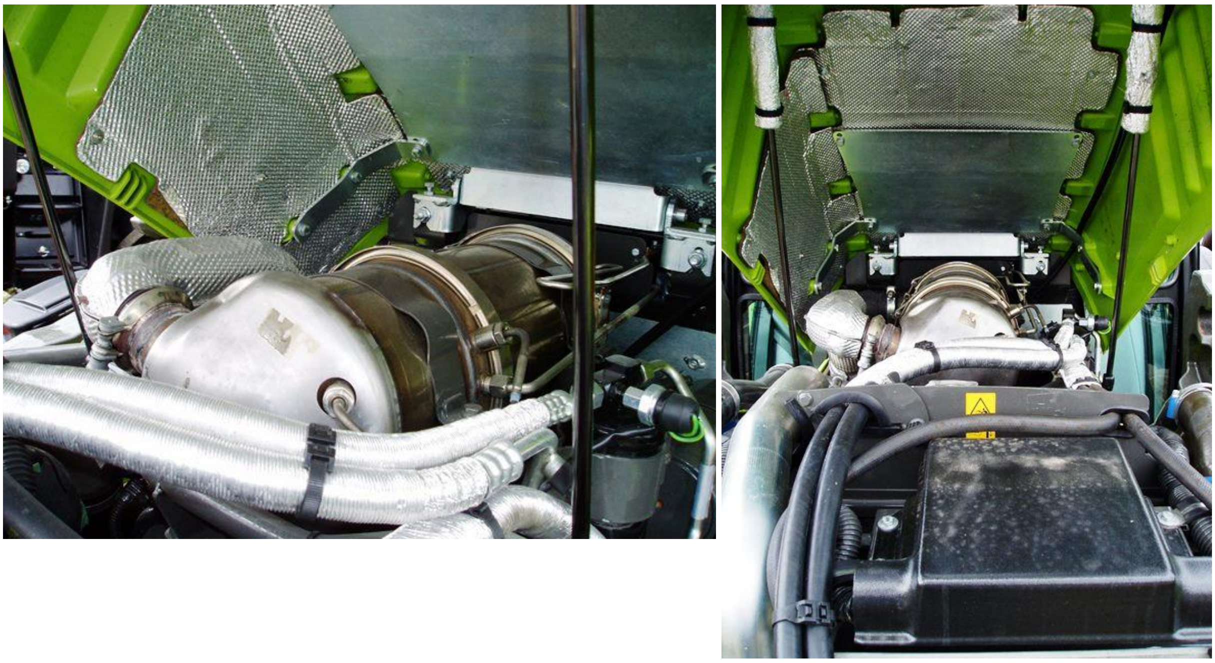

Figure 28: DPF mounted above the engine – note the heat shielding added to the underside of the bodywork and to the pipes and struts.

(Copyright TRL)

3.2.8 Selective Catalytic Reduction (SCR)

SCR reduces NOx emissions producing nitrogen (N_2) and water (H_2O). The reaction requires the addition of a reductant (this reductant is typically a urea solution, termed DEF in the US and marketed as AdBlue). The catalyst within the SCR can consist of either oxides of base metals (such as vanadium, molybdenum and tungsten), zeolites, or various precious metals.

To be efficient, the SCR must be within its nominal operating temperature (350-450 °C) NOx. Emission reductions of 85 to 98% have been stated. The SCR would be solely heated by the exhaust. Therefore, the placement of the SCR in relation to the engine and the engine's duty cycle are critical with respect to the SCR's performance.

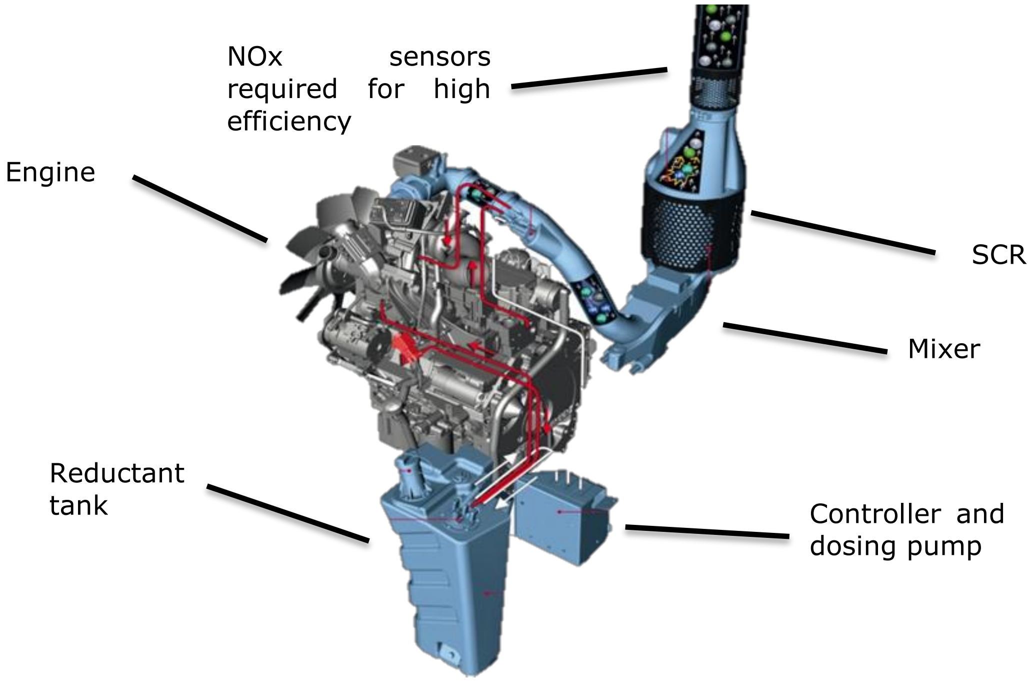

Figure 29: SCR system

(Copyright Fendt)

The SCR canister is relatively large compared to DOC or DPF. In addition to the SCR, the following are also required:

- Reductant tank – the dosing rate will vary by engine manufacturer and emission control strategy, but could be up to 10% of the fuel supplied. A tank over the percentage required is therefore recommended, as if the vehicle runs out of reductant, the engine will de-rate or stop until the tank is refilled. The tank also contains heaters (freezing between -10 and -20 °C) and sensors (for quantity, temperature and sometimes quality).
- A dosing pump – to pump the Reductant from the tank into the mixing area preceding before the SCR
- A control module – to control the amount of Reductant added.
- NOx sensors – for correct dosing and monitor functionality. Pre and post sensors may be required for higher conversion rates

Although readily available, the main design constraint is the amount of space needed for the installation.

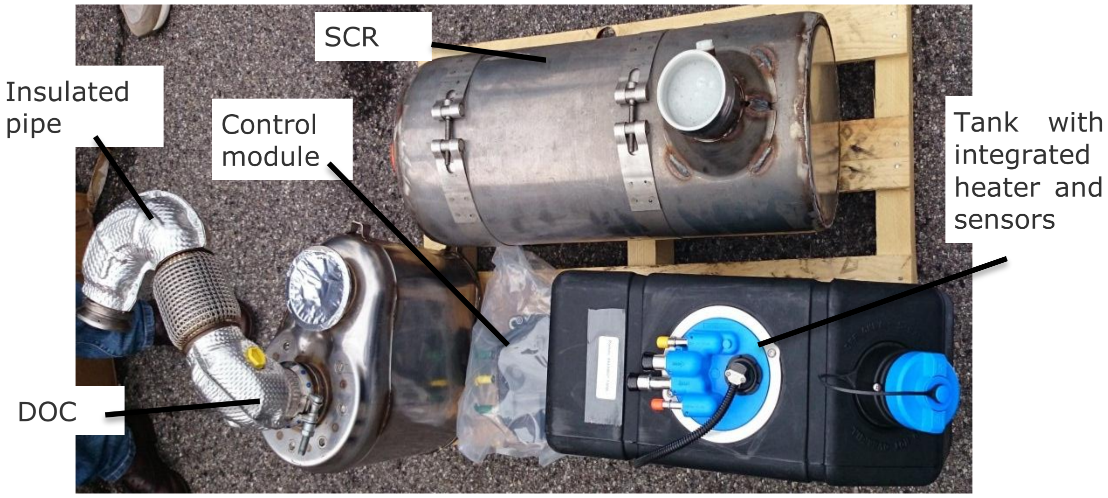

Figure 30: SCR components for 3.4l, 90 kW engine (including DOC for scale)

(Copyright TRL)

The use of SCR has been stated to reduce fuel consumption in some engine configurations, negating any reduction in fuel tank size to accommodate the reductant tank.

The SCR can effectively muffle engine noise; therefore a silencer is not required (as do other catalyst cans in the exhaust stream).

SCR of some form or another is generally accepted to be essential for reducing the NOx by the levels required by Stage IV and V.

3.2.9 Ammonia catalyst

SCR in its current form requires ammonia, derived from the urea reductant. The ideal ratio of ammonia to NOx is 1:1. However, under certain conditions, the SCR efficiency might be low (e.g. low temperatures, high exhaust flow rates etc.) or a higher ratio is used to ensure conversion. Under these conditions, ammonia may exit the SCR (known as ammonia slip).

To prevent the release of ammonia, an additional catalyst is placed immediately after the SCR. There are various terms for these devices, including:

- AOC: ammonia oxidation catalyst
- ASC: ammonia slip catalyst
- CUC: clean up catalyst

Any ammonia can either be oxidised to NOx (not really desirable) or it can be selectively oxidised to nitrogen. The ammonia catalyst is often packaged in the same can as the SCR.

3.3 Abatement methods in other sectors or under development (Task 3.2)

3.3.1 Particulate Oxidation Catalyst (POC)

A particulate oxidation catalyst (also called flow though filter or open filter) will capture particulates for a period of time, sufficient for its catalytic oxidation. Unlike a DPF, a POC will not block. Instead, the PM conversion efficiency will gradually increase in the absence of regeneration, allowing some of the particulates to pass through. POCs provide higher PM control than a DOC, but lower than a DPF

POCs were initially developed in the early 1980s, though DPFs were seen as the preferable choice as they offered better particulate reduction. However, there has recently been renewed interest in POCs, where only modest PM control is needed.

3.3.2 Catalysed Soot Filters (CSF)

A catalysed soot filter (CSF) is a diesel oxidation catalyst (DOC) to which filter elements has been added (BASF, 2014). Basically a combined DOC and DPF.

The DOC provides complete oxidation of CO and HC. However, the channels through which the exhaust flows are blocked at alternative ends. This forces the exhaust to flow through the porous walls of the monolith, trapping the particulates.

Regeneration occurs when additional fuel is combusted over the DOC, which creates additional heat to burn the soot in the filter. Passive systems are also available where NO_2 generated by the DOC continuously oxidises the soot.

3.3.3 SCR on Filter (SCRonF)

The "SCR on Filter" (SCRonF or SCRonF) is similar to a CSF, but instead of combining DOC and DPF, it combines SCR and DPF, controlling particulates and NO_x emissions.

These systems have been developed to meet the Euro 6 limits for diesel vehicles, where combining SCR and DPF onto a single substrate leads to both a weight saving and reduction in the space needed (BASF, 2012). At least two tractor/engine manufacturers are known to be currently working on its application on heavy-duty vehicles which also have space constraints.

For this system oxidation of CO and HC as well as stable oxidation of NO is required preceding the SCR. DOC is commonly employed for this purpose.

The SCRonF substrate has the same reductant use as a SCR only substrate as well as the same reductant mixing requirements, temperature requirements, and noise reducing capability, while removing the need for a DPF. With due regard to the engines needs and any other design changes, the volume of the substrate may change, ranges of no difference to a 20% increase in length has been given by stakeholders (Dr. Vonarb & Hohl, 2014).

This technology has been identified by tractor manufacturers as being an attractive technology for future developments of Stage IV and V compliant engines.

3.3.4 NOx Catalyst

One development of SCR identified is a catalyst system that employs the HC within the exhaust (i.e. diesel) as the reductant rather than urea, therefore, no longer requiring an additional tank, dossing system, control, etc. simplifying SCR considerably (Isuzu, 2014).

This is in early stages of development, Isuzu state that before this catalyst can be employed for practical applications the high oxygen concentration of the exhaust gas and the sulphur component of the diesel fuel need to be reduced.

3.4 Packaging

3.4.1 Combination cans

All of the above after treatment catalysts and filters (DOC, DPF, SCR, POC, CSF, SCRonF and NOx Catalyst) can be produced as a separate unit or "can". However, it is also possible to package together different emission reduction devices into a single can. Although the can size is larger, this can help fitting the device into the available space, retain heat, and protect the elements. Common combinations include:

- DOC followed by DPF – where NO_2 created by oxidation of NO in the DOC can aid regeneration (combustion of carbon) in the DPF.
- SCR followed by AOC – where any ammonia slip from the SCR is dealt with by the AOC (for Stage IV some ammonia slip control is considered essential (Majewski, 2005)).
- DOC + DPF + SCR + AOC all installed in one very large can, with reductant injection and mixing in between the DPF and the SCR.

- With SCRonF this amalgamated can becomes DOC + SCRonF + AOC.

Conversely, it should be noted that with these abatement systems in place a silencer is no longer required.

Although beneficial in some applications, it can be seen that the exact opposite strategy would be preferred for some tractors, where all round visibility is usually required.

3.4.2 Substrate shape and number

To accommodate the abatement systems within the vehicles the substrates, filters and mixers can be separated, shaped or split between two or more substrates.

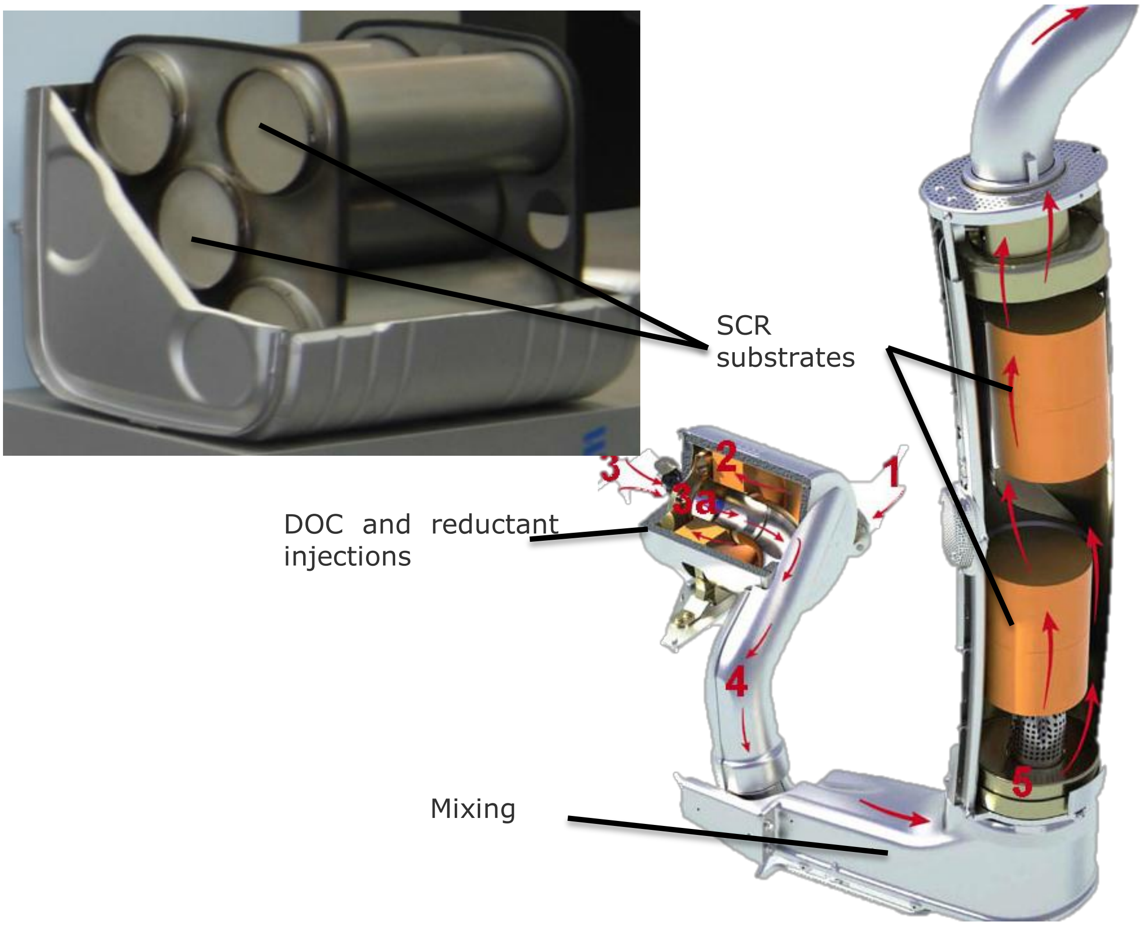

Figure 31: Cylindrical SCR substrates used parallel

(Copyright left: AECC, DAF. Right: Massey Ferguson[6])

It is possible to use multiple substrates – where two or more smaller substrates are used instead of one large one. These could be in parallel (i.e. side by side as shown in Figure 31) or in series (i.e. one after another). A parallel configuration allows the use of standard cylindrical substrates, while making it possible to fit different body shapes. Figure 31 shows an SCR in a square that can to be slung in a standard position under a truck (left), and the image to the right shows two substrates fitted within the vertical stack of a tractor using channels and guides to divide the exhaust flow between the two cans.

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[6] http://www.masseyferguson.co.uk/documents/tractors/MF8700_EN.pdf

A two SCR catalyst system (in series) with appropriate reductant control systems assists in the reduction of ammonia slip by monitoring its use midway in the system (Hsieh & Wang, 2011). This strategy could permit the ease of fitment onto tractors while reducing the space needed for ammonia slip catalysts.

Substrates for catalysts and filters are initially produced with a round cross section and are often used in this shape. However, it is possible to machine the substrate, prior to loading with the active components and canning, to produce other shapes, for example oval section, for specific fitments. However, this requires careful flow considerations to ensure that all of the substrate is evenly used. This method is widely used with DOC.

Cummins developed an experimental engine which utilising a SCRonF in the first catalyst, plus two other SCR's further downstream with multiple Urea injectors (Green Car Congress, 2014). Given the added complexity, this permits the in-engine bay SCRonF to remain small, while reducing the space requirements of the secondary SCRs.

3.5 Emission abatement strategies

To achieve the emission reductions required, the technologies have to be combined as part of the engine's entire emission abatement strategy. Different technologies are chosen based on both emissions and packaging, for instance Figure 32 shows four technologies used in series, the engine will also have two others (ECU and HPCR) and in some case may have a further one (EGR). By using many different technologies partial control of each emission is possible, specifically by controlling particulates with after treatment the engine-out emission of PM can be permitted to be greater while reducing the overall emission of NOx (running the engine at a lower combustion temperature); this allows the consumption of reductant to be reduced.

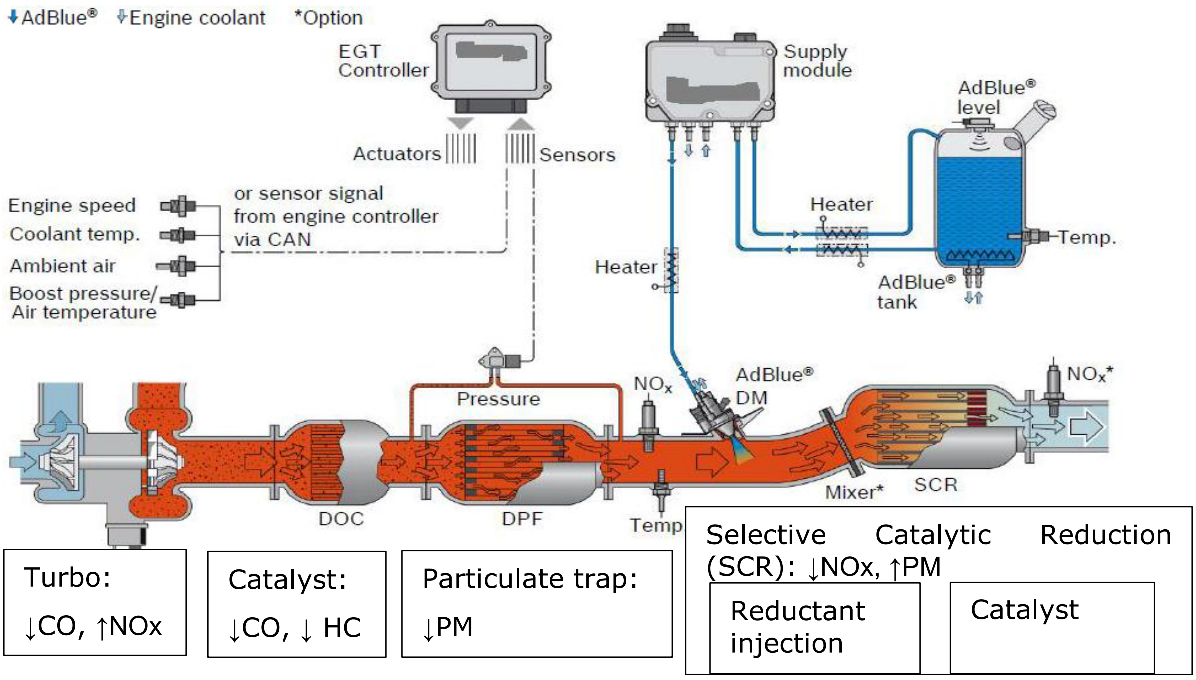


Figure 32: Schematic of a range of emission abatement technologies in one possible configuration, showing the device order in the exhaust flow (components not to scale)

(Copyright CEMA, Bosch)

An alternative design aim by one manufacturer was to not produce the pollutants to start with, rather than dealing with them later. Manufacturer "A" achieved this by designing a high efficiency combustion system incorporating high pressure injections systems (2 kbar), variable geometry turbochargers (VGT) and cooled EGR (C-EGR). The engine meets Stage IIIB (and US EPA Tier 4i) and to meet Stage IV and above SCR would be utilised. The engine is available with a range of power outputs from 55 kW to 129 kW. In addition this has also led to an improvement in fuel efficiency (around 5-10% lower fuel consumption). This strategy requires an increase in the size of the engine or parts and piping close to engine, while reducing the external after treatment requirements.

The third way is to perform all of the emission control with after treatment. This is commonly used to upgrade older vehicles to be used in low emission zones. Without any modification to the engine itself to partially control emission, the after treatment fitted must be quite large while not reducing the size of the engine or fuel consumption.

For NRMM engines used in tractors there has been a trend towards the engine based technology approach. HPCR, ECUs and turbocharging are used on all engines identified within the project. However some of the technologies have not been implemented industry wide, size constraints mean some compromise have to be made which require the technology balance to shift, specifically turbo choice and the use of EGR reducing the on-engine control of CO and NOx. However, PM and HC could be given greater control although improved HPCR (2 kbar). This configuration shows some similarities with the balanced configuration but with advances to some of the technologies.

Table 12 summarises these base configurations to meet the Stage IV emission limits;

Table 12: Emission abatement strategies for Stage IV

	Partial engine & aftertreatment based	Engine based	After treatment based	Size constrained, engine based
Additional	ECU	ECU		ECU
HC	DOC	HPCR (2 kbar)	DOC	DOC, HPCR (1-2 kbar)
CO	Turbo, DOC	Turbo (VGT or Two stage)	DOC	DOC, Turbo (single)
PM	DPF	HPCR	DPF	HPCR, DPF
NOx (reductant use, relative to fuel)	SCR (low)	C-EGR and SCR (2-3%)	SCR (variable)	SCR (10%)

3.6 Other considerations

3.6.1 Sulphur

Sulphur content requirements for fuel splits the market for diesel engines in two; 500 ppm and 10-15 ppm termed ULSD (Ultra Low Sulphur Diesel) (Annex 3.1 for an extract of the legislation). The engines used for these tractors are sold into both markets and therefore demand that the engines are capable of functioning with sulphur in the fuel.

Many of the emission abatement technologies suffer if there is too much sulphur in the fuel and therefore they cannot be used if the vehicles are sold into the other markets.

Diesel engines previously run on high sulphur diesel fuel should be capable of running on ULSD. The only problem is that the presence of sulphur can cause seals in the fuel system to swell. Running on ULSD, the seals can shrink back, resulting in possible fuel leakages until the seals are replaced.

3.6.2 Fuel

Typically, diesel is used as a fuel for tractors. Diesel does cost slightly more to produce than petrol. However, the fuel duty can bias this for road transport use (for example, in France petrol costs €1.54/litre while diesel costs €1.32/litre according to DG Energy's Oil Bulletin 7th July 2014). In addition, low tax diesel is available for non-transport use, which includes agriculture. In the UK, Belgium and The Netherlands, it is known as "Red Diesel" due to the red dye added to it to distinguish it from diesel which has had the duty paid.

Emission reduction could be achieved by switching to a different fuel. However, these could bring additional problems:

- Petrol engines would reduce the emissions of NOx and particulates. Petrol engine typically produce very little PM emissions and the NOx emissions can be handled by a three-way catalyst, which would also deal with CO and HC emissions from the engine. The same sized fuel tank could be used in place of the diesel tank with only slight reduction in range. However, petrol is generally only available as a road fuel and fuel consumption (in litres/kWh) is typically higher. There are no known non-road petrol fuels available apart from aviation fuel, so the cost would be very much higher. To run on petrol, a dedicated engine would ideally be required (retrofitting a diesel engine to run on petrol is a complex task and results in a less efficient engine than if it had been specifically designed for that fuel).
- CNG (compressed natural gas) could be used which again reduce the emissions as per a petrol engine. This would require the use of pressurised fuels tanks, which would have to be to set shapes (e.g. cylinders) for structural purposes. The available range would depend on the room available for the fuel tanks. Again, the optimum solution is to design a dedicated engine to run on CNG. However, dual fuel engines are also available; these operate as a compression ignition engine, but rely on a small amount of diesel to ignite the CNG in the combustion chamber.

3.6.3 Change of category

Stage IV will apply to engines producing 56 kW or more. For tractors in the range 37 to 56 kW, only Stage IIIB will apply. To meet stage III effectively requires the fitment of cooled EGR plus a DPF. This is a simpler solution than that required to meet Stage IV. It is possible that a number of the T2 tractors could be de-rated to produce just less than 56 kW in order to meet these less stringent emissions requirements. Alternatively, market forces (i.e. demand for lower costs tractors) could drive up demand for the lower powered T2 tractors.

3.7 Summary

The Stage IV emission step requires the reduction of NOx (while Stage IIIB and V cover PM and PN respectively). To counter this emission from diesel engines, SCR was the only technology identified to be capable of fully meeting the requirements of Stage IV. Cooling of the combustion process, the use of EGR, and using a naturally aspirated engine can all help reduce the NOx emissions (but raise PM emissions), which can in turn reduce the usage of reductant for SCR systems, but none can fully meet the requirements alone.

SCR consist of multiple parts, those critical in terms of positioning and size are the Reductant injector, Mixer, SCR substrate, and NOx sensor(s). Significant differences in the mixer volume and location have been seen on vehicles, early designs required long tubes of 300-500mm in length. However more sophisticated mixing can reduce this; one of the mixers produced by a large NRMM manufacturer, for instance, has a diameter of 177mm and length of 170mm, and the injector directly interfaces with it reducing piping lengths.

No evidence was found for possible future reductions in the SCR substrate size, but splitting the exhaust over two or more smaller substrates in parallel is used by at least one T1 manufacturer and regularly used on HDVs to fit available space.

The slightly earlier introduction of Stage IIIB requirements for power-plant categories L (130 - 560 kW) and M (75 - 130 kW) caused EAT solutions to be implemented upon these higher-powered tractors (generally T1 or T4.2 category) prior to smaller N-category (56 - 75 kW) vehicles. In the majority of cases >75 kW tractors have relied upon SCR-based EAT systems as part of their strategy to achieve Stage IIIB compliance and, in a number of cases, are now demonstrating Stage IV compliance by use of the same technology.

Conventional (T1 category) tractors within the 56 - 75 kW engine power range have been slower to demonstrate Stage IIIB compliance compared to larger engine tractors, but many such examples are being launched publically at the time of writing (Summer 2014).

Of the current technologies listed in Section 3.2, all except SCR together with an ammonia catalyst are already in use within the T2, C2 and T4.1 fleet. SCR is highly mature, but not yet used on certain engine sizes and vehicles pending the legislative requirement for reduced NOx. In addition, HPCR systems reaching pressures of around 1 kbar are in use within the NTT fleet, while the higher 2-3 kbar systems, which will assist with the Stage V PM requirements, are in use on other NRMM engines and are at the mid to late prototyping stage, approaching readiness, on the T2, C2 and T4.1 fleet.

Regarding Abatement methods in other sectors or under development:

- Particulate Oxidation Catalyst (POC) although fully developed is an older technology and not considered a viable solution as it does not fully limit PM
- Catalysed Soot Filters (CSF) are a fully developed technology, and depending on the packaging needs may be used as an alternative to a DOC and DPF separately
- SCR on Filter (SCRonF) is in use on light duty diesel vehicles and fully developed in that area, it is being developed for NRMM by some engine manufacturers. The use of SCRonF removed the need for a separate DPF with a length increase of 20%, which could be applied in the future when Stage V demands PM emission reduction.
- NOx Catalyst was, from the literature identified, considered to be in early development and so may not be ready for use in NRMM until after Stage V.
- The developments in using Combination cans and changing the substrate shape is in in use with NRMM engines. And both techniques have been shown on tractors.

4 Assessment of the technical requirements for compliance with Stage IV (Task 2)

4.1 Introduction

Reducing NO_x emissions to the level required to meet Stage IV could be achieved by a combination of

- Engine design adaptations, such as Adding or modifying Exhaust Gas Recirculation – EGR (section 3.2.4), and
- The addition of secondary after-treatment components, such as SCR (section 3.2.8 and 3.3.3).

The installation of these components on NTTs (Category T2 and C2) requires a balance between available space around the engine and any practical constraints, for example the need to place or attach implements to certain areas, and to ensure driver comfort and that he is afforded good visibility to operate the tractor effectively and safely.

SCR catalysts need to be placed close to the engine because the chemical reaction requires a high operating temperature, which puts constraints on unit packaging. Their high surface temperature makes external thermal insulation necessary, to protect adjacent components, the vehicle operator and nearby crops, depending upon the chosen siting location. These factors add to the space required for SCR installation. The size and shape of the exhaust after treatment (EAT) canister employed is dependent on the specific engine’s exhaust characteristics, such as temperature ranges and flow rates, these parameters being related to power rating. Typical dimensions of an SCR canister for a 56 – 80 kW off-road diesel engine would be approximately 425 mm long and 200 mm diameter (Figure 33). DPF canisters for such engines are of similar dimensions and present comparable heat generation / insulation and guarding issues (Figure 28).

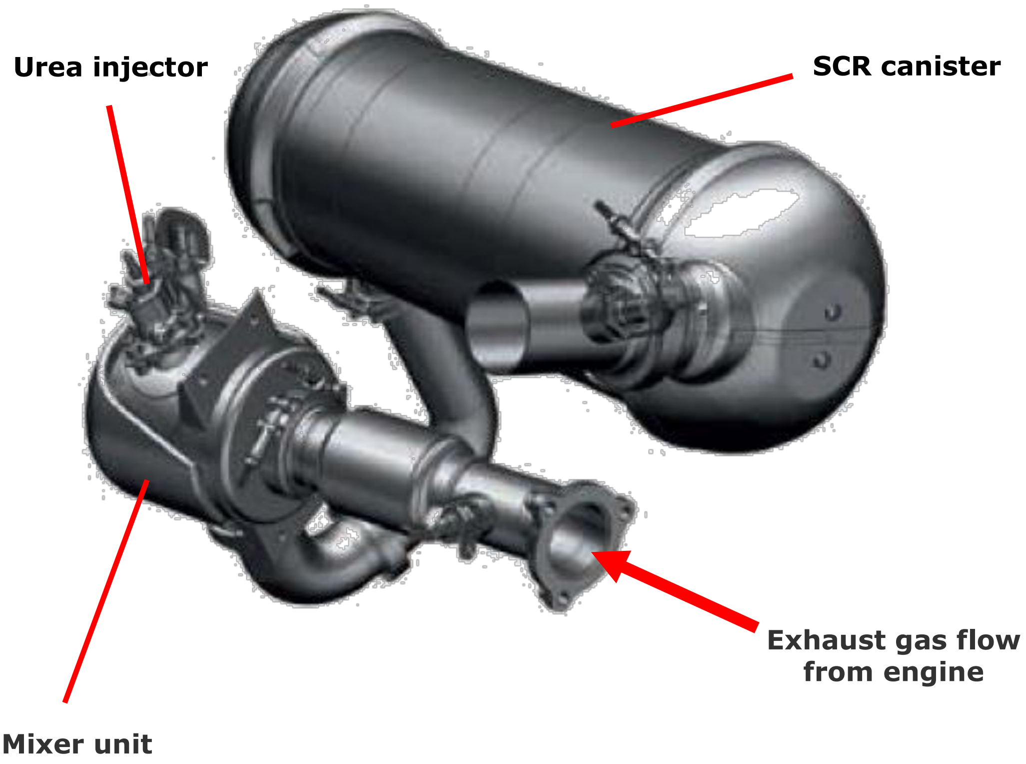


Figure 33: SCR system used on Stage IV-compliant 68-81 kW 4.4 litre JCB EcoMAX engines

(Copyright JCB)

In addition the SCR system also requires a mixer unit (Figure 33) and a storage tank for the reductant liquid (usually an aqueous Urea solution, commercially-available under the name AdBlue). The purpose of the mixer unit is to obtain uniform distribution of the reductant liquid within the exhaust gas flow, prior to its entry into the SCR canister. To achieve this objective, the dimensions of the mixer unit and its relative proximity to the engine are important design parameters.

The total combined mass of a SCR canister and mixer unit EAT system are typically 15 kg and therefore of no consequence in relation to total vehicle mass or potential side slope stability. Similarly, although a 75 KW engine is likely to require a reductant storage tank of approximately 15 litres capacity which, including contents, may have a mass of 25 kg, this is inconsequential when compared with a total (vineyard / orchard) NTT unladen mass of between 2,500 - 3,000 kg. The unladen mass of a typical C2 track laying tractor is approximately 4,000 kg. The unladen mass of T4.1 tractors is estimated to be in the range 3,500 - 4,500 kg, although this may be greater for the larger models. However, whilst EAT hardware mass may not be a significant issue, manufacturers have reported that the packaging of the system components upon the (narrow) vehicles is an engineering challenge.

Unlike the SCR canister and mixer unit, the reductant storage tank does not need to be as close to the engine; however locating the unit too far may be impractical. For instance, a long distance or height differential would affect pumping requirements. Additionally, as shown by Figure 29, the storage tank must also incorporate a heating system to prevent the reductant liquid from freezing at low ambient temperatures (< -11°C). Similarly the supply lines to/from the tank also require protection from freezing, however this is usually achieved by automatic purging of the liquid contents upon engine shutdown. Conversely the reductant must be maintained at <70 °C up to the point of injection, influencing both storage tank and supply line design.

The reductant storage tank should be easily accessible for (daily) re-filling. The aqueous urea solution is non-volatile and non-toxic, but is an irritant, so tank installation within the operator’s cab is possible, although a certain minimum distance from the user would be required. In practice, the extremely limited internal dimensions of the cabs fitted to vineyard/orchard T2 and C2 tractors and requirements for the operator’s field of vision, largely precludes this in-cab siting location.

Figure 34: Stage IIIA T2 tractor plastic diesel tank moulded to fit around footstep and mid-mounted ROPS support brackets

(Copyright TRL)

Manufacturers of narrow overall-width (T2 and C2 category) tractors have employed novel solutions upon their Stage IIIA-compliant vehicles in order to provide sufficient (diesel) fuel storage capacity. Figure 34 shows a plastic fuel tank fitted to an orchard-type T2 category tractor mounted under the operator's platform, alongside the transmission housing. Some additional capacity has been gained by shaping the tank around the platform footstep and (mid-mounted) ROPS (roll-over protection structure) support bracket. Of particular interest is the relatively close proximity of the (albeit heat-shielded) under-swept engine exhaust pipe.

Figure 35 illustrates a novel solution upon a T2 vineyard / orchard tractor fitted with a 71 kW 4-cylinder turbocharged and intercooled 4 litre Stage IIIA-compliant engine. A primary diesel tank of moulded-plastic construction is located at the front of the vehicle, in front of the (four) cooling radiators, but limited packaging space for engine ancillaries has caused the designers to incorporate the engine air filter housing laterally, within the fuel tank. This reduces fuel tank capacity (to 55 litres), so an optional belly-mounted tank of 25 or 40 litres capacity is offered to provide more capacity.

Industry sources have stated the typical fuel consumption of a 70 – 75 kW NTT to be approximately 20 litres/hour. This value refers to full-load operation, but in normal practice tractor fuel consumption is unlikely to exceed 75-80% of this level (Table 5). Current NTT fuel tanks hold approximately 70 litres and it is desirable to maintain this capacity and the associated time between refilling.

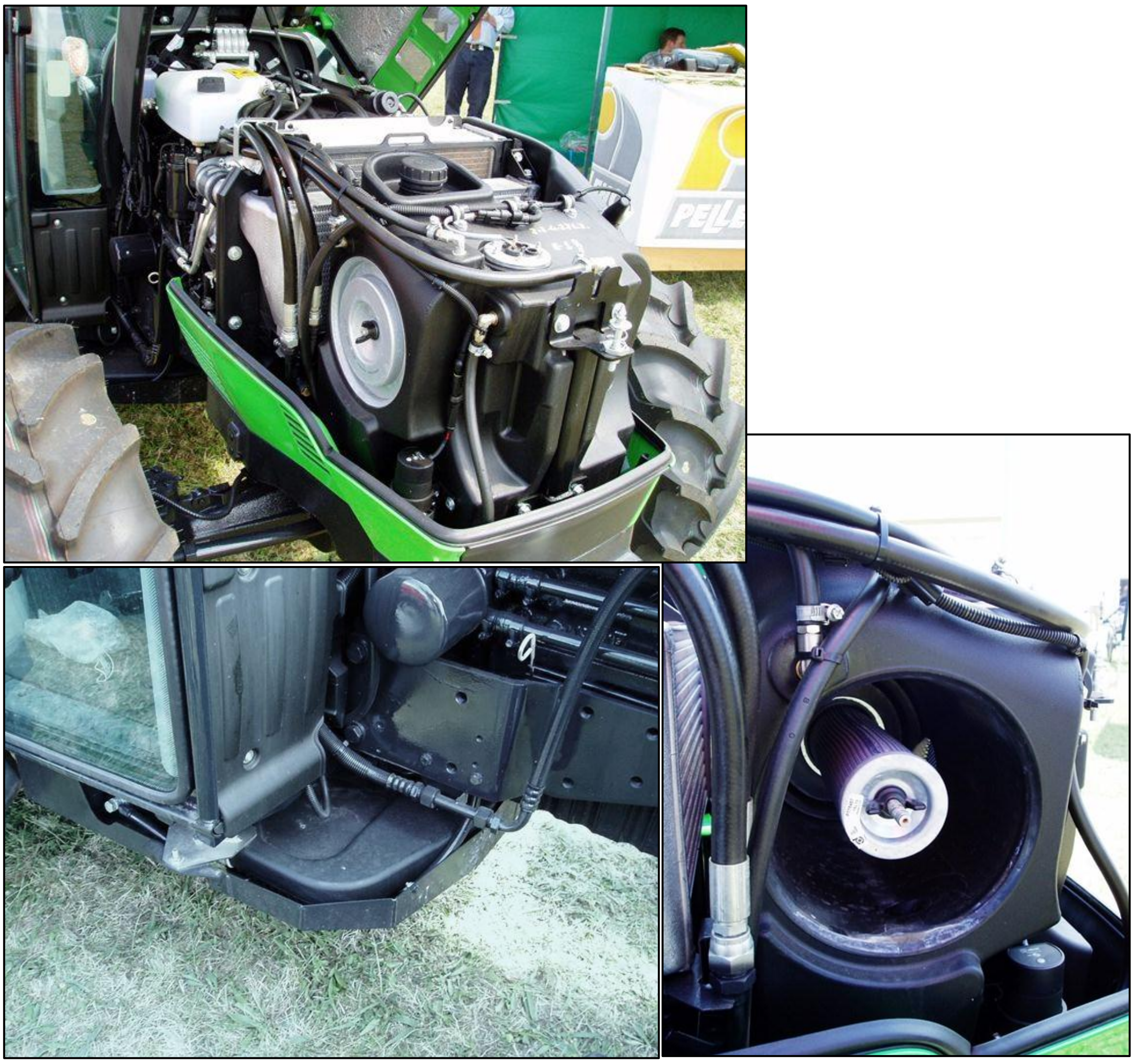


Figure 35: Front-mounted moulded plastic fuel tank on Deutz-Fahr T2 orchard tractor (top), incorporating integral engine air cleaner assembly (right). Reduced (55 litre) capacity supplemented by 40 litre belly-mounted fuel tank (bottom left)

(Copyright TRL)

The following sections detail the likely issues relating to installation of SCR-based EAT systems upon each of the (T2, C2 and T4.1) tractor categories considered by this investigation. The issues, fitment details and possible solutions are sourced from stakeholder information, manufacturer's technical literature and technical knowledge. Stakeholder information so far identifies issues in terms of current designs, equipment and accessories, while it should be understood that this report allows for the possibility that new tractor models will be developed and designs adjusted to accommodate any additional equipment.

4.2 Category T2

SCR-based EAT systems have been the solution of choice for Stage IV compliance upon larger (T1 category) vehicles. It is therefore pertinent to review the feasibility of installing such hardware upon the vehicles of interest to this study. T2 tractors are by definition more restrictive regarding the space and shape available for packaging engine ancillaries and, indeed, any vehicle components (Section 2.1). Depending upon their intended (vineyard, orchard or other) application, they also function with crops in close proximity to the sides or the top of the vehicle. Therefore if an SCR EAT system is to be used, careful packaging is required.

The degree of engineering challenge associated with packaging EAT system hardware is highly-dependent upon the overall width of the vehicle. As shown by Figure 5, T2 Narrow Track Tractors (NTTs) are produced in a range of width variants, depending upon their intended use. However, to manage production costs, these vehicle variants frequently share a common engineering platform (e.g. engine, transmission, hydraulic system), only axle assemblies and operator cab designs are specific to models of given overall width.

As discussed previously, an SCR EAT system requires both an SCR canister and injection or mixer unit, located in relatively close proximity to the engine, plus a storage tank and dispensing system for the reductant (aqueous urea). The reductant storage tank location is less critical. Gas flow characteristics between the injection / mixer unit and the SCR canister are very important, to ensure even distribution of the reductant liquid and subsequent efficient SCR operation. Industry stakeholders have stated that a minimum distance of 400 - 500 mm is required between the reductant injection point and the SCR canister, but no doubt this is dependent upon precise system design.

The engines of NTTs are commonly located at the front on the vehicle and this can affect visibility, both over the bonnet and to each side. Driving between crop rows demands clear views ahead, to the sides, to the wheels and to the rear of the vehicle, not only for precise directional control, but also to monitor equipment working in those areas. This further complicates the installation of ancillary devices. With this in mind, the feasibility of installing EAT canisters and/or a reductant tank in the locations shown in Figure 36, Figure 37 and Figure 38, for conventional and low-profile rigid-chassis and articulated-chassis T2 tractors, can be assessed.

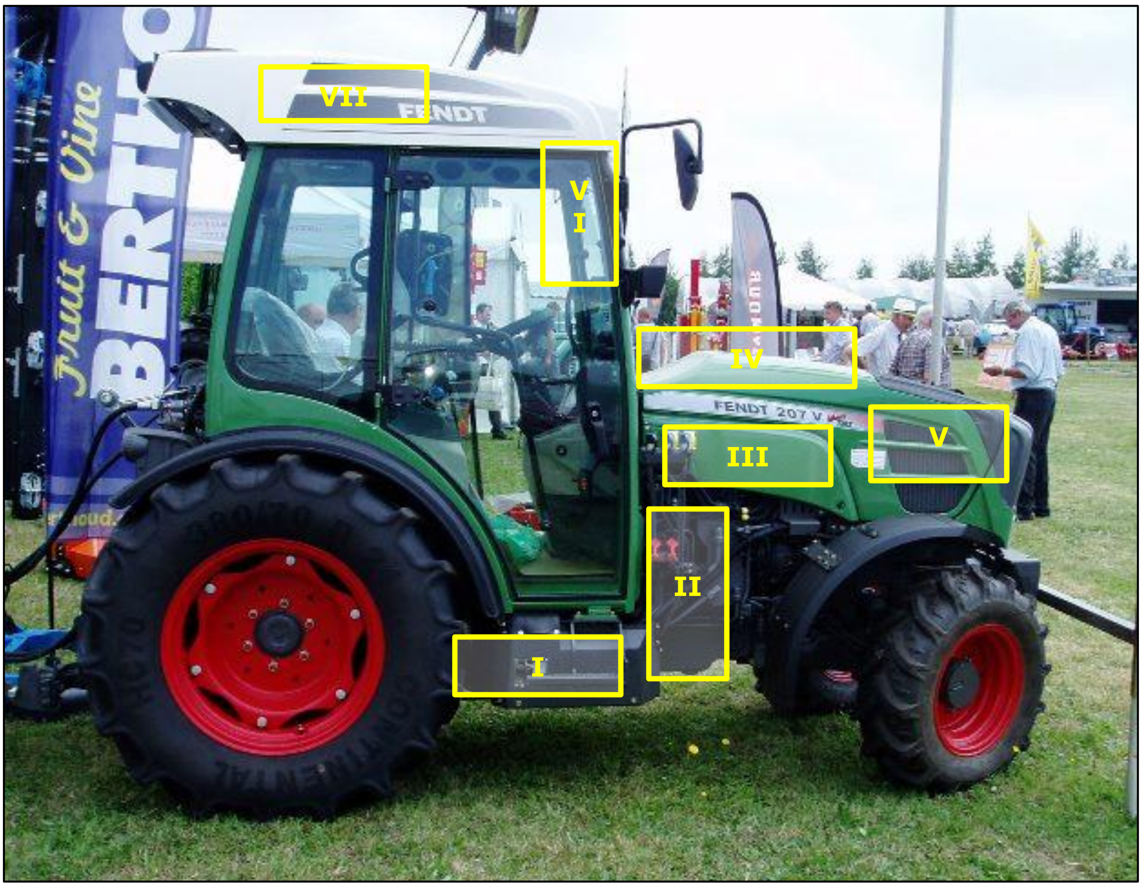


Figure 36: Some possible locations for EAT hardware on a conventional (tall) rigid-chassis T2 tractor

(Copyright TRL)

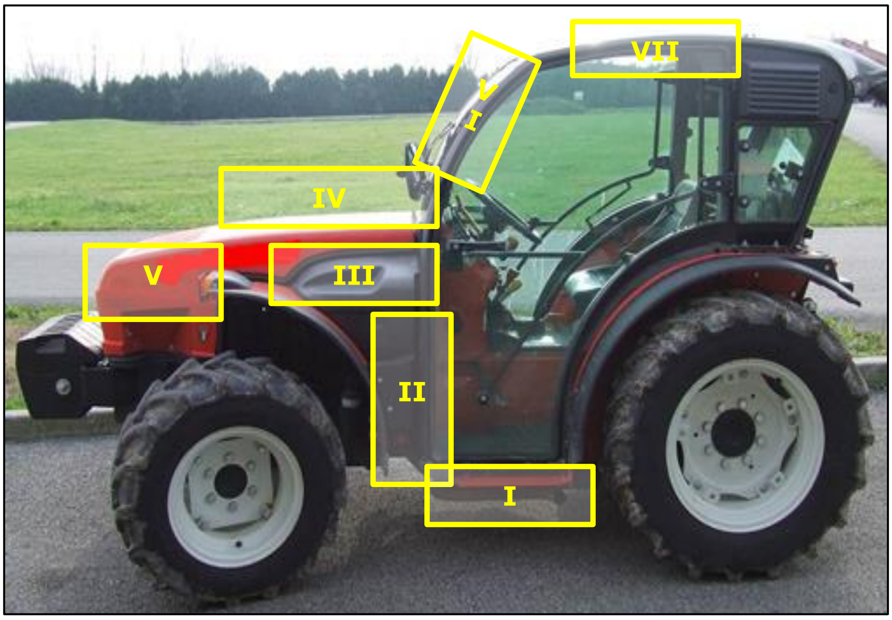


Figure 37: Some possible locations for EAT hardware on a low-profile, rigid-chassis T2 tractor

(Copyright CEMA)

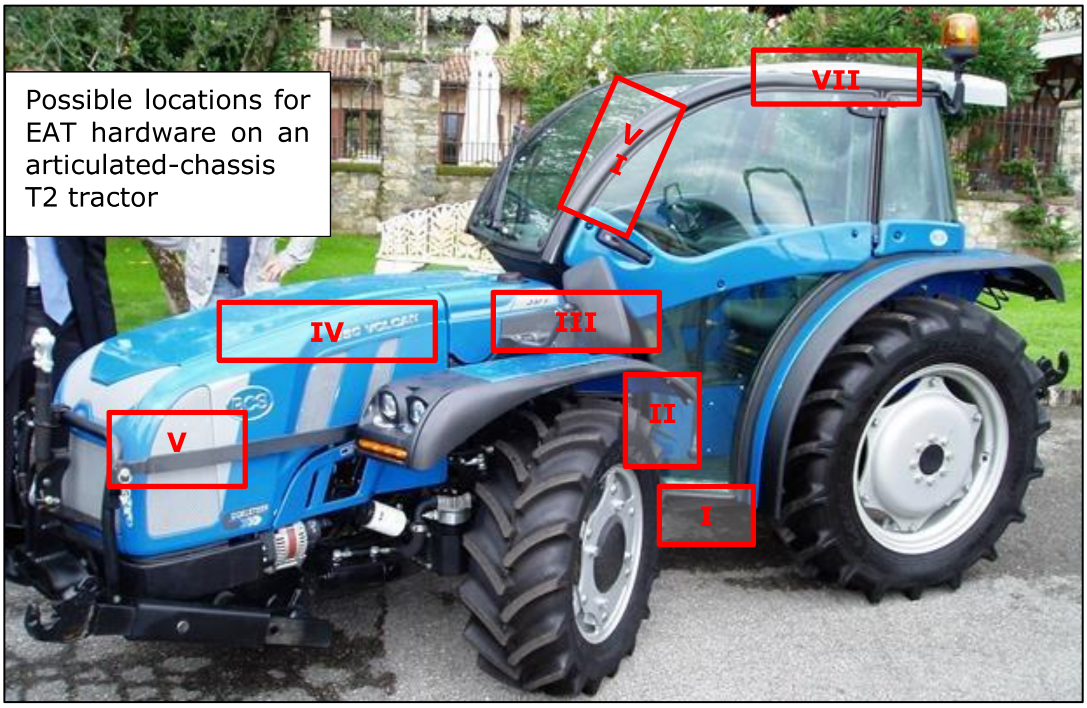


Figure 38: Some possible locations for EAT hardware on an articulated-chassis T2 tractor

(Copyright TRL)

4.2.1 Location I: Under the cab / platform floor

This location provides an appropriate distance from the engine to retain sufficient exhaust gas heat for efficient SCR catalyst function and space for installation of the reductant mixer unit, but the primary difficulty is the potential reduction of vehicle ground clearance. Installation of the SCR can and mixer unit here would require thin package design. Alternatively it may be necessary to raise the cab or platform marginally relative to the vehicle chassis to provide additional space. A thinner package would change heat retaining capabilities of the SCR device, requiring improved insulation. However, heat would still be transferred and could result in undesirable heating of the cab interior and the operator's feet.

Both the heat and space requirements could be assisted by a change to the operators seating position. Raising the footing and angling the legs upward, and adjusting the seat and steering wheel angle/position to suit are possible within the space available in the vehicle. However, such modifications could reduce operator visibility of attached implements, particularly to the rear, and would therefore probably be unacceptable.

Raising the cab / platform marginally may be acceptable for conventional rigid-chassis T2 tractors (Figure 36), but would not be feasible for low-profile T2 vehicles designed to operate in areas of restricted headroom (Figure 37 and Figure 38). So, for these particular vehicles, this location may not be particularly viable.

However, as shown by Figure 39, some space is available under the cab or platform floor on conventional rigid-chassis T2 tractors. It would also appear that other existing vehicle components (e.g. the front axle (4wd) driveshaft and associated guard) may pose a limitation to vehicle ground clearance before any appropriately-designed EAT hardware sited in this location.

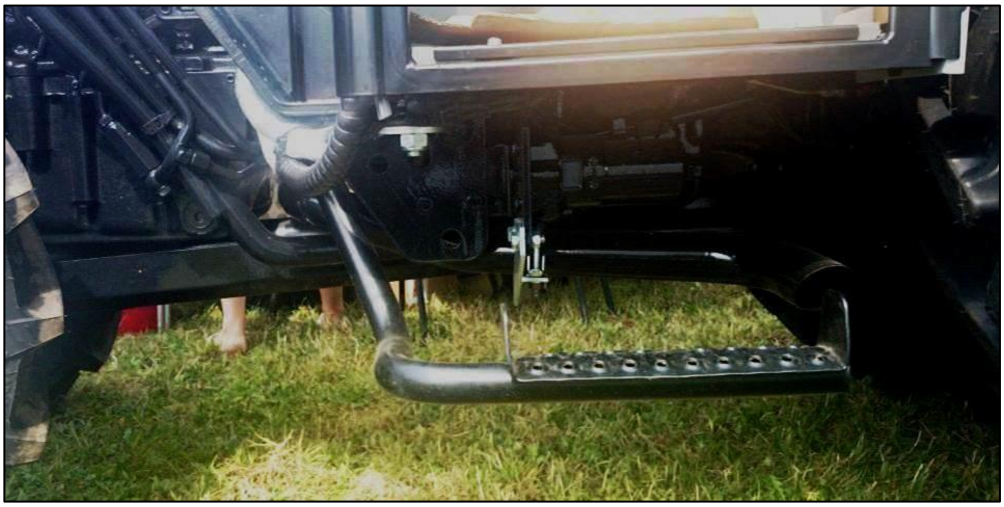


Figure 39: Area under the cab floor on a conventional, rigid-chassis T2 tractor

(Copyright TRL)

4.2.2 Location II: Between front wheel and door

This location provides an appropriate engine-to-SCR canister distance to retain exhaust gas heat, but space for packaging of both the mixer unit and SCR canister is limited. The area is close to the zones used for the door opening or cab access and for front wheel travel or stub axle rotation for steering on rigid-chassis vehicles. On articulated-chassis tractors, the front and rear tyres enter this area during steering (Figure 38), effectively precluding this particular location for siting of EAT hardware upon these vehicles.

Some NTTs are fitted with mid-mounted ROPS instead of operator cabs (Figure 4). Such ROPS, which are primarily intended for vehicles used in restricted height areas, are currently attached to the tractor chassis at this location. Also the location is occasionally used for mid-mounted implements (Figure 11) and also for attachment of front-mounted loaders (Figure 7, bottom-right). However, as discussed Section 2.1.1, front or rear-mounted versions of mid-mounted implements are available, are more popular and are more convenient to attach to the tractor. Also, the installation of a front-end loader on a vineyard/orchard NTT is not common due to problems of lateral stability introduced by the narrow vehicle wheel track width and the consequent danger of roll-over.

The SCR canister in this scenario would be fitted forward of the cab bulkhead. As for front wheel movement, the amount of space available (on a rigid-chassis NTT) depends on the vehicle's wheelbase and tyre size or wheel equipment choice. The NTTs shown in Figure 3 and Figure 36 indicate the potential existence of sufficient space to accommodate an SCR canister in this location: indeed, certain manufacturers already utilise the location for the exhaust silencer on Stage IIIA-compliant tractors (Figure 40).

Although they require secure attachment to the vehicle and are required to meet strict performance criteria, some scope exists for re-design of mid-mounted ROPS (Figure 41). Similarly, EAT canisters are increasingly available in a range of shapes (section 3.4), can be split into multiple substrates within a can and can be placed at any angle, allowing them to be fitted around other components.

Figure 40: Area between front wheel and door on a rigid-chassis Stage IIIA T2 tractor

(Copyright TRL)

4.2.3 Location III: Above the front wheel

This location, forward of the door opening, is related to a horizontal fitment. It provides an appropriate engine-to-SCR canister distance to retain sufficient exhaust gas heat and may also potentially accommodate the mixer unit.

The area here is used by some mid-mounted implements and, critically, is used by foldable, mid-mounted ROPS when in the lowered position. Depending on the wheel equipment choice and height, it may also be encroached upon by the front wheels of rigid-chassis tractors at certain steering angles and/or front axle articulation angles on uneven terrain. This location could reduce the operator's forward vision to the side of the engine hood or bonnet; particularly in the case of low-profile NTTs which feature a low driver's seating position (Figure 37 and Figure 38). Given the popularity of front-mounted implements for vineyard/orchard operations and the need for accurate vehicle directional control, maintenance of good forward vision on either side of the bonnet is an important requirement, which could potentially preclude the use of this location. However, developments in packaging of EAT hardware may well offer scope for its greater utilisation in the future (section 3.4).

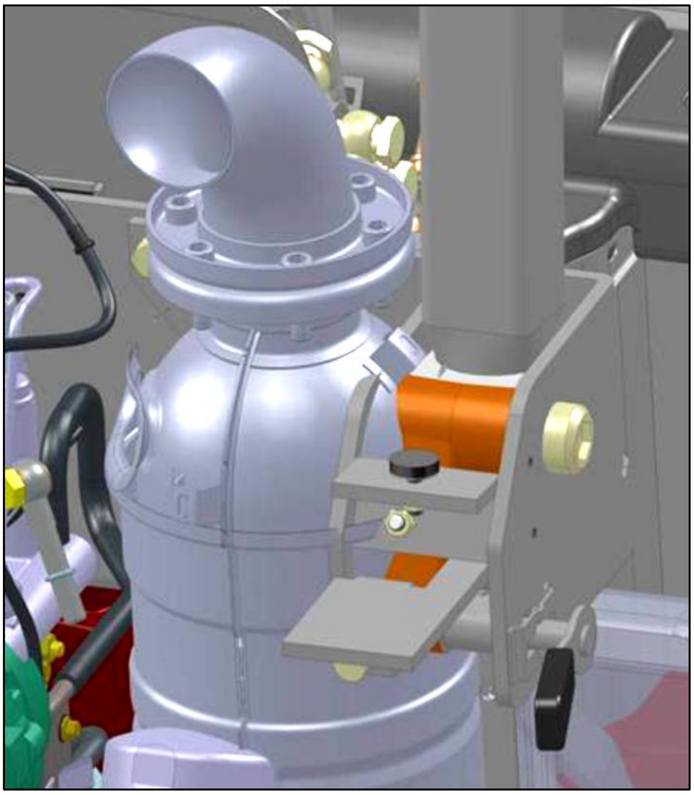


Figure 41: Interference with EAT canister indicates that the ROPS should be repositioned

(Copyright CEMA)

4.2.4 Location IV: Above the engine

This location provides an appropriate engine-to-SCR canister distance to retain exhaust gas heat and, potentially, space to locate the mixer unit. Whilst this has been the chosen location for SCR systems on some Stage IIIB and Stage IV-compliant agricultural tractors, to-date these have been larger (>75 kW) T1 category vehicles with greater space for EAT system packaging (Figure 28). Stakeholders indicated that this location was their preferred choice because it is likely to reduce design and manufacturing costs across model ranges (including T2 and C2).

Installing the SCR canister and mixer unit above the engine upon these (T1) vehicles has raised the bonnet height, somewhat to the detriment of the operator's field of forward vision. On larger T1 tractors which are not required to operate in areas of restricted height, this issue has been addressed by raising the cab or driver's seating position proportionally. However, this option is not necessarily acceptable for smaller T1 and NTT vehicles, particularly if they are required to operate in restricted headroom applications (Figure 5, Figure 37 and Figure 38). Industry stakeholders have commented that, in a certain instance, to accommodate an oval DOC canister above the engine of a rigid-chassis T2 vehicle (for Stage IIIB compliance); it has been necessary to raise the bonnet height by 150 mm. To meet Stage IV requirements the manufacturer in question would need to supplement the DOC with an SCR unit and, apparently, sufficient space is not available in this location to accommodate both units. However, the relative viability of this option will be dependent upon the future availability of EAT hardware in alternative packing formats.

The field of view issue only concerns over-the-bonnet vision. EAT hardware installation in this location would not affect vision to either side of the engine hood (Figure 42). To retain adequate forward visibility, it may be necessary to raise the driver's seating position slightly, which in turn would increase the overall height of vehicles fitted with cabs. This may be acceptable in the case of conventional rigid-chassis T2 vehicles (Figure 36), but it would not be suitable for those NTTs intended for operation in restricted-height applications (Figure 37 and Figure 38): these machines often having an overall height of <1.9 m.

Regarding any changes to the vehicle Centre of Gravity (CofG) and consequent lateral and/or longitudinal stability, the addition of a 40 kg EAT system (including reductant storage tank) is largely inconsequential when compared with a total (vineyard/orchard) NTT unladen mass of 2,500 - 3,000 kg. CofG location and consequent vehicle slope stability would therefore be unaffected. Raising the operator's cab by a significant distance would potentially raise the vehicle's Centre of Gravity (CofG) height and reduce stability. However, it is believed that, in order to minimise vehicle overall height, manufacturers would attempt to optimise engine hood design and thereby maintain the driver's field of vision with a minimum change in seating position height.

Figure 42: Over bonnet visibility with additional EAT hardware. Loss of viewing area negated with seating position change

(Copyright CEMA)

4.2.5 Location V: In front of the engine

This location provides an appropriate engine-to-SCR canister distance to retain sufficient exhaust gas heat, albeit possibly with the requirement for some additional thermal insulation. Also, sufficient space could be available to locate the mixer unit. Installation of SCR system hardware in front of the engine would require extending the bonnet length to create sufficient space for the additional components and/or extending the vehicle wheelbase (to prevent excessive frontal overhang).

Extending the length of the bonnet/tractor may affect the use of front-mounted implements and increase the turning radius. The extension necessary to house the SCR can, mixer unit and reductant tank would therefore need to be limited to the minimum achievable.

The ease of exploitation of this location differs between conventional rigid-chassis and articulated-chassis NTTs (Figure 43). In both instances the area in front of the engine is used to house the various cooling system heat exchangers (e.g. engine cooling, turbocharger intercooling, hydraulic system cooling and perhaps cab air conditioning). In the case of rigid-chassis tractors, the engine rarely extends beyond the front axle, making more space available in this area. This is then used to house the air intake filter and possibly the battery and/or the fuel tank (Figure 34). Articulated-chassis NTTs locate their power plants well-forward, over and partially in front of the front axle, to minimise vehicle wheelbase and enhance manoeuvrability. The various cooling packages are then sited in front of the engine, contributing to a substantial front-axle overhang. Scope for the addition of further (EAT hardware) items in this location may therefore be limited, but not necessarily impossible.

Figure 43: Stage IIIA T2 tractor front-of-engine detail - 81 kW rigid-chassis (left) and 68 kW articulated chassis (right)

(Copyright TRL)

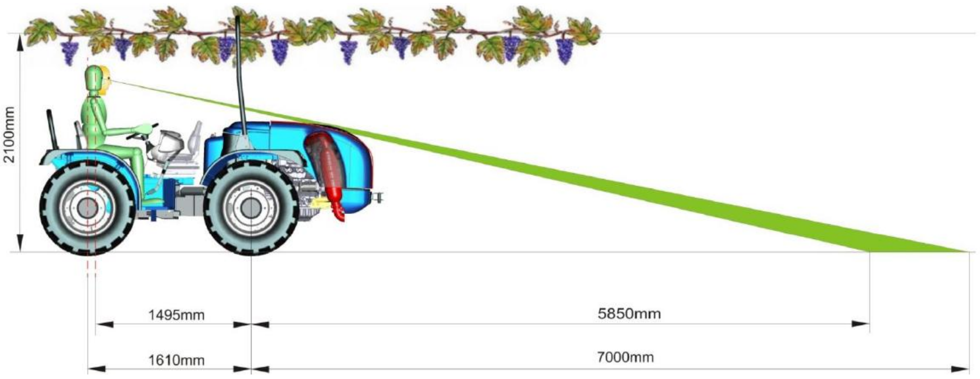


Figure 44: Influence of bonnet length on forward visibility

(Copyright CEMA)

A principal geometrical problem related to an extension of the bonnet and/or vehicle wheelbase could be reduced forward visibility from the driver's seating position (Figure 44). This would only be the case if the additional structure followed the bonnet leading edge contour, effectively extending the top of the bonnet. If the system was mounted lower, the sight lines could remain unchanged. If it was necessary to extend the bonnet, measures such as raising the seating height should alleviate the problem, but may incur certain other disadvantages, as discussed in Section 4.2.4.

Of potentially equal significance are the likely consequences of siting extremely hot (SCR canister and mixer unit) components to the front of the engine, within an area frequently used for cooling air admission. The restricted overall width of NTTs limits the engine hood frontal area. The solutions employed to-date to satisfy engine exhaust emission requirements have generally increased engine cooling requirements, which is a situation further exacerbated by increasing NTT engine power levels.

To obtain sufficient cooling airflow, most tractor manufacturers currently utilise air inlet grills on both the front sides and front / top face of the engine hood. The presence of any significant heat source (e.g. SCR canister) within this zone may potentially raise incoming air temperature and reduce vehicle cooling system performance, having an adverse effect upon vehicle fuel efficiency, therefore appropriate shielding and airflow modelling would be required during vehicle design.

4.2.6 Location VI: Alongside windscreen pillar

This potential location has several problems associated with it, which potentially precludes its use for installation of EAT hardware:

- The distance is possibly too great from the engine to retain exhaust gas heat for efficient SCR performance. However, additional thermal insulation could be installed on the device and the exhaust pipes leading to it.
- The operator’s lateral vision would be impaired by the attached components.
- NTT applications, with very few exceptions, require exhaust system hardware to be sited where it cannot contact or become entangled in passing vines / bushes / trees during in-field operation, i.e. exhaust down-swept under the vehicle.
- When fitted with operator cabs, low-profile NTTs intended for operation in restricted headroom applications feature curved front structural members to assist the passage of adjacent crops (Figure 37 and Figure 38). As above, siting EAT hardware in this location would not be acceptable.

Note that although slope-stability of these vehicles can be an issue, given the relatively low mass of the EAT hardware in comparison to that of T2 and C2 vehicles as a whole, this is not considered to be a concern.

4.2.7 Location VII: On top of the cab

This potential location has several problems associated with it, which potentially precludes its use for installation of EAT hardware:

- The distance is possibly too great from the engine to retain exhaust gas heat for efficient SCR performance.
- NTTs require low-level, down-swept exhaust systems.
- The height of the vehicle would increase to an unacceptable degree for many vineyard/orchard applications.
- A major heat source would be placed in close proximity to the operator’s cab ventilation system.

4.2.8 T2 tractor: Reductant tank locations

The reductant storage tank does not impose the same installation limitations as the SCR canister and mixer unit, in terms of proximity to the engine and likely heat generation. However, in a number of respects, it’s likely size (capacity) and connections to the mixer and dosing or control units, does impose constraints, particularly upon NTT vehicles where space is limited.

Possible locations for reductant storage may potentially include:

- Between the front wheel and cab door (Location II).
- At the rear of the tractor, possibly in longitudinal extensions of the rear mudguards.
- Within or as an extension to the cab roof (Location VII) – cabbed tractors only.
- Within the fuel tank (although not mixed): although this would reduce the fuel tank capacity which. (Section 4.1), is a critical issue for NTTs.
- Over wheel covers (a tank can be made to fit contours to a degree), but forward or implement visibility may be reduced. Wheel movement or front axle articulation may limit this option.
- Replacing a plastic cowling (the plastic container can have a double use, by replacing other covers located either within or outside of the cab).

4.2.9 Summary

There are many possible fitment locations of current abatement solutions for T2 tractors. Rigid and articulated tractors have a very different layout so the possible solutions will be different; moreover the configuration of each of the manufacturer's current models may necessitate different solutions.

The work presented in this section is intended as a feasibility assessment and not prescriptive design guidelines. This assessment allows for the possibility that new tractor models will be developed and designs of any parts adjusted to accommodate any additional equipment, for example ROPS or pipework.

Assuming an SCR EAT is used, below is a summary of each viable location:

For T2 tractors, locations II to V are all viable. For Articulated tractors locations IV and V are more of a possibility, however III could be chosen depending on the user's tyre choice.

- Location II: In some tractors, not only is there space between the front wheel and cab, but there is an exhaust silencer fitted there with ample space around for a larger canister. It is possible that tractor manufacturers could choose to modify their designs to create this space on future models. If this location is viable for a given model, the larger can would prevent the use with mid-mounted implements to one side of the vehicle, although mid-mounted implements are reducing is use anyway.
- Location III: A choice of wheel sizes means that this location above a front wheel is not always available, but if an operator chooses a smaller tyre option, together with above wheel EAT fitment, they could continue using mid-mounted implements.
- Location IV: Stakeholders highlighted above the engine to be the preferred location. Although it can affect the view by raising the overall bonnet height, it can be used with all T2 models (including all C2 vehicles), whereby reducing the number of designs needed. The disadvantage is that this location is already quite full, being used for Stage IIIB emission abatement equipment for instance, so unless that can be reduced in size or removed the bonnet height may become too high, especially for the very short articulated T2 vehicles (as well as C2 tractors).
- Location V: In front of the engine fitment would require the lengthening of the entire bonnet, placed between any front pick-up or PTO and the engine. This would not affect any implements, but could change the possible turning circle, so changes to the steering may be needed.

In addition, for rigid T2 tractors Location I, under the step is probably only truly viable if the SCR shape is flattened by splitting the substrate.

An interesting design difference with articulated tractors was that many had the option to rotate the seat. Given the possible visibility issues with lengthening the bonnet, it may just become more practical to use that position as default.

In conclusion, it may come down to multiple optional fitment locations that a customer could select depending on their specific needs. Providing the exhaust piping and/or EAT canister was proven to be comparable when the engine was type approved (i.e. is documented to keep within the required emission limits and performance range); the engine manufacturer is permitted to include multiple configurations of aftertreatment and exhaust pipework under one engine type approval.

4.3 Category C2

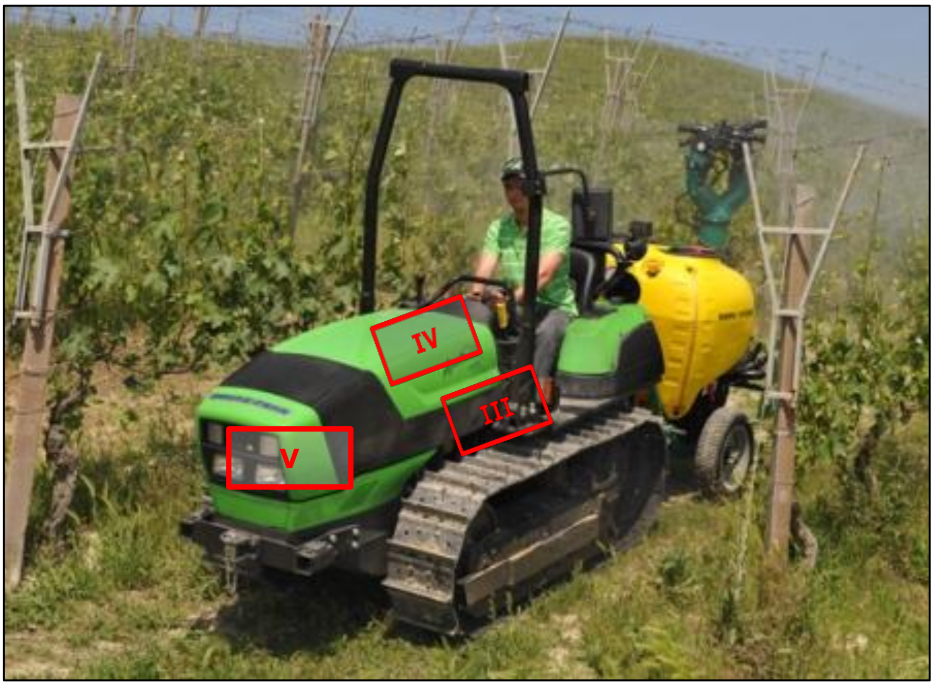


Figure 45: Some possible locations for EAT hardware on C2 track-laying tractors

(Copyright SDF)

Category C2 (narrow track-laying) tractors are similar in many respects to T2 vehicles, the main difference being that with a full-track laying system there is no gap present between the front and rear axles. The presence of the track units in close lateral proximity to either side of the engine or transmission limits scope for EAT system packaging on these vehicles.

With these aspects in mind, the Locations III, IV, and V (Section 4.2) offer greatest potential (Figure 45). Location I (under the cab / platform step) and at least half of the area defined by Location II (between the front wheel and cab door) do not exist on C2 tractors. Narrow (C2) track-laying tractors are more usually fitted with mid-mounted, foldable ROPS frames rather than operator's cabs (Figure 15 and Figure 45), in order to provide greater lateral and overhead clearance from growing crops in vineyards and orchards. Consequently, due to the nature of foldable ROPS, Locations VI and VII will not be available for EAT system installation. However, if a cab were fitted, these locations may be open to consideration, but the probability of crop entanglement is likely to be a restriction.

4.3.1 Location III: Above the track unit

Location III (above the front wheel), or rather above the upper surface of the track unit, may offer potential scope. Track-laying vehicles are usually skid-steered by adjusting the relative speed of the track units. Due to the steering characteristics of these vehicles, front and mid-mounted implements are rarely used; rather trailed or rear-mounted implements are most common (Section 0). Consequently the SCR canister and/or reductant tank could be placed on either side of the vehicle bonnet.

However, in order to enable the operator to maintain precise directional control of the vehicle, it is important to ensure adequate forward visibility alongside the bonnet/engine hood. Siting the EAT hardware closer to operator's station, rather than towards the front of the vehicle, is likely to overcome this particular issue. However, such siting may then interfere with the mid-mounted, foldable ROPS when in lowered position (Figure 45). Re-design of the ROPS could potentially overcome this issue, but this is not a trivial engineering task, would require re-homologation of the vehicle and may then result in the (higher) folded ROPS restricting operator forward vision. Widening of the ROPS frame may result in undesirable crop entanglement.

4.3.2 Location IV: Above the engine

The issues relating to siting the SCR canister and mixer unit in Location IV (above the engine) on C2 vehicles are largely identical to those which affect T2 vehicles (Section 4.2.4). Stakeholders indicated that this location was their preferred choice because it is likely to reduce design and manufacturing costs across model ranges. This location provides an appropriate engine-to-SCR canister distance to retain sufficient exhaust gas heat and, potentially, space to locate the mixer unit. However, the less frequent installation of an operator’s cab on C2 vehicles may permit the operator’s seating position to be raised, to maintain adequate field of forward vision, without adversely affecting the machine’s overall height.

Despite this potential advantage, the scope for exploitation of this location is open to debate, given the preference of manufacturers of T2 and C2 to maximise component commonality across these vehicle types (Section 2.4). This understandable desire may, however, be constrained by the possible requirement for individual EAT hardware installation solutions for T2 and C2 vehicles.

4.3.3 Location V: In front of the engine

Again, the advantages and disadvantages of siting EAT hardware in front of the engine on a C2 tractor are very similar to those previously discussed for T2 vehicles (Section 4.2.5). As shown by Figure 17 and Figure 45, the engine hood of a current Stage IIIA-compliant C2 tractor already extends beyond the front edge of the track units. However, that is not to suggest either that further extension of the engine hood is not feasible, or that all available space within the front of the hood is already fully-utilised. Similar issues of pre-heating of incoming cooling air (as discussed in Section 4.2.5) apply but, as previously stated, increased cooling system load may be an unfortunate but necessary consequence of exhaust emissions legislative compliance.

4.3.4 C2 tractor: Reductant tank locations

Regarding possible reductant tank locations, the absence of tall rear wheels on C2 vehicles creates considerably more space, immediately above the track units, to either side of the operator’s station. A tank could potentially be located here, or perhaps more conveniently within one of the moulded cowlings which border the operator’s station (Figure 15 and Figure 45).

4.3.5 Summary

For C2 tractors the possible locations for after treatment systems are much reduced compared to the T2 category, but there are three key viable locations, which also match those of both articulated and rigid T2 tractors. The approach is based on balancing any disadvantages with operators' needs.

The work presented in this section is intended as a feasibility assessment and not prescriptive design guidelines. This assessment allows for the possibility that new tractor models will be developed and designs of any parts adjusted to accommodate any additional equipment, for example ROPS or pipework.

- Location III: Fitment above a track unit could have a limiting factor on the view to one side. However, given appropriate heat shielding, there is much more scope for a C2 to locate the EAT further back in the vehicle, therefore reducing the impact of this for the driver.
- Location IV: Stakeholders highlighted above the engine to be the preferred location. Although it can affect the view by raising the overall bonnet height, it can be used with all C2 models (including all T2 vehicles), whereby reducing the number of designs needed. The disadvantage is that this location is already quite full, being used for Stage IIIB emission abatement equipment for instance, so unless that can be reduced in size or removed the bonnet height may become too high, especially for the very short articulated C2 vehicles (as well as T2 tractors).
- Location V: In front of the engine fitment would require the lengthening of the entire bonnet, placed between any front pick-up or PTO and the engine. However, for C2 vehicles front pick-up or PTOs are rare, with a preference for rear mounted or towed implements only. This location could change the possible turning circle; on the other hand tracked vehicles can turn very easily.

In conclusion, all three locations offer viable solutions for this tractor type, but have different potential advantages. Therefore, the manufacturers are likely to use their understanding of their user's needs to choose the most appropriate.

4.4 Category T4.1

The main operational requirements of category T4.1 high-clearance tractors (HCTs) are:-

- Adequate ground clearance to straddle crop rows.
- Sufficiently-low Centre of Gravity to ensure adequate stability on sloping ground.
- Tight turning circle for good headland manoeuvrability.
- Space for installation of implements/equipment, both under and above the vehicle frame.
- Location / design of vehicle components to avoid crop entanglement/damage.

These fundamental characteristics need to be maintained when attempting to site EAT hardware upon these vehicles.

As discussed in Section 2.3, apart from their operational applications, T4.1 tractors have little in common with T2 or C2 vehicles with respect to engineering design. HCTs generally feature a framework design, usually with the engine located above a main frame (one and two-row straddle) or underneath the main frame in a central nacelle, located to pass between two rows of crop (two-row straddle only). The latter vehicle type (Figure 20, Figure 21, Figure 46 and Figure 47) currently accounts for 60% of total T4.1 sales, primarily due to its enhanced stability characteristics over other 1-row and 2-row HCT designs. In all T4.1 designs, the engine and driving wheels are commonly connected by hydrostatic drivelines.

These constructional aspects (i.e. wider vehicle, greater freedom in engine positioning) permit a much greater range of options and present far fewer space constraints regarding the packaging of EAT system hardware and/or thermal insulation of components on T4.1 tractors. The key issue being that EAT hardware can potentially be located above the crop rows or vehicle framework and that narrow crop row spacing is not a restriction.

Safety aspects of T4.1 tractor operation mainly concern the greater possibility of roll-over due to their inherent high centre of gravity. As discussed in Section 2.3.1, the majority of T4.1 vehicles are constructed and used in France and therefore may follow the French national type-approval requirements for HCTs (NF U02-052-1 and NF U02-052-2); this specifies minimum lateral and longitudinal stability levels and requires the installation of approved ROPS. In practice, many designs of HCT offer very good slope stability.

However, whilst the possible installation of EAT hardware (e.g. SCR canister, mixer unit, urea storage tank) on an HCT may possibly be regarded as detrimental to vehicle slope stability, in reality the total mass of such EAT components (approximately 40 – 60 kg) is unlikely to be significant compared with the vehicle’s mass or that of attached implements. It therefore seems highly probable that manufacturers will find methods of incorporating the limited additional mass of SCR systems into safe designs of T4.1 tractors.

Possible locations for siting of EAT system hardware on T4.1 tractors are shown in Figure 46, and include:

I. Under the load platform / Over the engine compartment
II. Below the engine compartment
III. In front of the engine compartment
IV. Between the front and rear wheels
V. Behind the cab

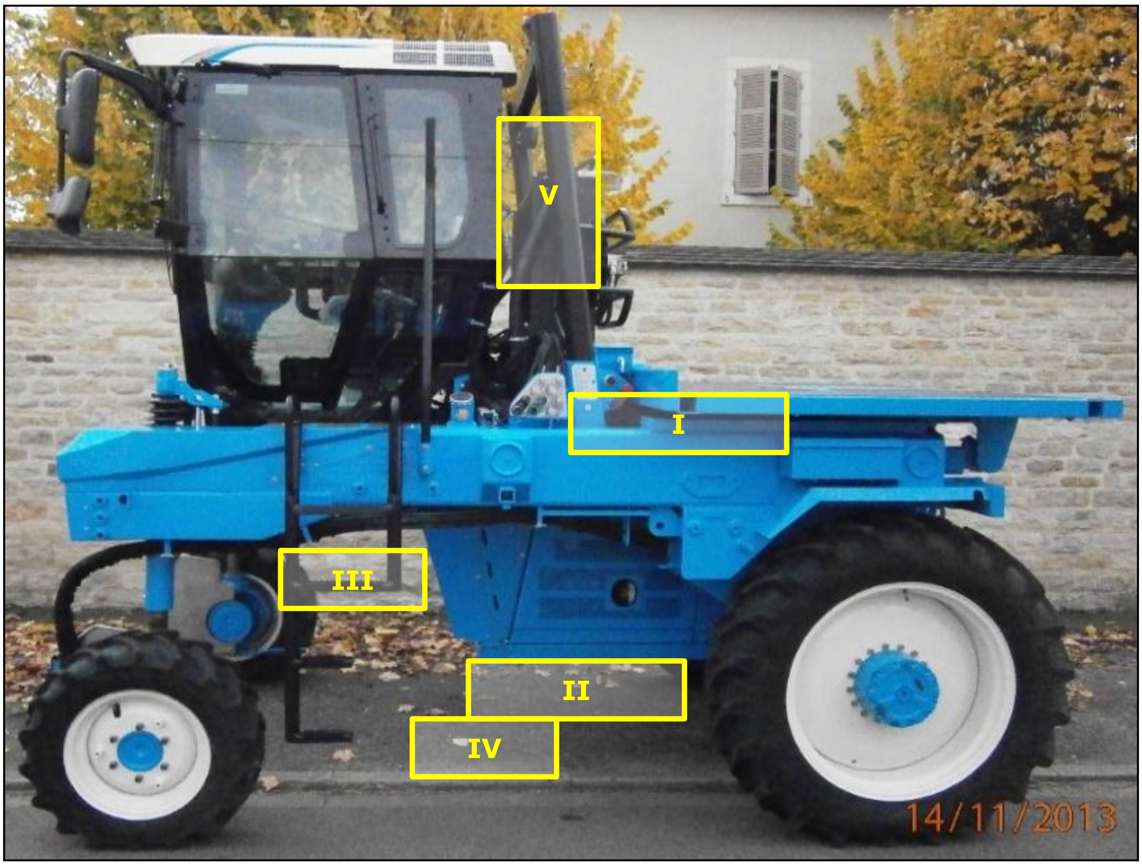


Figure 46: Some possible locations for EAT hardware on 2-row-straddle high clearance T4.1 tractors with a low, centrally-mounted engine

(Copyright CEMA / AXEMA)

Figure 47: Typical dimensions of a T4.1 tractor with low, centrally-mounted engine, configured to work in 1.05 m wide rows

(Copyright CEMA / AXEMA)

Figure 48: Degree of crop - machine clearance present as a T4.1 tractor undertakes leaf trimming operation in a vineyard

(Copyright CEMA / AXEMA)

Considering the potential viability of the each of the locations identified for possible siting of EAT hardware on T4.1 tractors:-

4.4.1 Location I: Under the load platform / over the engine

As discussed in Section 2.3.1, T4.1 HCTs are constructed in a variety of configurations, but the type shown in Figure 46, Figure 47 and Figure 48 is now the most common (Section 2.3). Because of the location of its powerplant, in a narrow, low-slung nacelle, centrally-located to pass between two crop rows, it potentially presents the greatest challenges to locating the EAT hardware.

Figure 48 shows that, during vineyard operations, there is limited clearance between the top of the crop rows and the underside of the vehicle structure, thereby precluding EAT hardware installation in this precise location. Increasing vehicle ground clearance would provide more space, but this is highly undesirable because of the consequent reduction in slope-stability. Similarly, we are informed by industry stakeholders that design constraints are imposed upon the maximum overall height of the load platform (for manual handling reasons).

Some space may be available immediately above the vehicle’s engine, particularly on other HCT variants where the powerplant is mounted above the vehicle’s main frame (Figure 19). However, in the HCT variant shown in Figure 48, space immediately above the engine would appear to be limited, but perhaps no more limited than in the case of a rough-terrain telescopic handler / forklift featuring a side-mounted engine, as is current common design practice for these machines. It would therefore appear that, whilst perhaps not trivial, scope exists to locate certain of the EAT components required in this location.

4.4.2 Location II: Below the engine compartment

This location is not particularly feasible on any of the current T4.1 designs. Those fitted with low-slung, centrally-mounted engine (Figure 46) would suffer an unacceptable reduction in ground clearance if EAT hardware were to be installed below the engine compartment.

Conversely, in the case of HCT designs with a high (above main-frame) mounted engine (Figure 19), the location of the mainframe would potentially preclude EAT hardware location, as well as the area being used for implements.

4.4.3 Location III: In front of the engine compartment

This particular option is only applicable to HCTs designs with a low-slung, centrally-mounted engine. Whilst space exists to extend the length of the engine nacelle on some machines (Figure 46), on others the central nacelle extends to the full length of the machine (Figure 20 – upper-left), housing the fuel and hydraulic oil tanks in addition to the powerplant. That is not to say that space could not be found within this ~2.7 m long nacelle to accommodate certain EAT system components in the vicinity of the engine.

Certain 2-row straddle HCT designs which feature part-length engine nacelles (Figure 46), offer the option of a hydraulically-actuated linkage which attaches to the front face of the nacelle. This is then used to attach and operate light-duty inter-row implements, thereby precluding the installation of EAT hardware in this location.

4.4.4 Location IV: Between the front and rear wheels

On first consideration, between the front and rear axles would appear to be a good location to site EAT system hardware, given that it could be guarded and insulated sufficiently to prevent crop damage. However, it must be remembered that HCTs are required to perform treatment operations both on the crop rows they straddle and on the soil / herbage between the rows. There is also a fundamental requirement to keep the tractor’s Centre of Gravity as low as possible, in order to maximise stability on sloping ground. For these reasons the vehicle designers have already made substantial use of these zones.

Figure 49: T4.1 tractor fitted with crop spraying equipment and saddle spray tanks

(Copyright CEMA / AXEMA)

Depending upon the season, the spaces between the front and rear wheels are used to locate inter-row soil tillage / weeding implements (Figure 19), ‘saddle’-type agrochemical storage tanks during spraying operations (Figure 49) or even grape harvesting modules on HCTs which can accept harvesting equipment. The existing utilisation of these areas by interchangeable implements therefore precludes their use for EAT hardware location.

4.4.5 Location V: Behind the cab

Whilst the location of EAT hardware on the rear load platform of a T4.1 tractor is not an option, the area immediately behind the operator's cab offers considerable opportunities. HCT manufacturers already utilise part of this area to house hydraulic system heat exchangers, oil storage tanks (Figure 50) and, in certain designs, the vehicle's engine (Figure 19). Of note is the use of this location to house the tractor's (vertically-orientated) exhaust in the majority of instances (Figure 19, Figure 46, Figure 47 and Figure 50).

It will be seen from Figure 50 that considerable space exists in this location to site a combined SCR canister and exhaust stack, potentially similar in design to those currently used on certain Stage IIIB and Stage IV-compliant T1 category tractors (Figure 31). Similarly, space exists at various points around the vehicle to locate the 15-20 litre capacity urea storage tank required by vehicles fitted with engines of the power rating typically found in T4.1 HCTs.

Figure 50: Area behind cab and exhaust system on a Stage IIIA T4.1 high-clearance tractor

(Copyright Tecnoma)

4.4.6 Summary

For T4.1 tractors, although there are some issues concerning the fitting of additional EAT system hardware to tractors with limited space available, the design flexibility permitted by the generic method of T4.1 HCT construction should result in a considerably less challenging design process compared to T2 and C2 vehicles.

It would appear that the space on or around the ROPS behind the operators cab, offers considerable scope to site EAT hardware on T4.1 vehicles. Even when, in occasional instances, this area may be fully-utilised, there is likely to be sufficient space elsewhere on the vehicle to site the necessary system hardware.

The work presented in this section is intended as a feasibility assessment and not prescriptive design guidelines. This assessment allows for the possibility that new tractor models will be developed and designs of any parts adjusted to accommodate any additional equipment, for example ROPS or pipework.

5 Environmental impact (Task 4)

To build upon the investigation performed in this report, an emission inventory has been performed for the European narrow track and high clearance tractors (T2, C2 and T4.1) for the following two scenarios:

- Vehicle meeting the Stage IV emission regulations join the fleet in the same rate (produced and purchased).
- Vehicle meeting the Stage IV emission regulations do not join the fleet (i.e. they are not produced or purchased). New vehicles would stay at Stage IIIB (either, pre-purchased before the Stage becomes compulsory or due to further derogation).

The difference between the emissions from these two scenarios shows the environmental impact of any further delay in the implementation of Stage IV to tractors of categories T2, C2 and T4.1.

Note; in the environmental impact assessment at first typical central values where taken for all tractor types allowing the magnitude of the emissions to be gauged and decide whether a more detailed micro simulation is required.

5.1 Timescales

The environmental impact will be performed for years relevant to the current legislative and potential future implementations dates. Due to specific concerns raised previous by stakeholders (CECE, CEMA, EUROMOT, 2006) (JRC, 2008), the tractors within category T2, T4.1 and C2 were granted three years derogation. Directive 2011/87/EU amending Directive 2000/25/EC, Article 4 details the dates of application and changes to that timetable for the specific engine categories granted by said derogation. These are outlined in Table 1. In addition, a sell off provision and flexibility must be considered:

1. +3 year derogation (2011/87/EU)
2. +2 year ‘Sell-off provision’ (97/68/EC or 2005/13/EC) for engine types already built
3. +40% or +20% flexibility (Stage IIIB or Stage IV respectively) of the previous five year annual average production volume

Taking this into account, vehicles may still be placed on the market up to 2 years after the deadline, and a further 20% of the sales the following year if the engine was produced prior to the deadline (See Annex 2 for further details). It has therefore been assumed that, with no further delay in the implementation of Stage IV, Stage IV tractors of categories T2, C2 and T4.1 will not appear in the fleet until late 2019. Therefore giving time for some models to enter the fleet 2021 has been taken as the date to perform the first analysis. The Stage V draft legislation is currently being reviewed by the European parliament so may change, however taking the draft date plus time for vehicles to enter the fleet the year 2025 has been taken for the second analysis.

5.2 Assessment of the Stage IV impact (Task 4.1)

The first step in the assessment is to determine the emissions for each type of tractor for each emission stage. This comprises of multiplying an appropriate emission value in g/kWh by the power demand (kW) to give the hourly emissions (g/h). However, the power demand will vary according to:

- The rated power of the tractor
- The activity which it is being used for

Where possible, the emission levels used will be the emission limits multiplied by emission factors, these factors have been derived from real-word emission testing of a given emission stage engine.

In addition to the NOx reduction calculations for the Stage IV, PM was calculated. Although there is no emissions change it is the subject of the preceding and following emission stages.

Just because a tractor has a 100 kW engine, does not mean the power demand will be 100 kW all for the time. Activities like crop spraying have a large power demand from the engine, where the maximum power, or close to it, might be used. However, other activities like crop maintenance only have a low power demand.

Table 13 has been developed from the information given by stakeholders listed in Table 5. The top half of the table (under the heading Power demand) shows the power demand for various operations. This is based on the rated power of the vehicle. The bottom half of the table (under the heading Time) shows the proportion of time different types of tractors are used for these operation over a typical year.

Table 13: Tractor power demand

	Spraying	Transport	Soil treatment	Crop maintenance	Irrigation	Harvesting	All
Power demand (percentage of rated power)							
Min	80%	40%	60%	20%	70%	80%	
Max	90%	50%	70%	30%	80%	90%	
Average	85%	45%	65%	25%	75%	85%	
Time (percentage of time)							
T2	55%	5%	15%	15%	5%	5%	100%
C2	57.9%	-	15.8%	15.8%	5.3%	5.3%	100%
T4.1	57.9%	-	15.8%	15.8%	5.3%	5.3%	100%

The actual rated power of each tractor is now known. However, it has been estimated that the average rated power within each band would be equivalent to two thirds of the range, apart from the larger T4.1 which have been taken to have a rated engine power of 100kW. The average rated engine power for each band is shown in Table 14.

Table 14: Typical tractor rated power (kW)

Assume 2/3 of range	Min (kW)	Max (kW)	Typical (kW)		
			T2	**C2**	**T4.1**
0-19 kW	0	19	14.25		
19-37 kW	19	37	32.5		
37-56 kW	37	56	51.25		51.25
56-130 kW	56	130	111.5	111.5	100

By multiplying the power demand percentage from the top of Table 13 by the typical rated power, the typical power demand has been calculated, as shown in Table 15.

Table 15: Typical power demand per activity (kW)

	Spraying	Transport	Soil treatment	Crop maintenance	Irrigation	Harvesting
T2						
0-19 kW	12.1	6.4	9.3	3.6	10.7	12.1
19-37 kW	27.6	14.6	21.1	8.1	24.4	27.6
37-56 kW	43.6	23.1	33.3	12.8	38.4	43.6
56-130 kW	94.8	50.2	72.5	27.9	83.6	94.8
C2						
56-130 kW	94.8		72.5	27.9	83.6	94.8
T4.1						
37-56 kW	43.6		33.3	12.8	38.4	43.6
56-130 kW	85.0		65.0	25.0	75.0	85.0

The typical power demand has then been multiplied by the percentage of time (from the bottom of Table 13) to derive the typical overall power demand shown in Table 16.

Table 16: Typical power demand (kWh) per hour of activity

	T2	C2	T4.1
0-19 kW	10.0		
19-37 kW	22.9		
37-56 kW	36.1		36.8
56-130 kW	78.6	80.1	71.8

For example, we have assumed that a T2 tractor in the 37-56 kW band will have a rated power of 51.25 kW (from Table 14: ¾*(*56-37) +37*) and its typical power demand (average over all the activities that it is used for) will be 36.1 kW (from Table 16).

The emission factors used in the analysis are the same as those used in the previous inventory calculations (CECE, CEMA, EUROMOT, 2006) and are shown in Table 17. These are based on the emissions limits (more information in Annex 2) multiplied by a factor:

- 0.8 for NOx
- 0.7 for PM

These multipliers were based on data observations from various sources. For Stage IIIB and Stage IV, the actual limits have been used as these vehicles are not currently present in the fleet; therefore observations of real-world emissions are not available for deriving the factors.

Table 17: Emission factors Stages I to IIIA, Emission limits Stage IIIB and IV

Stage	Category: net power (P) (kW)	Date	Oxides of nitrogen (NOx) (g/kWh)	Particulate Mass (PM) (g/kWh)
I	A: 130 ≤ P ≤ 560	1999.01	7.36	0.378
	B: 75 ≤ P < 130	1999.01	7.36	0.49
	C: 37 ≤ P < 75	1999.04	7.36	0.595
II	E: 130 ≤ P ≤ 560	2002.01	4.8	0.14
	F: 75 ≤ P < 130	2003.01	4.8	0.21
	G: 37 ≤ P < 75	2004.01	5.6	0.28
	D: 18 ≤ P < 37	2001.01	6.4	0.56

Stage	Category: net power (P) (kW)	Date	Oxides of nitrogen (NOx) (g/kWh)	Particulate Mass (PM) (g/kWh)
IIIA	H: 130 kW ≤ P ≤ 560 kW	2006.01	2.72	0.14
	I: 75 kW ≤ P < 130 kW	2007.01	2.72	0.21
	J: 37 kW ≤ P < 75 kW	2008.01	3.196	0.28
	K: 19 kW ≤ P < 37 kW	2007.01	5.1	0.42
IIIB	L: 130 kW ≤ P ≤ 560 kW	2011.01	2	0.025
	M: 75 kW ≤ P < 130 kW	2012.01	3.3	0.025
	N: 56 kW ≤ P < 75 kW	2012.01	3.3	0.025
	P: 37 kW ≤ P < 56 kW	2013.01	3.995	0.025
IV	Q: 130 kW ≤ P ≤ 560 kW	2014.01	0.4	0.025
	R: 56 kW ≤ P < 130 kW	2014.1	0.4	0.025

Using the emission factors (Table 17 in g/kWh) and the typical operational power demand and usage (Table 16 in kWh), the typical hourly emissions were calculated, these are shown in Table 18 and Table 19 for NOx and PM respectively.

Table 18: NO_x emission per hour of operation for the various tractor types and emissions stages (g/hour)

NOx (g/h)	T2				C2	T4.1	
Rated power	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Power demand	10.0	22.9	36.1	78.6	80.1	36.8	71.8
Stage IV				31.44	32.04		28.74
Stage IIIB			144.34	259.40	264.34	147.09	237.08
Stage IIIA		116.85	115.48	213.81	217.88	117.67	195.41
Stage II	73.94	146.64	202.34	377.32	384.50	206.19	344.84
Stage I	73.94	168.64	265.93	578.55	589.57	270.99	528.76

Table 19: PM emission per hour of operation for the various tractor types and emissions stages (g/hour)

PM (g/h)	T2				C2	T4.1	
Rated power	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Power demand	10.0	22.9	36.1	78.6	80.1	36.8	71.8
Stage IV				1.97	2.00		1.80
Stage IIIB			0.90	1.97	2.00	0.92	1.80
Stage IIIA		9.62	10.12	16.51	16.82	10.31	15.09
Stage II	5.98	12.83	10.12	16.51	16.82	10.31	15.09
Stage I	5.98	13.63	21.50	38.52	39.25	21.91	35.20

These tables show how for the Stage IV vehicles compared to the other stages there is a large reduction in the NOx emissions. Comparing Stage IV with Stage IIIA shows a large reduction in both NOx and PM emissions.

Based on this usage, together with the vehicle operating hours, the annual energy demand (kW times hours) and the annual emissions (g/h times hours) can be calculated. For this, the following two have been considered:

- **The first life:** consolidating all information from Section 2.5 this has been taken to be 7 years for all vehicle types. The typical usage is shown in Table 20.
- **The second life:** after the initial use, it has been assumed to be the typical operation hours drop to half those of the first life (representative of all high power demand operations being beyond its capability).

Table 20: Typical annual operating hours for the first life (hours/year)

	< 19 kW	19-37 kW	37-56 kW	56-130 kW
Hours/year	150	400	500	700

5.3 Scaling of the impact to the European fleet (Task 4.2)

The emissions determined in Task 4.1 have been scaled according to the number of vehicles in the fleet. Using the data from Task 1, the fleet composition has been derived for T2, C2 and T4.1 tractors. This is based on a number of assumptions:

- The sales data is valid for the whole of Europe.
- Sales figures do not vary each year (in practise, they will vary, but for this analysis, due to there being no official annual sates data, it has assumed to be constant).
- The useful machine life default had been taken to be 16 years for all tractor types. The CECE, CEMA, EUROMOT (2006) method has been used to determine the machines remaining in service. The distribution used for determining the number of machines in service is illustrated in Figure 51.
- The latest annual sales figure of 3,414 C2 tractors was used.

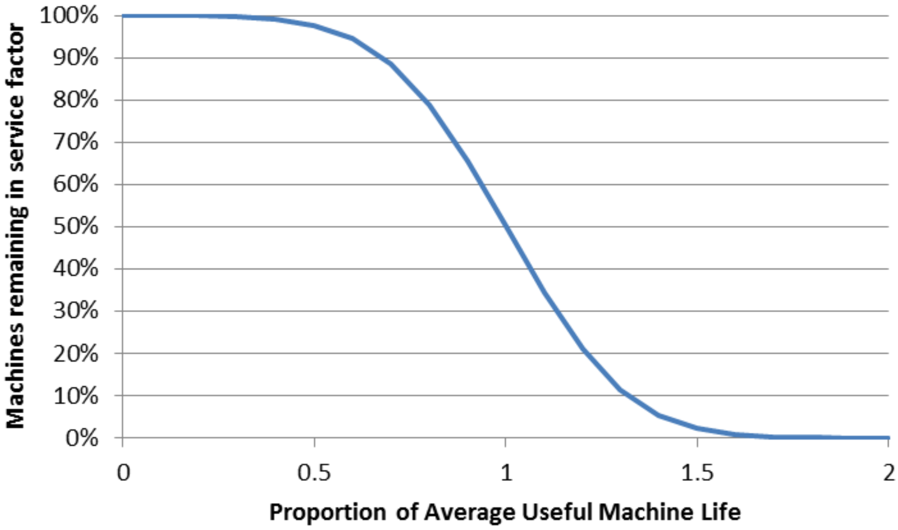


Figure 51: Reduction in machine population with machine life consumed (CECE, CEMA, EUROMOT, 2006)

5.4 Results

With all the required data, the final analysis was performed. This was done for the years 2021 and 2025, with and without the application of the Stage IV emission stage.

The disadvantage of further delaying the implementation of the Stage IV emission limits on T2, C2 and T4.1 tractors (power range 56kW to 130 kW) is:

- An annual increase in NOx of 7,030 tonnes or 39% in 2021 (Table 21).
- An annual increase in NOx of 16,379 tonnes or 108% in 2025 (Table 22).
- Cumulative emissions of 14,058 tonnes of NOx by 2021 (Figure 53)
- Cumulative emissions of 65,545 tonnes of NOx by 2025 (Figure 53)

5.4.1 Model results

Below are each fleet's NOx emissions for the years 2021 and 2025. A full breakdown of the analysis of the European T2, C2 and T4.1 fleet and its emissions are shown in Annex 5 and Annex 6, including the PM emissions.

Table 21: Effect of Stage IV on the 2021 (56-130 kW) NTT fleet

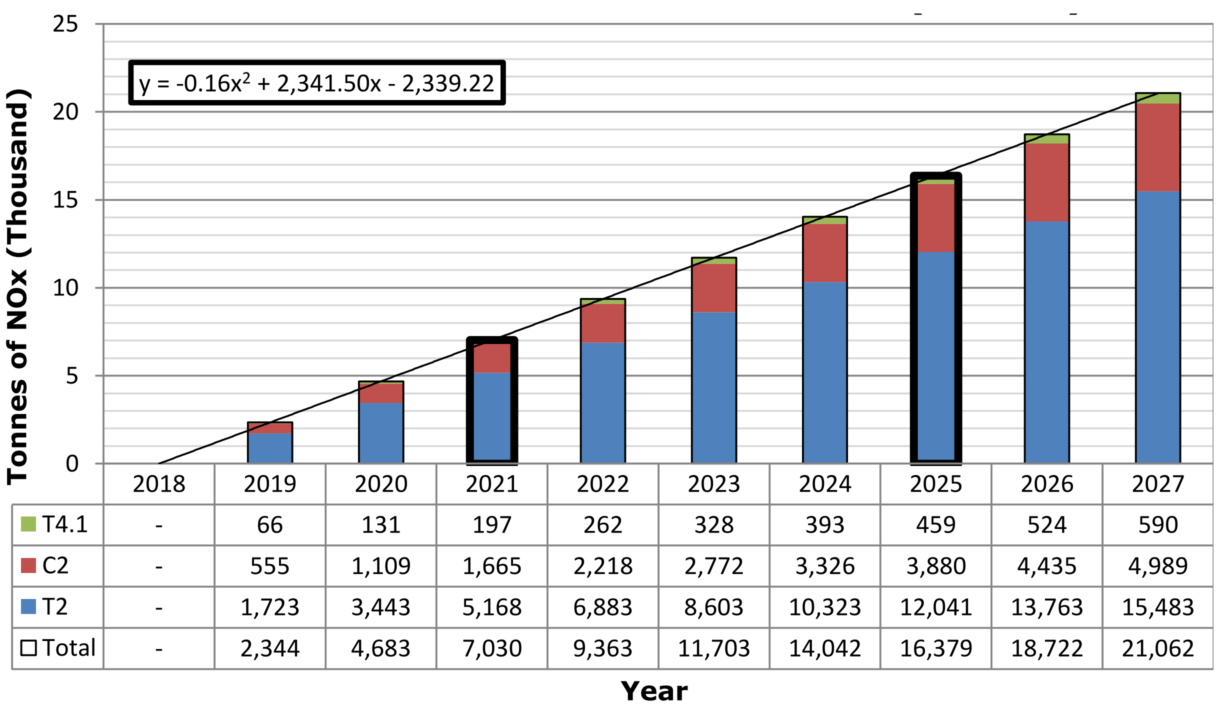
	T2 56-130 kW	C2 56-130 kW	T4.1 56-130 kW	Total 56-130 kW	Disbenefit
Base fleet (tonnes) including Stage IV					
NOx	13,323.87	4,293.20	507.52	18,124.59	
Modified fleet (tonnes) excluding Stage IV					
NOx	18,492.00	5,958.46	704.38	25,154.85	
Benefit					
NOx	5,168.13	1,665.26	196.86	7,030.26	38.79%

Table 22: Effect of Stage IV on the 2025 (56-130 kW) NTT fleet

	T2 56-130 kW	C2 56-130 kW	T4.1 56-130 kW	Total 56-130 kW	Disbenefit
Base fleet (tonnes) including Stage IV					
NOx	11,147.64	3,591.97	424.63	15,164.24	
Modified fleet (tonnes) excluding Stage IV					
NOx	23,188.26	7,471.68	883.27	31,543.21	
Benefit					
NOx	12,040.62	3,879.71	458.64	16,378.97	108.01%

Compared to EU this represents a relatively low proportion of NOx. However, given that the fleet values contain such large ranges and variability this is a reasonable estimate of the benefit. Further micro simulation of the sector is unlikely to provide a greater depth of understanding of the emissions generated.

Figure 52 shows the additional NOx emissions that would be experienced if Stage IV was not introduced in 2019. A baseline of zero additional NOx was set for 2018 and a model used to generate the results for 2021 and 2025. A trend line was generated allowing the intervening and following results to be forecast. The trend produced shows an almost linear increase year by year.

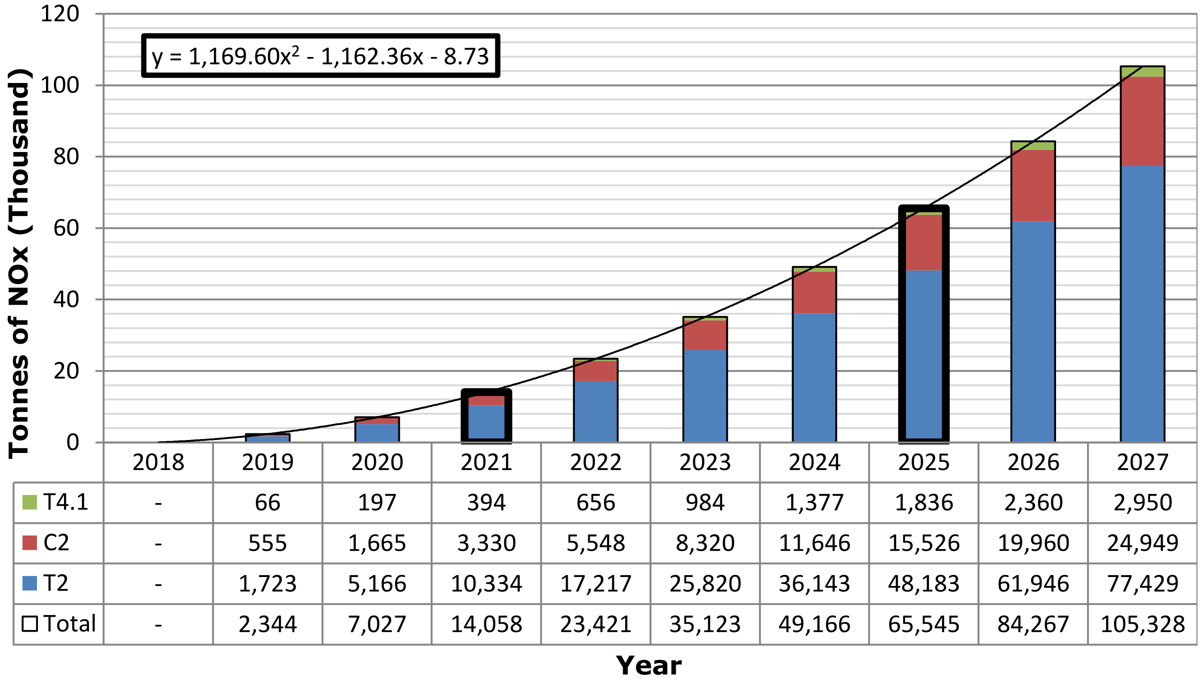


	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
🟩 T4.1	-	66	131	197	262	328	393	459	524	590
🟥 C2	-	555	1,109	1,665	2,218	2,772	3,326	3,880	4,435	4,989
🟦 T2	-	1,723	3,443	5,168	6,883	8,603	10,323	12,041	13,763	15,483
☐ Total	-	2,344	4,683	7,030	9,363	11,703	14,042	16,379	18,722	21,062

Figure 52: Yearly disbenefit in the emissions of NOx for T4.1, C2 & T2 tractors and the total, for the years 2018 – 2027. The years 2018, 2021 and 2025 generated from model, other years generated from trends

5.4.2 Cumulative calculation

With the forecast values it was possible to plot the cumulative disbenefit in NOx emissions (Figure 53). If the emission stage IV is not implemented, by 2021 a cumulative total of 14,000 tonnes additional emissions of NOx would have been emitted, and by 2025 this will have risen to 65,500 tonnes.



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
🟩 T4.1	-	66	197	394	656	984	1,377	1,836	2,360	2,950
🟥 C2	-	555	1,665	3,330	5,548	8,320	11,646	15,526	19,960	24,949
🟦 T2	-	1,723	5,166	10,334	17,217	25,820	36,143	48,183	61,946	77,429
☐ Total	-	2,344	7,027	14,058	23,421	35,123	49,166	65,545	84,267	105,328

Figure 53: Cumulative disbenefit in the emissions of NOx for T4.1, C2 & T2 tractors and the total, for the years 2018 – 2027. The years 2018, 2021 and 2025 generated from model, other years generated from trends

This cumulative calculation begins to show the potential disbenefit to the population in and around the grape growing regions because the harmful NOx emissions are heavier than air and are unlikely to be dispersed across a wide geographical area. Therefore the adverse health effects will predominantly affect populations within 200-800 m of the vehicle's use; i.e. the vine-growers themselves and the rural towns and villages in and around them will take the majority of the burden from the additional NOx pollution.

Stakeholders provided limited data on the distribution of the vehicles but stated that T2 tractors are used across all wine regions, C2 tractors are used in Spain, Italy, France and Greece, and that 95% of T4.1 tractors are used in France with the rest spread throughout the other wine regions. Annex 7 shows data on the EU grape and wine production. This is indicative of the regions using these tractors and therefore where will be most affected by the NOx emissions (FAO, 2014). Spain, France and Italy produce the vast majority of grapes and wine, and therefore will bear the majority of the burden.

5.4.3 Comparison with European emissions

Considering the yearly emissions, when placed against the entire NTT fleet (including all power ranges not within the scope of the Stage IV emission limits), the disbenefit for the year 2021 is 34.4%. The total NOx emissions from the agriculture category[7] within Europe for 2012 is forecast to be 481,800 tonnes[8] and the total NOx emission for the entire EU28 (all sectors) is forecast to be 8,478,600 tonnes. When compare against these fleets, the 7,030 tonne p.a. increase in NOx emissions represents 1.5% or 0.08% respectively (Table 23).

Table 23: Effect of no Stage IV on the 2021 NTT fleet per year

NOx	Without Stage IV (tonnes)	With Stage IV (tonnes)	Increase (tonnes, %)
56 – 130 kW NTT	25,154.85	18,124.59	7,030 (38.8%)
All NTT	27,458.76	20,428.50	7,030 (34.4%)
Agriculture sector	488,830.26	481,800.00	7,030 (1.5%)
EU28 (all sectors)	8,485,630.26	8,478,600.00	7,030 (0.08%)

If, however, the emissions for 2025 are considered, the proportion of Stage IIIB 56 – 130 kW NTT and HCTs would have increased such that the potential disbenefit becomes 73.2% (Table 24) and 3.4% for the agricultural sector.

Table 24: Effect of no Stage IV on the 2025 NTT fleet per year

NOx	Without Stage IV (tonnes)	With Stage IV (tonnes)	Increase (tonnes, %)
56 – 130 kW NTT	31,543.21	15,164.24	16,379 (108.0%)
All NTT	38,743.17	22,364.20	16,379 (73.2%)
Agriculture sector	498,178.97	481,800.00	16,379 (3.4%)

Although the assumption can be justified of the total NTT and HCT fleet staying level, the same cannot be said of the agricultural sector of for the total European emission. Figure 54 shows the NOx emission for 1990 – 2011 together with a forecast for total EU28

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[7] Agriculture/Forestry/Fishing: Off-road vehicles and other machinery

[8] European Environment Agency, http://www.eea.europa.eu/data-and-maps/data/data-viewers/air-emissions-viewer-lrtap

emission of NOx. This predicts that the total EU28 NOx is predicted to fall from 8.4 Mt to 5 Mt. No values could be obtained on the forecast specific to the agricultural sector.

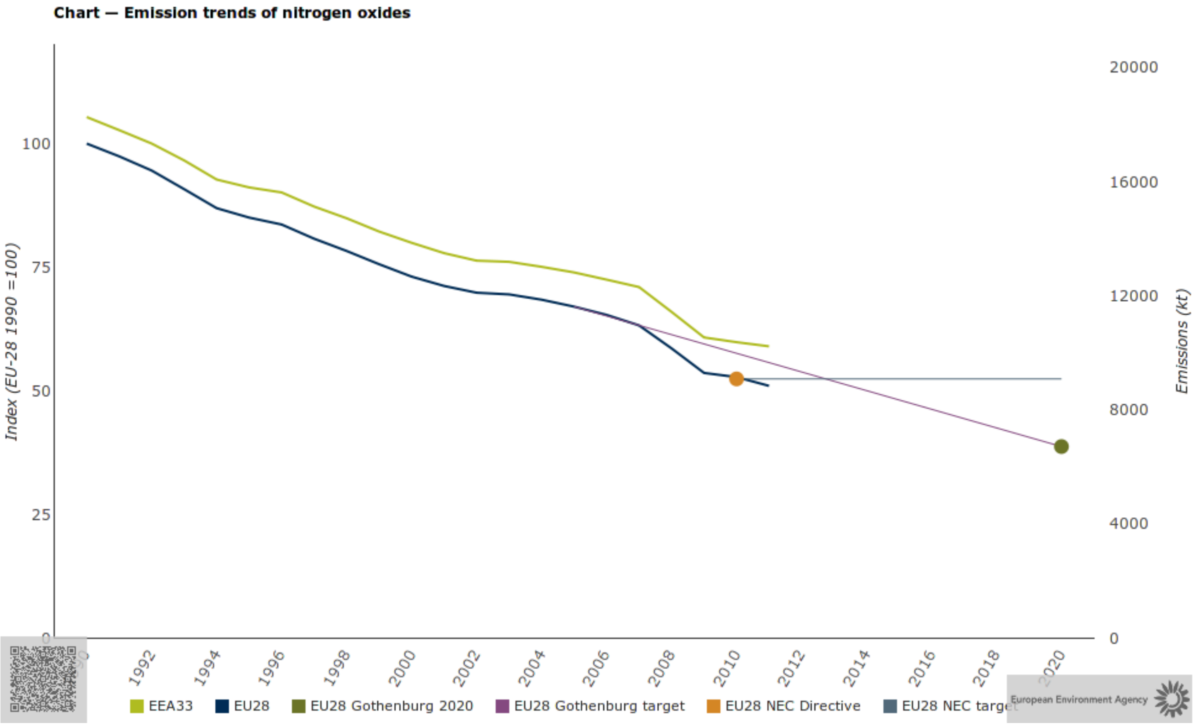

Figure 54: Total EU28 NOx emissions for 1990 – 2011, including the Gothenburg 2020 target (European Environment Agency, 2013)

Table 25: Effect of no Stage IV on the 2025 NTT fleet per year for the EU28 taking into account forecast reductions in total emissions

NOx	Without Stage IV (tonnes)	With Stage IV (tonnes)	Increase (tonnes, %)
EU28 (all sectors forecast)	5,093,628.97	5,077,250.00	16,379 (0.3%)

5.5 Summary

The environmental assessment found in the first analysis that if Stage IV was further delayed then approximately 7,000 tonnes of NOx emissions would be emitted for the year 2021.

In the second analysis the increase in penetration of additional Stage IIIB vehicles increases this potential addition to approximately 16,400 tonnes of NOx for the year 2025.

When assessed as a cumulative value, the non-introduction of Stage IV emission limits in 2019 would have cumulatively generated 14,000 tonnes of NOx by 2021 and this would have reached 65,500 tonnes by 2025. The heavier than air NOx will disperse in a relatively small area, meaning that the vine-growers themselves and the rural towns and villages in and around them will take the majority of the burden from the additional NOx pollution.

Considering Europe as a whole, narrow track tractors contribute to less than 1% of the current NOx emission for the EU. This study has identified that although the overall contribution from these vehicles will remain low, unless there is action, it is likely to proportionally increase over time as other sources become cleaner.

6 Discussion and conclusions

6.1 Discussion

There are already mature technologies which can be applied to NRMM engines that meet the Stage IV requirements. The concerns for feasibility instead concentrated on the effect on tractor design, farming techniques, and the commercial effects.

From the assessment of current and upcoming technologies, it was concluded that SCR was the only technology identified to be capable of fully meeting the requirements of Stage IV. This emission step requires the reduction of NOx, which although it can be partially reduced through other technologies, none can fully meet the requirements even when combined.

The emission control devices required for NTTs to meet the Stage IV emission targets are commercially available, and in use on HDVs and T1 tractors. Yet, in the current state of development direct application of existing systems on existing engines is likely to require mounting where it can cause issues with functionality or visibility.

- For a T2 tractor, locations II to V are all viable (between the cab and front wheel, above the front wheel, above the engine, and in front of the engine respectively).
- For articulated T2 tractors locations IV and V are more of a possibility, however III could be chosen depending on the user's tyre choice.
- For C2 locations III to V are all viable (above the track, above the engine, and in front of the engine).
- For T2 tractors, locations II is not always available and would prevent a mid-mounted implement to be used on one side, for T2 and C2 location III can be used if the customer chooses a small enough tyre, IV would need a raised bonnet, thus a raised seating position would also be needed, and V would lengthen the bonnet so improvements to steering would be needed for T2 tractors.

Overall, for T2 and C2 vehicles the solution may come down to multiple optional fitment locations that a customer could select depending on their specific needs. Providing the exhaust piping and/or EAT canister was proven to be comparable when the engine was type approved (i.e. is documented to keep within the required emission limits and performance range); the engine manufacturer is permitted to include multiple configurations of aftertreatment and exhaust pipework under one engine type approval.

For T4.1 there are very different design considerations, however it would appear that the space on or around the ROPS behind the operators cab, offers considerable scope to site EAT hardware on T4.1 vehicles. Given appropriate shielding and insulation of the pipes leading from the engine, or using this length for the reductant injection and mixing, would permit the SCR to be fitted on or near the ROPS frame.

Even given any shortcomings of current technology, it is not foreseen that there will be a technology in the short to mid-term that can be applied without at least some level of penalty. Indeed, looking historically at technology progression it is unlikely that the required devices will reduce in size significantly.

That said, methods used by abatement manufacturers to fit within constrained locations are well known and can be used in this case and it is possible they will mitigate some identified problems in the future (e.g. multiple smaller SCR substrates). Moreover, progress can be made on the dimensions of other components; the Stage IIIB abatement can be reduced in size or merged with the Stage IV EAT devices (i.e. CSF, SCRonF, VGT, etc.), piping can be rerouted, and other auxiliary parts where location is less critical can be relocated (e.g. the battery, ECU, etc.).

The difficulties faced by the tractor manufacturers were raised, but there are several large engine manufacturers supplying the market, and it is in their interest to develop engines which meet consumers' expectations. With the relatively large number of tractor producers, there is a competitive pressure from the tractor manufacturing customers to the engine and abatement manufacturers. This pressure promotes the development of new technologies including those which make the components smaller and reduced in complexity (and cheaper).

The engine manufacturers identified have experience in the abatement of NOx; either for engines of different sectors or engine sizes, where the NRMM or similar legislation has already come into effect. Likewise emission abatement producers are constantly developing the technology to meet the various reducing emission limits worldwide, while reducing size and complexity. The tractor manufacturers also have experience in the identified technology, the slightly earlier introduction of Stage IIIB requirements for power-plant categories L (130 - 560 kW) and M (75 - 130 kW) caused EAT solutions to be implemented upon these higher-powered tractors (generally T1 or T4.2 category) prior to smaller N-category (56 - 75 kW) vehicles. In the majority of cases >75 kW tractors have relied upon SCR-based EAT systems as part of their strategy to achieve Stage IIIB compliance and, in a number of cases, are now demonstrating Stage IV compliance by use of the same technology.

It is recognised that the development of a tractor does have significant cost and time needs. Of the companies identified in this study, it was not evident that any T2 or C2 producers have low enough staff numbers or turnover to be considered an SME[9], although many of the T4.1 producers may meet the criteria. Nevertheless, the specific product share of NTT or HCTs within their business could be of such a small size that the high levels of development cost required for each emission step need to be justified by foreseeable sales. It was stated by more than one stakeholder, that they may decide to exit the sector at the next emission step (Stage IV). However, one category of tractor which largely consists of small organisations (T4.1), also has the least level of technical difficulty in reaching the upcoming emission Stages with current technology.

Stakeholders highlighted the major cost implications they had and are experiencing in re-type approving engines for Stages IIIA and IIIB while creating their new models. To meet the new emission regulations after treatment systems will be required to be fitted externally of the standard engine bay area. Following this review, it is recognised that this is causing a step change in the tractor/engine/abatement manufacturer relationship.

Until the most recent emission stages a tractor manufacturer could wait until the design of a new tractor model before interacting up the supply chain. Now however, certain parts included within the engine type approval need to be selected and adapted to fit within the constraints of the tractor. If an engine model is already type approved it becomes a significant issue and cost to retest it and have it recertified. This added cost is likely taken by the tractor manufacturer.

However, the engine type approval process has a mechanism to include all comparable abatement systems with different after-treatment technologies and/or different layouts under a single approved engine family. Therefore, as Stage IV and V engines of the relevant power ranges are begin developed, the tractor manufacturers can liaise more closely from the early stages of their tractor design. By communicating the exhaust system and emission abatement design requirements, they can be integrated into the type approval process and be covered under a single approved engine family; therefore significant additional costs can be removed.

Based on the current legislation for Stage IV (including derogation, sell-off provisions and flexibility) and the draft legislation for Stage V, there is potentially a very short period between the need to develop two distinct model ranges, perhaps 2-3 years. It was evidenced by stakeholders that, the time needed to modify, test and validate a model for a given emission stage was a minimum of three years. Given the substantial cost for development of new models, from a competitiveness perspective tractor manufacturers argued that they would benefit if Stage IV is dropped.

The counterargument which must also be considered, from the viewpoint of legislation, is the overarching requirement for continual improvement to benefit society and human health. As is often the case, unless incentivised, developments without a clear

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[9] A small or medium-sized enterprise is defined by having; ≤250 employees or a turnover of ≤ €50m (Rugman & Collinson, 2012)

commercial advantage are not implemented. Moreover, if there is any real or perceived disadvantage manufacturers will only implement a change when it is seen all others in the market have done so, for fear of losing market share. Legislation for emission limits provides this incentive, allowing manufacturers to have a level playing field.

If the results of the environmental impact are considered, if Stage IIIB tractors are kept in circulation for 2-3 further years, a relatively small proportion of a region's NOx emissions would be released. But NOx is a harmful emission, it mostly effects the location it is emitted from, i.e. the farms and villages in amongst the vineyards, and looking at the emissions as a proportion must also consider the changing share of emission from other NRMM and road LDV and HDVs, where SCR has been entering the market for some time. Therefore if no legislation brought in the requirements it would not be long before NTT's and HCT's NOx emissions became of considerable concern.

6.2 Conclusions

This assessment has concluded that it is technically feasible to implement the new pollutant emission Stages IV, for T2, C2 and T4.1 categories of tractors.

To meet the new emission standards different powertrain technologies and after-treatment systems are likely to be required, it has been identified that all technologies needed are currently in use in other comparable vehicles. The integration of this equipment and the associated packaging or positioning on the vehicle may, in some instances, introduce operational limitation.

For rigid T2, articulated T2 and C2 vehicles there are three to four viable locations. Each has different potential advantages. Of the viable locations identified, the fitment will affect either mid-mounted implement usage, change the fields of view and/or alter the turning radius. Therefore, the manufacturers are likely to use their understanding of their user's needs to choose the most appropriate. Or offer multiple optional fitment locations that a customer could select depending on their specific needs. Providing the exhaust piping and/or EAT canister was proven to be comparable when the engine was type approved (i.e. is documented to keep within the required emission limits and performance range); the engine manufacturer is permitted to include multiple configurations of aftertreatment and exhaust pipework under one engine type approval.

For T4.1 high clearance tractors it has been identified that appropriate exhaust systems used on some T1 tractors may be viable for their use. Fitment locations such as behind the operators cab were identified to be viable.

An assessment of new vehicle sales estimated that there are 21,750 T2, 3,400 C2 and 500 T4.1 tractors sold in Europe annually. However, 50% of the T2 vehicles are of ≥56 kW engine power and therefore subject to Stage IV emissions requirements. Rigid-chassis T2 vehicles represent approximately 83% of this ≥56 kW market segment.

Furthermore, in Europe, the total fleet size in 2013 is estimated to be 358,859 for T2, 56,331 for C2 and 8,250 for T4.1. The average annual usage is 600 - 700 hours for T2, 350 - 650 hours for C2 and 400 hours for T4.1 vehicles. The average frontline vehicle life for T2, C2 and T4.1 is 7 – 10, 16 and 7 - 10 years respectively, but each vehicle may expect a further secondary life (at reduced annual usage) of up to 10 years.

The environmental assessment found that if Stage IV was not attained in 2019, then approximately 7,000 tonnes of additional NOx emissions would be emitted for the year 2021 and approximately 16,400 tonnes of additional NOx emissions for the year 2025. The increase in additional NOx emissions in 2025 compared to 2021 is associated with the greater proportion of vehicles that could have met Stage IV criterion if it was introduced in 2019. When assessed as a cumulative value, the non-introduction of Stage IV emission limits in 2019 would have cumulatively generated 14,000 tonnes of NOx by 2021 and this would have reached 65,500 tonnes by 2025. The heavier than air NOx will disperse in a relatively small area, meaning that the vine-growers themselves and the rural towns and villages in and around them will take the majority of the burden from the additional NOx pollution.

Moreover, while the year's emissions for 2021 present a 1.6% increase in this sector, or 0.08% of the entire EU28, the 2025 emissions this will represent a 3.4% increase in the sector and by applying the emission reductions agreed in the Gothenburg 2020 target, the proportion becomes 0.32% against the entire EU28's yearly emissions.

Until the most recent emission stages tractor manufacturers could wait until the near final design of a new tractor model before fully interacting with their supply chain. Now however, certain parts included within the type approval need to be selected and adapted to fit. As Stage IV and V engines of the relevant powers are being developed, the manufacturers will need to liaise more closely from the early stages of their tractor design. By understanding the exhaust system and emission abatement design requirements, it is proposed by this study that these can be covered under a single approved engine family, significantly reducing additional costs.

It has been recognised that the time required on Research and Development for a new vehicle is approximately 3 - 4 years, whereas the gap between stage IV and V is likely to be 2 - 3 years. For this sector the cost in proportion to income is large, consequently, it has been indicated by stakeholders that it makes commercial sense to skip Stage IV. However, with the saving possible with greater collaboration with engine producers it may still be possible to produce both stage IV and V vehicles, as it could reduce both costs and time (for re-certification).

Type-approval records suggest certain manufacturers may homologate selected smaller T1 vehicles and/or side-by-side utility vehicles within the T2 category, possibly thereby benefiting from current derogations in engine exhaust emissions legislation. Should further derogations be considered in the future, it may be worthwhile to review their methods of implementation, in order to minimise possible misuse.

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Glossary

More terms need to be added before final report to assist the reader.

Term	Definition
AdBlue	See Reductant
Adsorption	The accumulation of atoms or molecules on the surface of a material
AECC	association for emissions control by catalyst
AXEMA	French agricultural machinery manufacturers' trade association
CECE	Committee for European Construction Equipment
CEMA	Committee for European Agricultural Tractor Manufacturers
CI	An engine that works under the compression-ignition principle, e.g. diesel engine
CO	Carbon monoxide
CO_2	Carbon dioxide
CofG	Centre of Gravity
CR-DPF	Continuously Regenerating DPF, a DPF that regenerates using NO_2
CRT	Continuously Regenerating Trap, see CR-DPF
DEF	See Reductant
DOC	Diesel oxidation catalyst: catalytic converter used to reduce CO and HC emissions. By converting: CO and O_2 into CO_2, and HC and O_2 into CO_2 and H_2O
DPF	Diesel Particulate Filter, a filter which traps exhaust particulates (PM or soot), which then catalyses or burns of the PM
EAT	Exhaust After Treatment, a general term exhaust based emission abatement systems
EGR	Exhaust Gas Recirculation: use of some of the exhaust gas to dilute the combustion change gas, resulting in lower temperatures and lower NOx formation.
Engine family	A manufacturer's grouping of engines which, through their design, are expected to have similar exhaust emission characteristics and which comply with the requirements of Directive 2000/25/EC
Engine manufacturer	The person or body who is responsible to the approval authority for all aspects of the type-approval process and for ensuring conformity of production of the engines
EU	European Union
HC	Hydrocarbons
HCT	High clearance tractor (category defined in Directive 2003/37/EC as T4.1, with a clearance of >1m)
kbar	Kilo bar, where 1 bar equals 100,000 Pascals
Mt	Million tonnes
NO_x	Nitrogen oxides
NRMM	Non-road mobile machinery (emissions directive 97/68/EC)
NTT	Narrow track tractors (categories defined in Directive 2003/37/EC as T2 and C2, with a track width of less than 1.15 m)
OEM, or Original equipment manufacturer (tractor manufacturer)	A manufacturer of a type of tractor (final product)

Term	Definition
p.a.	Per annum, per year
Particulate trap	See DPF
PM	Particulate matter, also used to denote Particulate mass as distinct from PN
PN	Particulate number
POC	Particle oxidation catalyst – traps the particles for regeneration by oxidation, but unlike a DPF will not block up.
PTO	Power take-off
Reductant	Diesel Exhaust Fluid: the urea based fluid injected into the exhaust prior to the SCR> Within the SCR, NOx is catalytically reduced by the ammonia into water and nitrogen. Commonly called AdBlue in Europe.
ROPS	Rollover protective structures (or systems)
s.p.	Self-propelled
SCR	Selective catalytic reduction: uses an additive (see DEF) to reduce NOx emissions. By converting: NO_x into N and H_2O
SOF	Soluble Organic Fraction, includes heavy hydrocarbons from the fuel and engine oil. Which is the fraction of particulate matter extracted in the laboratory using organic solvents, hence the name.
UNECE	United Nations Economic Commission for Europe

Annex 1 LEGISLATIVE TIMESCALES

Table 26:Non-road mobile machinery - timetable DIRECTIVE 97/68/EC, as amended

Stage	Engine Type	Engine power	Type Approvals	Placing on market	Existing stock	Latest deadline
I	A	130 kW ≤ P ≤ 560 kW	01-Jul-1998	1999	*"Member States may postpone each date mentioned in the above requirement for two years in respect of engines with a production date prior to the said date"* *Article 9, 4.*	2001
	B	75 kW ≤ P < 130 kW	01-Jul-1998	1999		2001
	C	37 kW ≤ P < 75 kW	01-Jul-1998	1999		2001
II	D	18 kW ≤ P < 37 kW	01-Jan-2000	2001		2003
	E	130 kW ≤ P ≤ 560 kW	01-Jan-2001	2002		2004
	F	75 kW ≤ P < 130 kW	01-Jan-2002	2003		2005
	G	37 kW ≤ P < 75 kW	01-Jan-2003	2004		2006
IIIA	H	130 kW ≤ P ≤ 560 kW	01-Jul-2005	2006	*"For each category, the requirements shall be postponed by two years in respect of engines with a production date prior to the said date"* *Article 9, 4a.*	2008
	I	75 kW ≤ P < 130 kW	01-Jan-2006	2007		2009
	J	37 kW ≤ P < 75 kW	01-Jan-2007	2008		2010
	K	19 kW ≤ P < 37 kW	01-Jan-2006	2007		2009
IIIB	L	130 kW ≤ P ≤ 560 kW	01-Jan-2010	2011		2013
	M	75 kW ≤ P < 130 kW	01-Jan-2011	2012		2014
	N	56 kW ≤ P < 75 kW	01-Jan-2011	2012		2014
	P	37 kW ≤ P < 56 kW	01-Jan-2012	2013		2015
IV	**Q**	**130 kW ≤ P ≤ 560 kW**	**01-Jan-2013**	**2014**		**2016**
	R	**56 kW ≤ P < 130 kW**	**01-Oct-2013**	**2014**		**2016**

Table 27: Power agricultural or forestry tractors – timetable DIRECTIVE 2000/25/EC, as amended

Stage	Engine Type	Engine power	Type Approvals	Placing on market	Existing stock	Latest deadline	Sell off provision
I	A	130 kW ≤ P ≤ 560 kW	Missing	2001	"For engines of categories A to G Member States may postpone the dates laid down in paragraph 3 for two years with respect to engines with a production date prior to the said date." Article 4, 5.	2003	
	B	75 kW ≤ P < 130 kW	01-Jan-2001	2001		2003	
	C	37 kW ≤ P < 75 kW	01-Jan-2001	2001		2003	
II	D	18 kW ≤ P < 37 kW	01-Jan-2001	2002		2004	
	E	130 kW ≤ P ≤ 560 kW	01-Jan-2001	2002		2004	
	F	75 kW ≤ P < 130 kW	01-Jan-2002	2003		2005	
	G	37 kW ≤ P < 75 kW	01-Jan-2003	2004		2006	
IIIA	H	130 kW ≤ P ≤ 560 kW	01-Jan-2006	2006	"For engines of categories H to R, the dates laid down in paragraph 3 shall be postponed for two years with respect to engines with a	2008	
	I	75 kW ≤ P < 130 kW	01-Jan-2006	2007		2009	
	J	37 kW ≤ P < 75 kW	01-Jan-2007	2008		2010	
	K	19 kW ≤ P < 37 kW	01-Jan-2006	2007		2009	
IIIB	L	130 kW ≤ P ≤ 560 kW	01-Jan-2010	2011		2013	2015
	M	75 kW ≤ P < 130 kW	01-Jan-2011	2012		2014	2016
	N	56 kW ≤ P < 75 kW	01-Jan-2011	2012		2014	2016

Stage	Engine Type	Engine power	Type Approvals	Placing on market	Existing stock	Latest deadline	Sell off provision
	P	37 kW ≤ P < 56 kW	01-Jan-2012	2013	production date prior to the said date" Article 4, 6.	2015	2017
IV	**Q**	**130 kW ≤ P ≤ 560 kW**	**01-Jan-2013**	**2014**		**2016**	**2018**
	R	**56 kW ≤ P < 130 kW**	**01-Oct-2013**	**2014**		**2016**	**2018**

Annex 2 **EMISSION LIMITS, STAGES IIIA TO V**

Table 28: Emission limits for engines for use in other applications than propulsion of locomotives, railcars and inland waterway vessels

	Category: net power (P) (kW)	Carbon monoxide (CO) (g/kWh)	Hydrocarbons (HC) (g/kWh)	Oxides of nitrogen (NOx) (g/kWh)	Particulates	
			Sum of (HC + NOx) (g/kWh)		(PM) Mass (g/kWh)	(PN) Number (#/kWh)
Stage IIIA	H: 130 kW ≤ P ≤ 560 kW	3.5	4.0		0.200	-
	I: 75 kW ≤ P < 130 kW	5.0	4.0		0.300	-
	J: 37 kW ≤ P < 75 kW	5.0	4.7		0.400	-
	K: 19 kW ≤ P < 37 kW	5.5	7.5		0.600	-
Stage IIIB	L: 130 kW ≤ P ≤ 560 kW	3.5	0.19	2.0	0.025	-
	M: 75 kW ≤ P < 130 kW	5.0	0.19	3.3	0.025	-
	N: 56 kW ≤ P < 75 kW	5.0	0.19	3.3	0.025	-
	P: 37 kW ≤ P < 56 kW	5.0	4.7		0.025	-
	#: 19 kW ≤ P < 37 kW	*Staying at stage IIIA*				-
Stage IV	Q: 130 kW ≤ P ≤ 560 kW	3.5	0.19	0.4	0.025	-
	R: 56 kW ≤ P < 130 kW	5.0	0.19	0.4	0.025	-
	#: 37 kW ≤ P < 56 kW	*Staying at stage IIIB*				-
	#: 19 kW ≤ P < 37 kW	*Staying at stage IIIA*				-
Stage V [not yet finalised]	NRE-#-7: P > 560 kW	3.50	0.19	0.35	0.045	-
	NRE-#-6: 130 ≤ P < 560 kW	3.50	0.19	0.40	0.015	1x10^12
	NRE-#-5: 56 ≤ P < 130 kW	5.00	0.19	0.40	0.015	1x10^12
	NRE-#-4: 37 ≤ P < 56 kW	5.00	4.70		0.015	1x10^12
	NRE-#-3: 19 ≤ P < 37 kW	5.00	4.70		0.015	1x10^12
	NRE-#-2: 8 ≤ P < 19 kW	6.60	7.50		0.40	-
	NRE-#-1: 0 ≤ P < 19 kW	8.00	7.50		0.40	-

Annex 3 LEGISLATION

Annex 3.1 Sulphur in fuel

The European Directive 2009/30/EC now specifies that ultra-low sulphur diesel fuel (ULSD: less than 10 ppm sulphur) is used for all non-road mobile machinery. Lower sulphur fuels will produce lower emissions of particulates and SO_2. Low sulphur fuel is also a requirement for some of the latest emissions reduction technologies.

From “Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC”, Article 4:

> *"2. Member States shall ensure that, no later than from 1 January 2008, gas oils intended for use by non-road mobile machinery (including inland waterway vessels), agricultural and forestry tractors and recreational craft may be placed on the market within their territory only if the sulphur content of those gas oils does not exceed 1,000 mg/kg. From 1 January 2011, the maximum permissible sulphur content of those gas oils shall be 10 mg/kg. Member States shall ensure that liquid fuels other than those gas oils may be used in inland waterway vessels and recreational craft only if the sulphur content of those liquid fuels does not exceed the maximum permissible content of those gas oils."*
>
> *"However, in order to accommodate minor contamination in the supply chain, Member States may, from 1 January 2011, permit gas oil intended for use by non-road mobile machinery (including inland waterway vessels), agricultural and forestry tractors and recreational craft to contain up to 20 mg/kg of sulphur at the point of final distribution to end users. Member States may also permit the continued placing on the market until 31 December 2011 of gas oil containing up to 1,000 mg/kg sulphur for rail vehicles and agricultural and forestry tractors, provided that they can ensure that the proper functioning of emissions control systems will not be compromised."*

Annex 4 STAKEHOLDER INFORMATION: EMISSION ABATEMENT STRATEGIES

Annex 4.1 Manufacturer "B"

Manufacturer “A” outlined their view on how the various stages could be met; these are listed in Table 29.

Table 29: Possible technology choices regarding; sulphur content, Stage, engine size (meeting, 13/6/2014)

Stage	IIIA	IIIB	IV	V
max Sulphur	500 ppm	10-15 ppm		
≤56 kW (<3 l)	No EGR No DPF No SCR	No EGR No DPF No SCR	Not applicable	EGR DPF
	EGR	EGR DPF or DOC		EGR DPF SCR
>56 kW (>3 l)	No EGR No DPF No SCR	EGR DPF	EGR SCR	
	EGR DPF or DOC	EGR DPF/DOC SCR	EGR DPF/DOC SCR	

Note: “No EGR” means no external EGR (some internal EGR may be employed)

“EGR” means external cooled EGR

Key to emission reduction steps: IIIA → HC & PM → IIIB → NO_x → IV → PM → V

Annex 4.2 Manufacturer "C"

Manufacturer “C” had just, at the time of writing, released details of US EPA Tier 4b engines. These employ common rail engine technology together with a diesel oxidation catalyst (DOC) and a PM catalyst. However, the engines available are all below 56 kW.

Annex 4.3 Stakeholder "D"

Stakeholder "D" produced a table of possible emission abatement strategies based on information from and engine developer and producer.

Table 30: Possible technology choices presented by a stakeholder based on data from an engine manufacturer (courtesy AECC)

	Stage IIIA (US Tier 3)	Stage IIIB (US Tier 4i)	Stage IV (Tier 4)
56 - 130 kW	Base engine, iEGR or e-EGR-C (10% rate)	Add FIE (>1800 bar) 15% cooled EGR. No after treatment	DOC and SCR (88-90% efficiency). No DPF
130 – 560 kW		Increase P_{max} FIE >2000bar e-EGR (rate ~25%) DOC and DPF	SCR (80-82% efficiency)
		SCR(78-80% efficiency)	DOC SCR (93-94% efficiency) No DPF

Annex 4.4 Stage IIIB

In general, the methods used to-date to achieve Stage IIIB compliance upon standard (T1 category) tractors have fallen into one of the following approaches, depending upon engine power level

Table 31: Emission abatement strategies for Stage IIIB

	≥75 kW		<75 kW	
On engine	CEGR VGT	HPCR and ECU, turbo with intercooling	HPCR and ECU, turbo with intercooling, C-EGR	
After treatment	DOC, DPF	SCR	DOC	DPF
Note		Most numerous	SCR generally not employed	

Annex 5 ENVIRONMENTAL IMPACT RESULTS - 2021

The results are presented in the following tables:

- Table 32: EU fleet for 2021, assuming Stage IV NTT vehicles appear in 2019
- Table 34: NO_x emissions for the European fleet
- Table 33: PM emissions for the European fleet

- Table 35: Modified fleet, assuming all Stage IV vehicles remain at Stage IIIB
- Table 36: NO_x emissions for the modified fleet (all Stage IV vehicles are Stage IIIB)

Note: The highlighted areas show the shift in fleet from Stage IV to IIIB.

Annex 5.1 EU fleet for 2021, assuming Stage IV vehicles appear in 2019

Table 32: European fleet size – base fleet

a. First life

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV				32,387	10,241		1,350
Stage IIIB			18,044	21,573	6,821	200	899
Stage IIIA		42,700	13,488	21,495	6,797	149	896
Stage II	2,306						
Stage I							
Total	2,306	42,700	31,532	75,455	23,859	349	3,145

b. Second life

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV							
Stage IIIB							
Stage IIIA		34,178	25,239	51,313	16,225	280	2,139
Stage II	2,926	20,000	9,311	31,364	9,917	103	1,307
Stage I	213	3,936	8,366	20,019	6,330	93	834
Total	3,139	58,115	42,916	102,695	32,472	476	4,280

c. Total

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV				32,387	10,241		1,350
Stage IIIB			18,044	21,573	6,821	200	899
Stage IIIA		76,878	38,728	72,808	23,022	429	3,034
Stage II	5,232	20,000	9,311	31,364	9,917	103	1,307
Stage I	213	3,936	8,366	20,019	6,330	93	834
Total	5,445	100,815	74,448	178,151	56,331	825	7,425

Table 33: Annual PM emissions – base fleet

a. First life

PM	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV				44.55	14.36		1.70	60.61
Stage IIIB			8.15	29.68	9.56	0.09	1.13	48.61
Stage IIIA		164.36	68.23	248.38	80.03	0.77	9.46	571.24
Stage II	2.07							2.07
Stage I								
Total	2.07	164.36	76.38	322.61	103.95	0.86	12.29	682.52

b. Second life

PM	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV								
Stage IIIB								
Stage IIIA		65.78	63.84	296.47	95.53	0.72	11.29	533.63
Stage II	1.31	51.32	23.55	181.21	58.39	0.27	6.90	322.95
Stage I	0.10	10.73	44.96	269.87	86.96	0.51	10.28	423.41
Total	1.41	127.84	132.34	747.55	240.87	1.49	28.48	1,279.99

c. Total

PM	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV				44.55	14.36		1.70	60.61
Stage IIIB			8.15	29.68	9.56	0.09	1.13	48.61
Stage IIIA		230.15	132.06	544.85	175.56	1.49	20.75	1,104.86
Stage II	3.38	51.32	23.55	181.21	58.39	0.27	6.90	325.02
Stage I	0.10	10.73	44.96	269.87	86.96	0.51	10.28	423.41
Total	3.47	292.20	208.72	1,070.16	344.83	2.36	40.76	1,962.51

Table 34: Annual NO_x emissions – base fleet

a. First life

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV				712.8	229.7		27.2	969.69
Stage IIIB			73.5	3,917.3	1,262.2	0.8	149.2	5,403.15
Stage IIIA		229.2	55.0	227.1	73.2	0.6	8.7	593.68
Stage II	25.6							25.58
Stage I								
Total	25.6	229.2	128.5	4,857.3	1,565.1	1.5	185.0	6,992.1

b. Second life

NOx (tonne/year)	T2 0-19 kW	19-37 kW	37-56 kW	56-130 kW	C2 56-130 kW	T4.1 37-56 kW	56-130 kW	All
Stage IV								
Stage IIIB								
Stage IIIA		91.7	51.4	271.1	87.3	0.6	10.3	512.5
Stage II	16.2	586.6	471.0	4,141.9	1,334.6	5.3	157.8	6,713.4
Stage I	1.2	132.8	556.2	4,053.6	1,306.1	6.3	154.4	6,210.5
Total	17.4	811.0	1,078.6	8,466.6	2,728.1	12.2	322.5	13,436.4

c. Total

NOx (tonne/year)	T2 0-19 kW	19-37 kW	37-56 kW	56-130 kW	C2 56-130 kW	T4.1 37-56 kW	56-130 kW	All
Stage IV				712.8	229.7		27.2	969.7
Stage IIIB			73.5	3,917.3	1,262.2	0.8	149.2	5,403.1
Stage IIIA		320.9	106.4	498.1	160.5	1.2	19.0	1,106.1
Stage II	41.8	586.6	471.0	4,141.9	1,334.6	5.3	157.8	6,739.0
Stage I	1.2	132.8	556.2	4,053.6	1,306.1	6.3	154.4	6,210.5
Total	43.0	1,040.2	1,207.1	13,323.9	4,293.2	13.6	507.5	20,428.5

Annex 5.2 Modified fleet, assuming all Stage IV vehicles remain at Stage IIIB

Table 35: European fleet size – modified fleet (all Stage IV vehicles are Stage IIIB)

a. First life

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV				32,387	10,241		1,350
Stage IIIB			18,044	21,573	6,821	200	899
Stage IIIA		42,700	13,488	21,495	6,797	149	896
Stage II	2,306						
Stage I							
Total	2,306	42,700	31,532	75,455	23,859	349	3,145

b. Second life

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV							
Stage IIIB							
Stage IIIA		34,178	25,239	51,313	16,225	280	2,139
Stage II	2,926	20,000	9,311	31,364	9,917	103	1,307
Stage I	213	3,936	8,366	20,019	6,330	93	834
Total	3,139	58,115	42,916	102,695	32,472	476	4,280

c. Total

	T2 0-19 kW	 19-37 kW	 37-56 kW	 56-130 kW	C2 56-130 kW	T4.1 37-56 kW	 56-130 kW
Stage IV							
Stage IIIB			18,044	53,960	17,062	200	2,249
Stage IIIA		76,878	38,728	72,808	23,022	429	3,034
Stage II	5,232	20,000	9,311	31,364	9,917	103	1,307
Stage I	213	3,936	8,366	20,019	6,330	93	834
Total	5,445	100,815	74,448	178,151	56,331	825	7,425

Table 36: Annual NO_x emissions – modified fleet (all Stage IV vehicles are Stage IIIB)

a. First life

NOx (tonne/year)	T2 0-19 kW	 19-37 kW	 37-56 kW	 56-130 kW	C2 56-130 kW	T4.1 37-56 kW	 56-130 kW	All
Stage IV								
Stage IIIB			8.15	74.23	23.92	0.09	2.83	109.22
Stage IIIA		164.36	68.23	248.38	80.03	0.77	9.46	571.24
Stage II	2.07							2.07
Stage I								
Total	2.07	164.36	76.38	322.61	103.95	0.86	12.29	682.52

b. Second life

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV								
Stage IIIB								
Stage IIIA		65.78	63.84	296.47	95.53	0.72	11.29	533.63
Stage II	1.31	51.32	23.55	181.21	58.39	0.27	6.90	322.95
Stage I	0.10	10.73	44.96	269.87	86.96	0.51	10.28	423.41
Total	1.41	127.84	132.34	747.55	240.87	1.49	28.48	1,279.99

c. Total

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV								
Stage IIIB			8.15	74.23	23.92	0.09	2.83	109.22
Stage IIIA		230.15	132.06	544.85	175.56	1.49	20.75	1,104.86
Stage II	3.38	51.32	23.55	181.21	58.39	0.27	6.90	325.02
Stage I	0.10	10.73	44.96	269.87	86.96	0.51	10.28	423.41
Total	3.47	292.20	208.72	1,070.16	344.83	2.36	40.76	1,962.51

Annex 6 ENVIRONMENTAL IMPACT RESULTS - 2025

The results are presented in the following tables:

- Table 37: EU fleet for 2025, assuming Stage IV NTT vehicles appear in 2019
- Table 39: NO_x emissions for the European fleet
- Table 38: PM emissions for the European fleet

- Table 40: Modified fleet, assuming all Stage IV vehicles remain at Stage IIIB
- Table 41: NO_x emissions for the modified fleet (all Stage IV vehicles are Stage IIIB)

Note: The highlighted areas show the shift in fleet from Stage IV to IIIB.

Annex 6.1 EU fleet for 2025, assuming Stage IV vehicles appear in 2019

Table 37: European fleet size – base fleet

a. First life

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV				75,455	23,859		3,145
Stage IIIB			31,532			349	
Stage IIIA		42,700					
Stage II	2,306						
Stage I							
Total	2,306	42,700	31,532	75,455	23,859	349	3,145

b. Second life

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV							
Stage IIIB			4,457	21,216	6,709	49	884
Stage IIIA		49,842	32,349	61,460	19,434	358	2,562
Stage II	3,110	7,745	4,225	15,509	4,904	47	646
Stage I	29	529	1,884	4,509	1,426	21	188
Total	3,139	58,115	42,916	102,695	32,472	476	4,280

c. Total

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV				75,455	23,859		3,145
Stage IIIB			35,989	21,216	6,709	399	884
Stage IIIA		92,542	32,349	61,460	19,434	358	2,562
Stage II	5,416	7,745	4,225	15,509	4,904	47	646
Stage I	29	529	1,884	4,509	1,426	21	188
Total	5,445	100,815	74,448	178,151	56,331	825	7,425

Table 38: Annual PM emissions – base fleet

a. First life

PM	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV				103.80	33.45		3.95	141.20
Stage IIIB			14.24			0.16		14.40
Stage IIIA		164.36						164.36
Stage II	2.07							2.07
Stage I								
Total	2.07	164.36	14.24	103.80	33.45	0.16	3.95	322.03

b. Second life

PM	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV								
Stage IIIB			1.01	14.59	4.70	0.01	0.56	20.87
Stage IIIA		95.93	81.82	355.10	114.42	0.92	13.53	661.71
Stage II	1.39	19.87	10.69	89.61	28.87	0.12	3.41	153.97
Stage I	0.01	1.44	10.13	60.79	19.59	0.11	2.32	94.38
Total	1.41	117.24	103.64	520.09	167.58	1.17	19.81	930.94

c. Total

PM	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV				103.80	33.45		3.95	141.20
Stage IIIB			15.25	14.59	4.70	0.17	0.56	35.27
Stage IIIA		260.29	81.82	355.10	114.42	0.92	13.53	826.08
Stage II	3.46	19.87	10.69	89.61	28.87	0.12	3.41	156.04
Stage I	0.01	1.44	10.13	60.79	19.59	0.11	2.32	94.38
Total	3.47	281.61	117.88	623.88	201.03	1.33	23.76	1,252.97

Table 39: Annual NO_x emissions – base fleet

a. First life

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV				1,660.8	535.1		63.3	2,259.17
Stage IIIB			2,275.8			25.7		2,301.45
Stage IIIA		1,995.9						1,995.86
Stage II	25.6							25.58
Stage I								
Total	25.6	1,995.9	2,275.8	1,660.8	535.1	25.7	63.3	6,582.1

b. Second life

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV								
Stage IIIB			160.8	1,926.3	620.7	1.8	73.4	2,783.0
Stage IIIA		1,164.8	933.9	4,599.3	1,482.0	10.5	175.2	8,365.8
Stage II	17.2	227.1	213.7	2,048.2	660.0	2.4	78.0	3,246.7
Stage I	0.2	17.8	125.3	913.0	294.2	1.4	34.8	1,386.7
Total	17.4	1,409.8	1,433.7	9,486.9	3,056.8	16.2	361.4	15,782.2

c. Total

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV				1,660.8	535.1		63.3	2,259.2
Stage IIIB			2,436.6	1,926.3	620.7	27.5	73.4	5,084.4
Stage IIIA		3,160.7	933.9	4,599.3	1,482.0	10.5	175.2	10,361.7
Stage II	42.8	227.1	213.7	2,048.2	660.0	2.4	78.0	3,272.3
Stage I	0.2	17.8	125.3	913.0	294.2	1.4	34.8	1,386.7
Total	43.0	3,405.7	3,709.5	11,147.6	3,592.0	41.9	424.6	22,364.2

Annex 6.2 Modified fleet, assuming all Stage IV vehicles remain at Stage IIIB

Table 40: European fleet size – modified fleet (all Stage IV vehicles are Stage IIIB)

a. First life

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV							
Stage IIIB			31,532	75,455	23,859	349	3,145
Stage IIIA		42,700					
Stage II	2,306						
Stage I							
Total	2,306	42,700	31,532	75,455	23,859	349	3,145

b. Second life

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV							
Stage IIIB			4,457	21,216	6,709	49	884
Stage IIIA		49,842	32,349	61,460	19,434	358	2,562
Stage II	3,110	7,745	4,225	15,509	4,904	47	646
Stage I	29	529	1,884	4,509	1,426	21	188
Total	3,139	58,115	42,916	102,695	32,472	476	4,280

c. Total

	T2				C2	T4.1	
	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW
Stage IV							
Stage IIIB			35,989	96,672	30,567	399	4,029
Stage IIIA		92,542	32,349	61,460	19,434	358	2,562
Stage II	5,416	7,745	4,225	15,509	4,904	47	646
Stage I	29	529	1,884	4,509	1,426	21	188
Total	5,445	100,815	74,448	178,151	56,331	825	7,425

Table 41: Annual NOx emissions – modified fleet (all Stage IV vehicles are Stage IIIB)

a. First life

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV								
Stage IIIB			2,275.8	13,701.4	4,414.8	25.7	521.9	20,939.6
Stage IIIA		1,995.9						1,995.9
Stage II	25.6							25.6
Stage I								
Total	25.6	1,995.9	2,275.8	13,701.4	4,414.8	25.7	521.9	22,961.0

b. Second life

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV								
Stage IIIB			160.8	1,926.3	620.7	1.8	73.4	2,783.0
Stage IIIA		1,164.8	933.9	4,599.3	1,482.0	10.5	175.2	8,365.8
Stage II	17.2	227.1	213.7	2,048.2	660.0	2.4	78.0	3,246.7
Stage I	0.2	17.8	125.3	913.0	294.2	1.4	34.8	1,386.7
Total	17.4	1,409.8	1,433.7	9,486.9	3,056.8	16.2	361.4	15,782.2

c. Total

NOx	T2				C2	T4.1		All
(tonne/year)	0-19 kW	19-37 kW	37-56 kW	56-130 kW	56-130 kW	37-56 kW	56-130 kW	
Stage IV								
Stage IIIB			2,436.6	15,627.7	5,035.5	27.5	595.3	23,722.6
Stage IIIA		3,160.7	933.9	4,599.3	1,482.0	10.5	175.2	10,361.7
Stage II	42.8	227.1	213.7	2,048.2	660.0	2.4	78.0	3,272.3
Stage I	0.2	17.8	125.3	913.0	294.2	1.4	34.8	1,386.7
Total	43.0	3,405.7	3,709.5	23,188.3	7,471.7	41.9	883.3	38,743.2

Annex 7 EU28 GRAPE AND WINE PRODUCTION

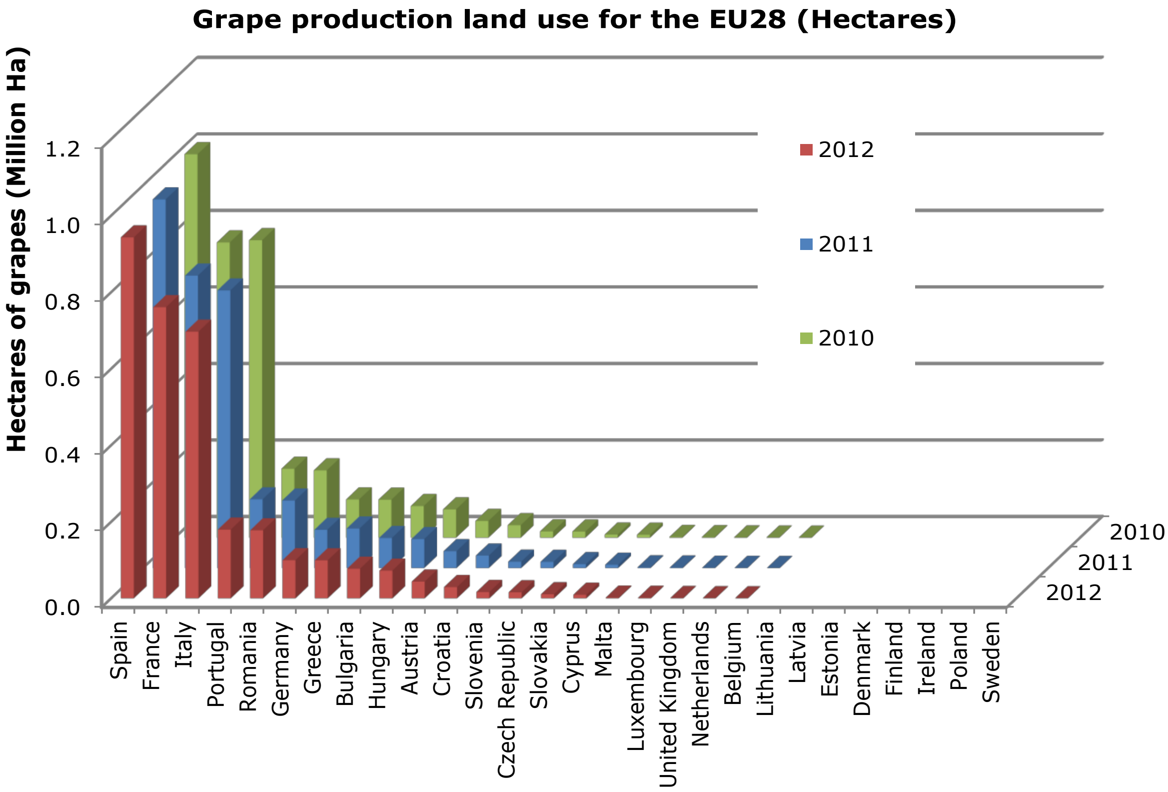

Figure 55: Area harvested for grape production in the EU28 (Ha) (FAO stat; Food and agriculture organisation of the UN)

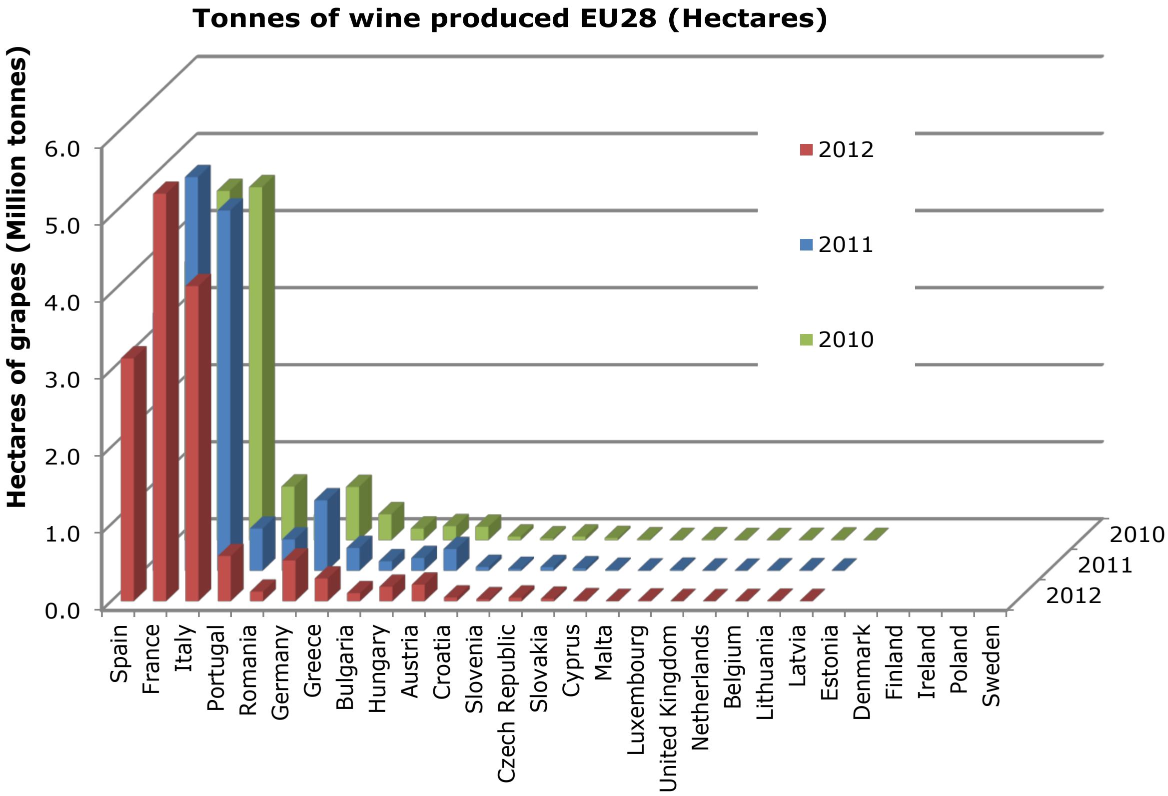

Figure 56: Wine production in the EU28 (tonnes) (FAO stat; Food and agriculture organisation of the UN)

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