



Renewable and Low-Carbon Fuels for Climate-Smart EU Agricultural Machinery: Circular Agriculture in Action

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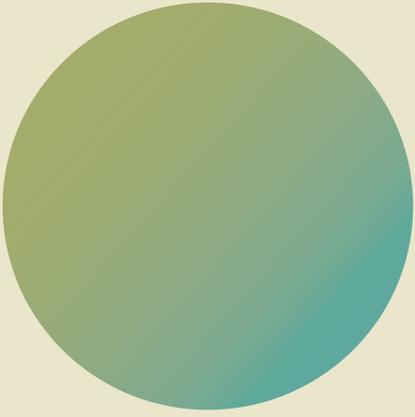
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1. Introduction: the options for climate-smart EU agricultural machinery

To limit the global average temperature increase to substantially below 2°C no perfunctory measures can be taken and all sectors must meet stringent reduction targets.

The agriculture sector accounts for 10% of the total EU27 greenhouse gas (GHG) emissions (from crops, livestock and soils), and an additional ~1% of total EU27 GHG emissions can be attributed to agriculture from the combustion of fossil fuels during the normal course of operating agricultural machinery. Conventional fuel is therefore not the most critical, but still a contributor, of the overall agricultural carbon footprint. Agriculture, as a part of a circular economy, can only become sustainable when it overcomes its major dependency on fossil fuel. Our industry is not seeking softer measures for agriculture, nor does it claim to provide a best pathway. Instead, we urge the intelligent and effective use of all the available options within the agricultural production process with consideration of the specific conditions and capabilities of each farmer and of the sector to achieve the highest possible reduction. That includes smart use of machinery to increase the energy efficiency of production processes, electrification of the fleet and the use of renewable and low carbon fuels. Figure 1 depicts an overview of the options. In this diagram 'well to tank' indicates the cycle from raw material to an energy source that can be used to drive/operate a machinery. The term 'tank to wheel', or in relation to agriculture 'tank to crop', is an indication of how 1 tonne of fuel or kWh contributes to 1 tonne of crop. It is important to look at both. When looking only at tank to wheel for CO₂ reduction, also known as

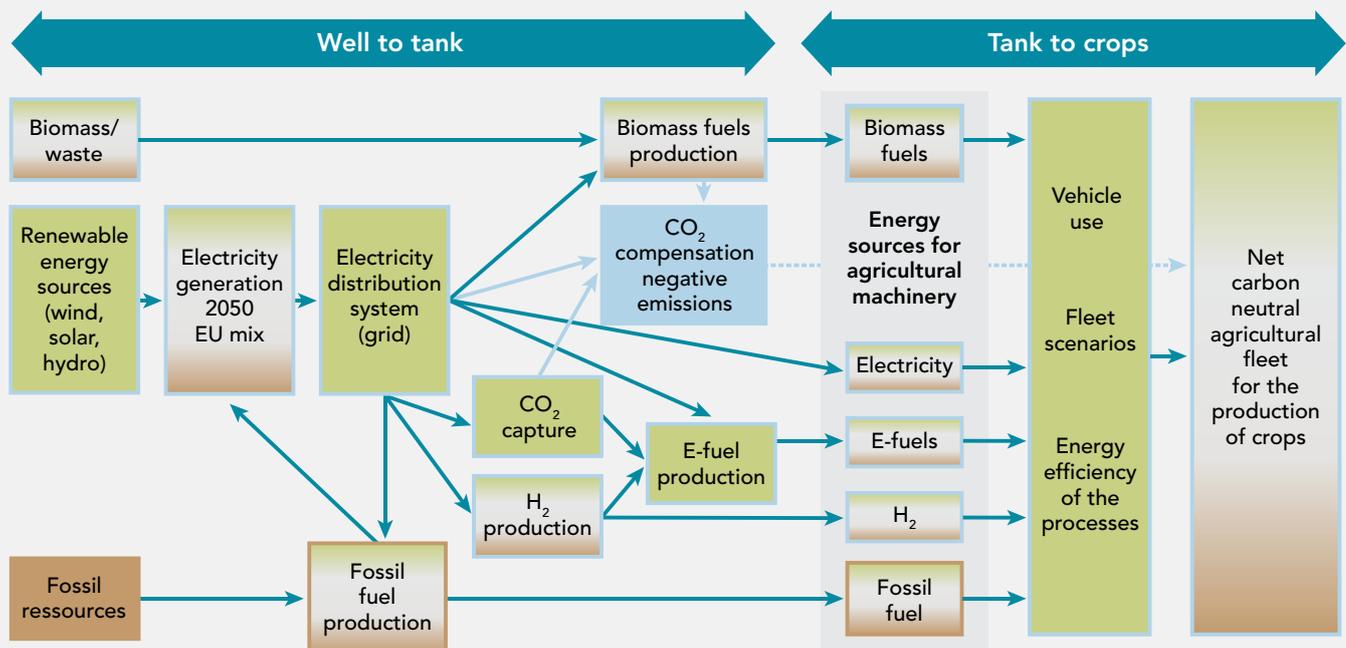
the "tailpipe approach", internal combustion engine technology using renewable and low-carbon fuels, e.g. circular biomass-based fuels or e-fuels, would not be considered (except non-hydrocarbon-based fuels, like H₂ or NH₃). However, in the short to medium term, this alternative approach could provide a better life cycle carbon footprint reduction when compared to Battery Electric Vehicles.

Looking deeper into the options, the EU's "Fit for 55" package defines electrification as key technology to decarbonise the EU transport sector.

Agriculture, as a part of a circular economy, can only become sustainable when it overcomes its major dependency on fossil fuel.

In future farms there could be an abundance of energy due to solar parks and windmills. Therefore, **electrification with batteries** of the agricultural machine fleet seems a logical next step. However, its uptake will depend on future technology development to solve the issues of weight, energy density and fast refuelling of energy storage on-board. Due to these restrictions, in the short to medium term, the viability of this technology for agricultural machinery is likely to stay in the light vehicle segments or for hybrid use in medium/high power vehicles with an internal combustion engine and electrification mainly of functions, including those on the towed/mounted implements. The latter can be seen as a complementary means for farmers to reduce carbon emissions but are limited in scope.

Figure 1. Overview of the options considering the circular nature of the process from Well to Crops in relation to the use of agricultural machinery.



Although more compact than full battery electric systems, the main challenges related to ‘**electrification**’ with **hydrogen fuel cells** are the high costs, weight and volume of hydrogen storage systems. As a result, for large-sized agricultural machines, it may prove challenging to store a high volume of hydrogen fuel on-board in order to support the long operational hours that are currently provided by conventional fuels.

Other challenges include the requirement for high grade of fuel purity, contamination of the fuel cell from airborne particles in an agricultural application, on farm storage and fuelling infrastructure, high cooling demand and logistics. Resolution of these challenges requires significant investment.

As a result, for the short and medium term, full **electrification of mid and large sized agricultural machinery for high power applications is not a practicable alternative to combustion engines.**

Technological progress in the coming decade will define the long-term potential of electrification.

In this respect, renewable and low-carbon fuels such as biomass fuels and e-fuels provide the highest potential.

As a result, consideration must be given to measures that contribute to a reduction in CO₂ emissions from agricultural machines, whilst providing increased energy security, by facilitating the use of renewable and low carbon fuels in combustion engines. This includes the production, quality assurance and storage of these fuels as well as their use in agricultural machinery compliant to the relevant EU legislation.

This paper outlines CEMA’s position on the potential of renewable and low carbon fuels when using agricultural machinery with combustion engines and the challenges to be overcome to provide climate-smart European agriculture.

¹ <https://ourworldindata.org/emissions-by-fuel>

2. The renewable and low-carbon fuels under consideration

The focus of this paper is on three groups of Renewable and Low Carbon fuels: biomass fuels, green hydrogen and e-fuels.

Biomass fuels

Liquid and gaseous biomass fuels certified according to the EU sustainability criteria enable substantial GHG emission reductions when compared to conventional fossil fuels. Obviously, the area of energy crops, grown for biofuels, must be carefully balanced with the needs for food and feed production, both regionally and globally and without causing deforestation, degradation of habitats or loss of biodiversity². The implication of the use of energy crops for biomass fuel production is that there will be no increase in land area, currently used for food and feed crops.

Alternative production methods and other EU sustainability targets such as those on protein import, nitrogen leakage, soil protection etc. could facilitate this balance that includes the valuation of crops, as well as the increased and combined use of materials such as waste, manure and residues. There is also a significant potential to incentivise the scale-up of biomethane sourced from fugitive methane emitted from agricultural organic waste materials, particularly livestock manure, which can deliver negative carbon emissions as well as a circular economy model for livestock farming.

In this paper, with regards to biomass fuels, we focus mainly on:

Liquid fuels

- **Renewable diesel** (also known as **HVO**, Hydrotreated Vegetable Oil): liquid Biofuel produced from vegetable oil, animal fat/tallow and/or waste cooking oil being converted to hydrocarbon chains using hydrogen. Its physical and chemical properties are almost identical to conventional diesel, it can be used in any type of engine and is better suited for winter operations than biodiesel. Although the fuel can be derived from the same feedstock as FAME, its stability is higher than that of FAME and equivalent to conventional diesel due to the hydrogenation process.
- **Biodiesel** (known as **FAME**, Fatty Acid Methyl Ester): liquid Biofuel produced by transesterification of vegetable oils, animal fat/tallow and/or waste cooking oil with methanol. Its physical and chemical properties are quite similar but not identical to that of conventional fossil diesel. Traditional internal combustion engines can run with a 7% biodiesel blend (B7) without adaptations to the latest stage V engines but higher blends, due to potential alkali metal, e.g. sodium and potassium, contaminations, require more adaptations in design to ensure functioning/durability of the engine and emission compliance, including the necessary conformity tests and engine reapproval.



² <https://ourworldindata.org/emissions-by-fuel>

- **Vegetable oil fuel:** Oil produced from oil plants directly on farms or in regional refinery facilities. On a case by case basis with adaptations, traditional combustion engines can run on vegetable oil. Yet, due to the absence of quality checks on locally produced and stored oil, its durability and quality, and thus compliance to the respective standards and exhaust emissions limits, are more challenging in comparison to biodiesel and HVO. Vegetable oil fuel has the potential to be produced and consumed within agricultural production systems.

Gaseous fuels

- **Biomethane:** Gaseous fuel produced as biogas, which is then further upgraded to biomethane, from agricultural biomass, manure*, or from the organic fraction of municipal solid waste. It can also be produced from dual use plants, double cropping areas, intercropping sources or biomass from high biodiversity areas not affecting food production capacity. The upgrade process from biogas to biomethane can be done at the farm or locally/regionally. Dedicated engine design is necessary but the technology is readily available. It can be used directly as a gas (CNG), or may be liquified (LNG). LNG provides two and a half time greater volumetric energy storage than CNG, thus it offers refuelling intervals comparable to liquid fuels. LNG requires storage at a low temperature to maintain methane in a liquid state. Heat slowly affects storage tanks causing the stored LNG to evaporate and produce a substance known as boil-off gas (BOG) which needs to be vented. This is a particular problem due to the seasonal use of agricultural machinery.

As we focus on these most promising options for Europe, alternatives such as bioethanol and other biomass fuels are not considered in this paper.

The production of the biomass fuels, detailed above, not only fit within the EU resilience strategy for the reduction of imported energy but also in the EU Green Deal which puts a clear focus on increasing the share of renewable energies in the overall power mix.

For example within the **RePowerEU** initiative the intention is to grow biomethane production from 3 bcm to 35 bcm by 2030, a 700 % increase. Moreover, depending on the feedstock source of biomethane production, it has the potential to lower the carbon footprint significantly or generate a negative carbon balance.

In 2021, the share of renewable energy was 22.2%. Bioenergy (biomass for energy) continues to be the main source of renewable energy in the EU in terms of gross final consumption, with 59% of all renewables and 10% of all energy sources to the gross final energy consumption. Bioenergy is derived from a wide range of feedstocks, one of them being biomass from agriculture (crop residues, bagasse, animal waste, energy crops, etc.). Agriculture clearly plays a vital role in generating renewable energy sources. In terms of end use, the heating and cooling sector is the largest end-user using about 75% of all bioenergy whilst biomass fuels for transport account for 12%. Given the limitation of biomass sources, the increase of bioenergy for transport is not only a matter of production increase but also of prioritisation of the biomass fuel available in particular for sectors, such as agricultural machinery, that are hard to abate.

* notably biomethane sourced from livestock manure is carbon negative

E-fuels

According to the European Commission E-fuels are 'renewable fuels of non-biological origin' (RFNBO), meaning liquid and gaseous fuels, the energy content of which is derived from renewable electricity sources, like wind and solar, rather than biomass. Other ingredients are water, for the production of H₂ by electrolysis, and CO₂. Hydrogen produced in this process is called green or renewable hydrogen. The Renewable Energy Directive (RED II) demands that RFNBOs deliver at least a 70% CO₂ reduction compared to the fossil fuels that they seek to replace. E-Fuels are therefore a sustainable alternative to fossil fuels, as drop-in replacement fuels, to be used in existing infrastructure and thus decisively and affordably reduce CO₂ emissions in the transport and heating market.

Green hydrogen

Hydrogen, as a 'renewable fuel of non-biological origin' (RFNBO), in the text referred to as green hydrogen, can also be used in an internal combustion engine.

Hydrogen engines are currently in development and have much in common with diesel, petrol or natural gas engines. However, where other alternative fuel engines rely on offsetting to get to net-zero, a hydrogen engine is zero-carbon from the outset. Hydrogen could be potentially stored as a liquid or more commonly in gaseous form in pressure vessels on machines. The advantages of hydrogen are that it is a mobile fuel, which can be refuelled quickly, in a similar manner as refuelling today. There are many parallels between hydrogen and compressed natural gas (CNG) in terms of machine installation. A major problem remains in the storage capacity and the weight of storage. Hydrogen production is now starting to ramp up, with significant investment from the heavy duty sector across the EU as well as in the USA, India and China to dramatically increase the quantity of hydrogen produced and also reduce the price for the consumer. As such, if the issues surrounding the rural infrastructure can be overcome, it is also a viable option for farmers.





3. The long term role of sustainable biomass fuels and its uptake in the context of a circular agriculture

The most popular biomass fuel consumed in the EU is biodiesel (FAME), the main feedstock crop for biomass fuels originating from the EU production is rapeseed (ca. 70% of the EU biofuels' cropland area)³. The EU is a global leader in producing and using biodiesel, with an annual domestic supply of around 13 mil.t. The main national markets covering two-thirds of the EU total demand are France, Germany, Spain, Sweden, and Italy⁴.

The use of HVO in engines is not a widespread practice yet. Only a few EU countries have established HVO production on an industrial scale so far, while the trend is increasing⁵. HVO is a very suitable drop-in replacement fuel for diesel engines but its availability is limited.

There is use of vegetable oil in engines. In some countries with a strong tradition of rapeseed production (e.g. in Germany), many small local and on-farm oil mills exist producing pure vegetable oil fuel for their own consumption or for a close regional circle of customers.

As earlier outlined, it is not a drop-in replacement fuel and engine adaptations are necessary. Quality assurance could be an issue.

In 2018, 7.4 mil. ha of agricultural land was required to produce crops for EU biomass fuels of which half was located within the EU. **The share of EU biomass fuels' area was 3% of EU agricultural land and 0.5% of global agricultural land use⁶.** So far, there was no reason to fear any substantial competition between biomass fuels and food and feed production. Any significant increase of biomass fuel production will have to be carefully balanced.

Any significant increase of biomass fuel production will have to be carefully balanced.

The use of sustainable biomass fuels reduces overall direct GHG emissions by between 65% and 90% when compared to fossil diesel⁷.

³ https://ec.europa.eu/energy/sites/ener/files/renewable_energy_progress_report_com_2020_952.pdf
⁴ <https://ebb-eu.org/about-biodiesel/>, <https://www.eurobserv-er.org/res-in-transport-barometer-2021/>

⁵ https://www.ufop.de/index.php/download_file/10598/
⁶ https://energy.ec.europa.eu/system/files/2020-10/renewable_energy_progress_report_com_2020_952_0.pdf
⁷ <https://ebb-eu.org/about-biodiesel/>

These reductions can be significantly different, depending on the crop used. For biodiesel from rapeseed and pure rapeseed oil fuel, the direct GHG savings go up to 70%⁸, accounting for the direct certified emissions from each step of the supply chain (crop-to-wheel cycle). GHG savings from rapeseed-based biodiesel, taking into account total direct and indirect emissions, amount to ca. 60%. It is important to underline the higher GHG savings potential of biofuels produced and consumed directly on the farm, since the emissions derived from fuel transportation and distribution are equal or close to zero.

There is a concept of decentralized biofuels' supply within a circular agriculture. This concept suggests producing a portion of biomass fuels locally; either in local on or near farm refineries or within regional value chains including the processing industry. Certainly, this local model can be applied to the production of sustainable biomethane sourced from the fugitive methane emitted from livestock manure and as such, biomass fuels would be primarily preserved for use in agriculture. This model would require only slight to moderate modifications to local infrastructure in comparison to other models e.g. electrification or hydrogen.

On average, using 1t of biomass fuel to replace a fossil fuel, saves over 2t of CO₂ emissions, even when including ILUC impacts. Direct GHG emissions of crop-based biomass fuels may additionally decrease with sustainable improvements in agricultural yields through smart agricultural practices.

European agriculture will be resilient against energy supply shocks by becoming independent of fossil fuel in the medium term. The complementary sustainability effects within circular agriculture should also be considered,

such as enhanced regional value chains, shorter and closer cycles between production and consumption of biofuels and adequate utilisation and evaluation of by-products such as oil seed meal.

Every kilogram of crop-produced biodiesel and other vegetable oil-based fuels generates two kilograms of vegetable proteins, its use supporting the European feed and food supply security. While the EU imports about two-thirds of vegetable proteins used in agriculture, biofuel by-products provide a sustainable base of internal supply and assist in balancing out the dependence on imports. In the case of rapeseed oil, **rapeseed meal** is a valuable, **non-GMO**, protein product which **can largely substitute soybeans** that are usually imported from overseas at a higher price⁹. The traditional allocation method used for EU estimations of GHG emissions ignores the additional provision of feed resources from local biofuel crops. The Renewable Energy Directive (RED II) considers it appropriate to evaluate by-products for a policy analysis by using the substitution approach, i.e., to expand the system to account for substitution when the production and use of fuels generate by-products. This would allow the calculation of a more realistic **total GHG emission reduction potential from regional rapeseed oil fuel (>100%)**.

The above examples show the potential. Beyond the crops mentioned there are several other alternatives to produce biomass fuel, like waste/residues, wasted cooking oil, sewer/landfill/biowaste gas and biogas fuels. Many of these alternatives originate in agricultural production and may ensure considerable GHG emission savings.

⁸ https://www.ble.de/EN/Topics/Climate-Energy/Sustainable-Biomass-Production/sustainable-biomass-production_node.html

⁹ https://www.ufop.de/files/2416/3360/6699/GdW_4021_en_2048.jpg



In the context of the Green Deal, there is also a demand for different production methods such as **crop diversification**. This entails increasing the crop diversity in a field both in space and time, for example by using multiple cropping, intercropping and rotation methods. In relation to carbon farming there is a need for **permanent ground coverage and increase in soil biodiversity** for optimal carbon sequestration. This will result in **additional and optimised production of crops** which could be added to the mix of resources for biofuel production. Avoiding conflict with existing crop production through sustainable yield increases, additional crops produced on current agricultural land or on marginal and abandoned land, and thus low ILUC feedstock production, will further reduce the risk of indirect GHG emissions from crop-based biomass fuels. Circular agriculture

biomass fuel production within a certain land use boundary, whilst not compromising the food and feed demands, is therefore possible.

Biomethane produced from fugitive emissions from livestock manure can also contribute to delivering a circular economy model for livestock agriculture and play a part in resolving the ammonia emission problem. Its core **environmental benefit** is the carbon balance, which is negative in case of manure from livestock, and an additional overall benefit of the restoration of soil organic matter by applying the digested biological material as an excellent natural fertilizer. There is also an immediate reduction of GHG emissions from manure being processed in biogas plants, as methane gas, that would otherwise be emitted naturally, is being captured in the fuel production cycle.

¹⁰ <https://www.europeanbiogas.eu/avoided-emissions-from-biogas-and-biomethane-can-lead-to-a-negative-carbon-footprint>

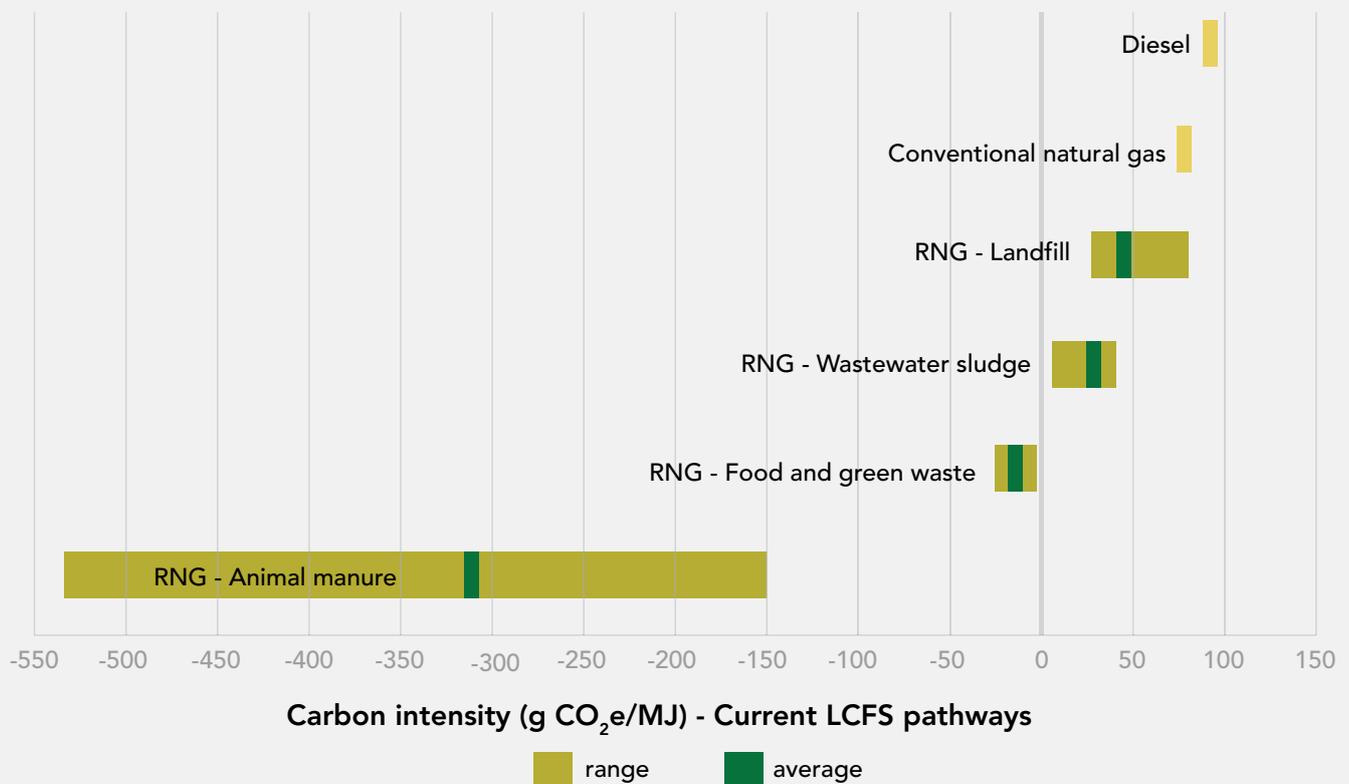
An additional benefit of on farm biomethane generation is that the cost for fuel transportation and distribution are not relevant and can therefore be negated as carbon emissions. Biomethane produced from city waste, manure, or agricultural waste has the best CO₂ balance of any currently known energy source and can potentially reach **more than 200% GHG savings when compared to EU fossil fuels**¹⁰ (Figure 2).

Biomethane production creates business opportunities for farmers beyond the application of digested biomass for fertilization and the use of gaseous fuel in their own agricultural vehicles. It enables on farm heat and electricity generation as well as the potential supply into the national gas grid for relevant off farm applications.

Above all, it is a concrete example of the circular economy functioning in agriculture by deploying the principle of an energy independent farm, i.e. a farm capable to produce food in a sustainable way, to minimise CO₂ emissions and produce themselves the renewable fuel they need.

Besides the additional opportunity of diversification of the farm business model, biomass fuels provide more options for farmers to contribute to the CO₂ reduction targets. As a result, biomass fuels are not necessarily a transition fuel till 2030 but also beyond.

Figure 2 The overall well-to-wheel figures for a range of fuels, emphasizing the negative emissions value of manure sourced biomethane.



Notes: "Green waste" refers to yard clippings, grass, leaves and brush (e.g. from residential curbside pickup programs, that is codigested with food waste). gCO₂e/MJ = grams of carbon dioxide equivalent per megajoule. Source: based on raw data from CARB (2020a), modified by WRL.

¹¹ https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf

4. Technological and regulatory challenges and opportunities for the use of sustainable biomass fuels

It is important to note that only the biomass from resources with a low risk of indirect land use change (ILUC), not impeding food production, can be currently certified for sustainable biofuels in the EU. The first sustainability criteria for biomass fuels were established in 2009 by the EU Renewable Energy Directive (RED I). Since then, along with the update in 2018 (RED II), the GHG saving target for sustainable biofuels from new production facilities has increased from 35% to 65%. In 2015, **a ceiling of 7% for biomass fuels produced from food crops in the total fuel energy mix** was introduced to address the ILUC risk from biofuels. The RED II sets limits on the use of biofuels derived from resources with a high risk of ILUC, for example palm oil, with a significant expansion in land with high carbon stock such as forests, wetlands, and peatlands.

The Renewable Energy Directive revision 2022 (RED III)¹¹ increases the cap on bio-based components in diesel fuel from 7% (B7 blend) to 10% (B10 blend). The overall limit for biofuels from crop feedstocks was kept at 7%, while the share of advanced biofuels is set to increase accordingly.

We recognize that **there is not one prevailing solution to fit all the needs related to renewable and low-carbon fuels.** The promotion of alternatives within a long-term EU support strategy should **encourage the exploration of different technologies to guarantee a suitable range of options for farmers.** The estimated EU agricultural machinery inventory as of 2019 was around 4.6 million units, including 3.5 million tractors and 0.8 million combine harvesters. Machines with Stage IIIA emissions and below made up over 50% of the total fleet. By 2030, we expect a major phase-out of the Stage IIIA inventory. The Stage IIIB and Stage IV inventory would still account for ca. 25%, while the share of Stage V machines should increase to at least 65%¹².

Overall, the cost of engines has already grown during various stages of exhaust emission reduction regulations, as complexity of adaptation increases with each emission stage. **The use of some biomass fuels will require additional investment by manufacturers to adapt vehicles and engine designs.**

In relation to the use of **biodiesel (FAME)**, engines from Stage IIIA and earlier could be eligible for the use of B100 blend (100% biodiesel; FAME complying with the European standard EN 14214), and this could be achieved with no engine modifications but would necessitate additional requirements such as appropriate underground/isolated storage with low day/night time temperature differences. Due to the need for Exhaust Gas Aftertreatment Systems (ATS), although type dependant, Stage IIIB and Stage IV engines are currently limited to a maximum of a B30 blend (complying to EN 16709, with 30% biodiesel in accordance with EN 14214 and 70% diesel following EN 590). No substantial changes are necessary to engines from Stage IIIB and Stage IV for the use with biodiesel above B30, however some modifications to the Engine Control Unit's (ECU) parameters are recommended.

For Stage V engines, the blend limit is set at B7 (7% biodiesel), and EU regulations require additional emissions certification at the maximum allowed biodiesel blend level above B7 (EU 2017/654, amending EU 2016/1628¹²). **An EU wide smooth certification procedure for biodiesel and biodiesel blends between B7 and B100 are needed for the immediate usage of these fuels in the existing fleet and to reduce the financial burden for manufacturers when approving new machines under the existing and forthcoming emission regulations.** A simplification of the engine emission approval process to provide the required certification to allow for the use of fuels other than diesel (such as biodiesel) would be welcomed.

Where biodiesel (FAME) is not true drop-in replacement fuel and only certain blends are possible, HVO is able to replace fossil diesel partly or completely.

Pure HVO fuel meets the requirements of EN 15940 requirements and, as long as the final blend complies with the EU Fuel Quality Directive 98/70/EC as amended and/or the European standard for EN 590 "Automotive fuels - Diesel - Requirements and test methods", no separate engine certification for Stage V is necessary. Producers already offer such blends, e.g. R33, a diesel mix with a maximum of 7% FAME and 26% HVO that remains in compliance with EN 590 and thus can be used in any diesel vehicle. This provides a means to deal with the limited availability of HVO but still offer a CO₂ reduction with currently approved engines.

There is a lack of applicable European standards for the use of **pure vegetable oil fuels**. The main issues identified are quality assurance during production and the retainment of quality in storage, in particular in the case of farmers refining their own vegetable oil.

With regards to **biomethane**, agricultural vehicles are comparable to transport vehicles. EN 16723-1 lists the quality specifications for injection into the gas grid and EN 16723-2 for use in road transport. These are the reference standards that may be met at the farm level. Stage V Engine certification to run on biomethane is available.

Production of sustainable biomass fuels can only take place at a significant scale if there is sufficient political support and demand for it; currently and beyond 2030. To date, market uncertainty concerning the EU biofuels' regulations in the light of outdated "food or fuel" arguments has hindered respective innovation and investment. In accord with other industries, **we call for the unleashing of the full potential of sustainable, low ILUC risk, biomass fuels in Europe.**

¹² https://circabc.europa.eu/sd/a/4415ad0e-7946-4fa9-a432-d4c700c6915d/190503_NRMM_final_v3.pdf

¹³ <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0654&from=DE>



5. Technological and regulatory challenges and opportunities for the use of green hydrogen

At present, the adoption of hydrogen engines in agricultural machines is hindered by several technological gaps and challenges. These include the supply chain as well as the infrastructure for green hydrogen production, which is still in its infancy and unable to offer cost competitiveness across the EU. Moreover, green hydrogen production relies on renewable energy sources such as solar and wind, which may not be available in the necessary density in all regions of the EU. Importantly, the infrastructure to distribute hydrogen is missing in EU today, and would be difficult to be constructed, especially away from the main road networks. For these reasons, the agriculture industry has so far been reluctant to implement hydrogen based solutions. There have been significant investment both at EU level and within member states over the past few years and there is a growing momentum to increase the production levels. However, the vehicle storage and refuelling systems are required to function at a significantly higher pressure range than for example CNG or LPG in order to provide an acceptable duty cycle

to prevent constant refuelling. This is also creating challenges surrounding the logistics of hydrogen. Finally, to bring hydrogen combustion powered equipment in line with diesel equivalents across the EU, hydrogen needs to be included as a reference fuel within the legislation for the type approval for internal combustion engines for non-road mobile machinery (2016/1628).

Although hydrogen could assist in future in realising these goals, there are significant technological improvements required. Moreover, adoption of hydrogen may require changes to operator's practices; for example, an increased frequency of refuelling caused by the limitations of the volume of hydrogen that can be carried on the vehicle combined with the low volumetric energy density of hydrogen systems. Clearly hydrogen is not a readily available option for farmers today, and for it to become a viable alternative solution in the agriculture sector further investments to scale up the production, development and innovation of infrastructure and vehicle systems is needed.

6. Technological and regulatory challenges and opportunities for the use of e-fuels

Considering e-fuels are produced in the EU only from renewable energy sources like solar and wind, and that this 100 % renewable energy is the basis for a comparison between electric cars and cars with internal combustion engines running on e-fuels, the overall efficiency of the electric car would be 5 times higher than for e-fuel driven cars. This was the finding of T&E in their 2017 study¹⁴.

There are however limits on the renewable energy production in the EU. It must be underlined that biomass for energy (bioenergy) continues to be the main source of renewable energy in the EU; forestry being the main source of biomass for bioenergy (logging residues, wood-processing, residues, fuelwood, etc.). Being self-sustainable in the production of renewable energy for the short and middle term might be very difficult if imported energy in the form of fossil fuel for transport is increasingly replaced by electricity to be produced in the EU.

More importantly however, it should be clear that the EU is not the best region for either wind or solar energy production and there are many obstacles. In Germany for example, the efficiency of solar power systems is only 39% (969 h (full load hours in DE) / 2,500 h (maximum full load hours worldwide) * 100)¹⁵. Similar efficiency differences can be observed for wind energy. It is true that more energy is needed to produce e-fuels than for direct electric applications; however, this is compensated by the higher energy yield at

favorable locations, meaning that efficiency differences in production compared to direct electrification are equalised. It is also clear that renewable electricity from Patagonia or North Africa can only be imported by converting it into "transportable" molecules. As a result, compared to a direct use of locally produced renewable energy within an electric drive by outsourcing the production to more favourable regions in the world, the energy conversion could be limited to 1.1 to 1.6 times, depending on the scenario, due to the higher efficiency of renewable energy production¹⁶.

An increase in the replacement of conventional diesel by e-fuels is not particularly feasible before 2030 at the earliest but the discussions are now ongoing. The prohibitively high price for e-fuels when combining carbon with green hydrogen can only be solved with sufficient scaling up. The related industries will only invest if there will be a stable demand for high volumes of e-fuels to justify the investments. Therefore, it must be clearly defined what part of the market will use e-fuels for a long time period. There is an overall political consensus that the use of e-fuels is inevitable for those sectors that are hard to abate and for which their energy needs cannot be satisfied by electrification; primarily, aviation and maritime shipping (recital (1) of the RED II).

¹⁴ <https://www.transportenvironment.org/discover/e-fuels-too-inefficient-and-expensive-cars-and-trucks-may-be-part-aviations-climate-solution/>

¹⁵ Calculated on the basis of the average yield efficiency of solar installations in Germany in 2019, cf. BMWi (2020). For maximum full-load hours worldwide, see Fasihi und Breyer (2020), Baseload electricity and hydrogen supply based on hybrid PV-Wind power plants, Journal of Cleaner Production, Nr. 243, 2020.

¹⁶ https://www.efuel-alliance.eu/fileadmin/Downloads/RPT-EN-Frontier-UNITI_MWV_Effizienz_Antriebssysteme_26_10_2020_stc_translation_20_11_2020_stc.pdf

Given that combustion engines remain the main power source for off-road sectors like for agricultural, forestry and construction machinery, and that they are to be considered sectors that are similarly hard to abate like maritime and aviation, access to suitable e-fuels should be facilitated.

The main issue will be the cost of e-fuels with renewable hydrogen currently not competitive with fossil-based hydrogen. CO₂ pricing might ensure that the costs of GHG emissions are borne by the polluters, for example producers and consumers; this way, important incentives can be provided for the development of clean energy. To accelerate the transition from fossil fuels to sustainable renewable alternatives, such as e-fuels, an appropriate price is essential. The main instruments regulating CO₂ pricing in the European Union will be the Energy Tax Directive (ETD) and the Emissions Trading Scheme (ETS).

Similarly, and in addition to blending fossil fuels with biomass fuels, e-fuels can also be added to the mixture under certain conditions like on quality. The Renewable Energy Directive (RED III) will set the combined share of advanced biofuels and biogas produced from a select list of feedstock and of renewable fuels of non biological origin in the energy supplied to the transport sector at a minimum of 1% in 2025 and 5,5% in 2030.

Besides the issue of reducing the cost of production of e-fuels and their availability in the agricultural sector, it is equally important to consider that the use of a drop-in replacement fuel does not add cost to either specific infrastructures for distribution and storage or for the modification of engine technologies.



7. Political and financial challenges for a fossil fuel free agriculture

The lack of economic incentives for the production and usage of biomass fuels, green hydrogen and e-fuels in agricultural machines, coupled with uncertainties around fuel taxation and subsidy regulations, are among the major risks for a higher uptake in agriculture. Biomass fuels, green hydrogen and certainly e-fuels are more expensive than agricultural fossil diesel. This situation would not change if the national agricultural fossil diesel subsidy was discontinued and the introduction of a national CO₂ price for fossil diesel was considered.

Obviously, higher prices for biomass fuels, green hydrogen and e-fuels, as compared to conventional diesel, hinder their broader market acceptance in the energy mix for agriculture. A fuel price increase, similar to the one caused by the current war Russia and the Ukraine, should not be a driver for these fuels but a fair neutral mechanism that takes into account the sustainability of their production from well to wheel.

For a larger scale use of biofuels, green hydrogen and e-fuels, the CO₂ pricing and taxation of fossil diesel needs to be such that it makes the use of sustainable biofuels an attractive proposition. **Each fuel must be taxed in accordance with its climate contribution.** In other words, fuels that deliver better than zero carbon, such as biomethane derived from the fugitive methane emitted from manure, should receive the highest level of incentivisation and so be taxed the least (an example is the California - Low Carbon Fuel Standard concept). As a result their production will be promoted.

We welcome the Energy Taxation Directive (ETD) revision to harmonize the tax concessions on fossil diesel between EU Members States and to remove outdated tax exemptions encouraging the use of fossil fuels¹⁷. We call on enabling an EU wide level playing field for biomass fuels and e-fuels through the revised EU Climate, Energy and Environmental Aid Guidelines (CEEAG)¹⁸. We would appreciate **a long-term alignment between the EU regulations and national initiatives around taxation and promotion for the range of different fuels that are expected to be used in agriculture.**

We also support a Europe wide call for **a robust incentive mechanism, based on life cycle analysis, which would attract substantial investments into sustainable biomass fuels, green hydrogen and e-fuels.** Since biomass based alternatives to fossil diesel in circular agriculture require a certain set of local infrastructure and region-specific production technologies, a strong political commitment from European and national authorities is needed. For example, **support either from the EU Structural and Investment Funds and/or directly from the EU CAP budget towards local production of biomass fuels** is desirable. It could be complemented by supporting regional logistics and advanced technological solutions for the use of biomass fuels.

Subsidy schemes might also be linked to the carbon farming eco-schemes. There could be incentives for farmers to produce their own low-carbon fuel. This should be linked to the principles of the circular economy due to local or regional production.

¹⁷ <https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52021PC0563>

¹⁸ https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6982

Currently it is only linked to the outputs of the land due to agricultural farming and not to the inputs. If farmers are rewarded for growing crops (also for production of biofuels) that bring carbon matter into the soil, why not for using the biofuel in their engines? The extra benefit being that it concerns not only sustainable local production but also local use; that is unique about the sector.

8. Conclusions and recommendations

Currently, there is no single technology or energy carrier capable of entirely replacing diesel and diesel technology. A combination of technologies and energy carriers, most suitable for a specific sector, region and farm conditions must be selected. The main hindrance when considering a move towards electrification with batteries or H₂ fuel cells for the agricultural sector remains to be the limitations of energy density and design for energy storage. Consequently any hybrid electrification, mainly of functions, including those on the towed/mounted implements, should be seen as a complementary means for farmers to reduce carbon emissions but are limited in scope.

In agriculture and other off-road mobile machinery sectors, alternative fuels will become progressively relevant. In the short to medium term, we primarily envisage the replacement of fossil fuels by biomass fuels in combustion engines as the most realistic solution. Sustainable biomass fuels substantially reduce GHG emissions in comparison with fossil diesel, even when accounting for the ILUC impacts. In some cases, biomass fuels such as biomethane can even deliver negative GHG emissions (> 200 %).

It would also assist in increasing the EU's energy independence for agricultural production.

We welcome the revision of the Renewable Energy Directive (RED III) that provides certainty for renewable energy production. Under these limits, and the possibilities to enhance the circular economy in agriculture, there should also be greater political acceptance of support to farmers in their investments.

This should not only be translated into lower taxation/higher subsidies but additionally be rewarded with credits. The Energy Taxation Directive could play a crucial role in achieving this.

For the long-term, we expect a mix of electrification, green hydrogen, biomass based fuels and e-fuels to be used in the agricultural sector, yet still at different rates dependent upon the type of vehicles and energy demands for specific farming operations. The agricultural machinery industry is fully committed to continuing this path on a voluntary basis, by offering new innovations to the farming community covering powertrains and other machinery elements, as well as diverse agricultural production systems.

We fully support the ambition to make European agriculture both climate and energy neutral. Energy produced within the short carbon cycles of circular agriculture, in the form of sustainable biomass fuels and valuable by-product proteins and organic fertilizers, can play a significant role in ensuring European feed and food supply security. With self-supply of energy, agriculture can become a prosumer, both consuming and producing energy for

local communities, which would increase the economic health of rural communities, improve their energy security and make them more resilient. Primary food production will be more resilient with independence from fossil fuel use. Within a circular agriculture, biomass fuel production can be sustainable within certain land use boundaries whilst not compromising demands for food and feed. Risk for indirect GHG emissions from crop based biomass fuels can be further diminished by focusing on low ILUC feedstock production and can be provided with no conflict with existing crop production.

We underline that biomass fuels must unleash their full potential for the EU Green Deal. The volume of biomass fuels available to the transport sector can be fully utilised by mid and high power offroad machines following the transition of light vehicles to electric propulsion; this is why the existing technical regulatory gaps around biomass fuels must

be closed. We stand ready to undertake the technological adjustments necessary for the full scale use of biomass fuels in agricultural machinery.

In future, e-fuels can play their role to further reduce the footprint of the agricultural machinery fleet as easy drop-in replacement fuels and as part of the next Renewable Energy Directive.

An easy way to achieve the Green Deal targets in agriculture is to make biomass fuels, green hydrogen and e-fuels a more attractive alternative. This could be achieved for example by taxing each fuel in accordance with its climate contribution. In other words, low carbon fuels should receive the right appropriate tax incentive. E.g. biomethane derived from fugitive methane emitted from manure, should get a higher level of incentives and thus be taxed less.



In summary, we would like to make the following main recommendations to European decision makers:

- Support in raising awareness that combustion engines remain a necessary key energy converter for agricultural machinery in the long-term due to its specific types of use. Changes to existing designs will be financially impossible to realise with engine development in car and truck industry being halted.
- Agriculture should be recognised as a key sector for the use of e-fuels and HVO as drop-in replacement fuels. Besides the difficulty to replace combustion engines, a main argument is that existing storage infrastructure and engines can be used, significantly reducing the cost for farmers when making the transition. A robust political framework is needed for investment in the scale up and uptake of these fuels. This must facilitate the applicability of alternative fuels for agricultural purposes and grant the necessary financial support.
- For a successful adoption of the use of renewable and low-carbon fuels instead of conventional diesel, a short and long term EU wide strategy must be established which would include feasible targets and specific taxation and incentives encouraging the use of biomass fuels (crop and waste based), green hydrogen and e-fuels in agricultural industry. Public incentives and taxation should be proportionate to the climate contribution of the various biomass fuels and e-fuels and calculated based on a life cycle assessment.
- The transformation to zero CO₂ emission must be seen and handled as an investment with a proper assignment of value; this is certainly true for agriculture. Both farmers and industry need a clear perspective to plan accordingly as the development processes for new products have a required lead times.

- Clear targets and incentives will encourage farmers to invest, with a good return of investment, into machinery running on biomass based fuels, on-farm or regional small mills, biogas/biomethane plants, and farm fuelling infrastructure.
- To promote CO₂ reduction within agriculture production, authorities should look at a well to wheel (well to crop for agriculture) and not a tailpipe emission approach to enable a portfolio of options, as wide as possible, to suit farmers' needs.
- The European Commission should continue to promote research in alternative biomass resources for the production of advanced biomass fuels including by exploration for potential new feedstocks and by supporting the commercialisation of technologies to convert feedstocks available at scale, in particular wastes and residues, including non-food crops, from new production methods that serve for better carbon sequestration and increased biodiversity.
- Within the competition between FAME and HVO for feedstock in the form of waste streams such as used cooking oil and animal fat, preference should be given to HVO as a perfect drop-in replacement fuel.
- Raising the awareness of farmers, contractors and advisers of the state of the art technologies/practices must be promoted; this could be a combination of providing proof of concept of innovative tools/ practices through demonstration farms and supported by the flagship eco-scheme precision farming.



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