carbone4

ROAD TRANSPORT – ASSESSING THE CLIMATE BENEFITS OF SECOND-GENERATION BIODIESEL

Life-cycle emissions and abatement costs of FAME from used cooking oil and animal fats

Mobility Division

Stéphane Amant
Senior Manager
Mobility Division Manager

Marion Subtil
Consultant

July 2023

CONTENTS

GLOSSARY

CO_2e: "CO_2 equivalent"[1]

FAME: Fatty Acid Methyl Ester

VOME: Vegetable Oil Methyl Ester

AFME: Animal Fat Methyl Ester

UCOME: Used Cooking Oil Methyl Ester

HVO: Hydrotreated Vegetable Oil

GHG: Greenhouse gases

NGV / CNG / LNG: Natural Gas for Vehicles / Compressed NG / Liquefied NG

NCV (or LHV): Net Calorific Value (or Lower Heating Value)

---

[1] Common unit of measurement for all greenhouse gases, representing the amount of carbon dioxide that would cause the same total radiative forcing over a given period of time.

Introduction

WHY CARRY OUT THIS STUDY?

As we tackle the climate challenge, the mobility sector has no choice but to reinvent itself. By means of new practices, by addressing demand itself and by adopting new technologies: the scale of the challenge calls for action on every front. Consequently, efforts to support the low-carbon mobility transition must inevitably focus on the energy transition of road vehicles, independently of the necessary efforts to promote modal shifts and alleviate demand.

One generally acknowledged criterion used to rank the available energy options is the carbon footprint – evaluated over the full life cycle – of different types of vehicles, including private cars, light commercial vehicles, buses and tractor units. In 2020, to inform debate and help stakeholders make the best possible decisions in full possession of the facts, Carbone 4 published a summary of its research on the subject[2], in which only the alternatives likely to see large-scale development were covered. This new publication supplements the first edition with a look at some more "niche" solutions, which typically raise many questions. Additionally, in our previous study, it was not possible to comprehensively address the subject of "biofuels", as the field is rife with special situations, making a nuanced approach essential. In view of these two observations, this study looks at the **most common "second-generation" biodiesels**: **fatty acid methyl esters, specifically those obtained from used cooking oil and animal fats**.

WHAT ARE WE TALKING ABOUT?

The use of diesel biofuels (known as "biodiesels") **as a substitute for petroleum-derived diesel** is a potential route for **decarbonizing** the transport sector. In 2019 in France, such fuels represented 7.3% of the energy contained in diesel[3]. They **mainly consisted of FAME** ("Fatty Acid Methyl Esters") — which accounted for 87.5% by volume of biodiesel in France in the same year[4], and synthetic biodiesels.

---

[2] Carbone 4 (2020), *Transport routier : quelles motorisations alternatives pour le climat ? (Road transportation: what alternative motorisations are suitable for the climate?)*

[3] Actual total quantity of energy in the diesel sector, according to the French Ministry of Ecological Transition, *Panorama 2020 des biocarburants incorporés dans les carburants en France (2020 overview of biofuels incorporated into fuels in France)*

[4] French Ministry of Ecological Transition, *Panorama 2020 des biocarburants incorporés dans les carburants en France (2020 overview of biofuels incorporated into fuels in France)*

"First-generation" FAME are obtained from **vegetable oils extracted from oilseed crops** (rape, soybean, palm, etc.) — these are known as **VOME**. **"Second-generation"** FAME, available in **smaller quantities,** may be obtained from:

- **Used Cooking Oil —** known as **UCOME,**
- **Animal Fats —** known as **AFME**,
- Or **vegetable oil production waste** (palm oil, rapeseed oil, etc.)**, sewage sludge and food waste** — these FAME are currently produced in very small quantities and are not covered in this document.

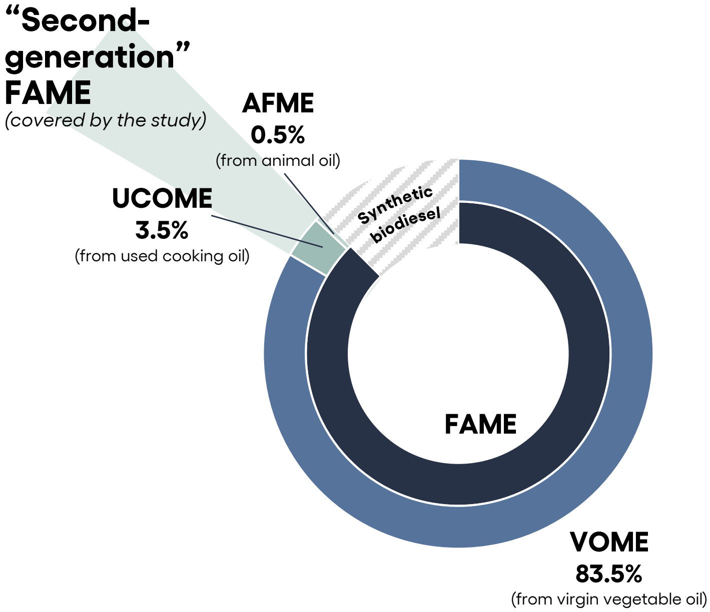


Figure 1 - Volumes of biodiesel contained in diesel in France in 2020 (source: Ministry of the Ecological Transition)

This publication focuses primarily **on UCOME and AFME — so-called "second generation" FAME**.

1 - What exactly is a "second-generation biodiesel"?

Currently, most second-generation FAME biofuels are produced from **used cooking oils and animal fats** and are respectively known as **UCOME** (Used Cooking Oil Methyl Ester) and **AFME** (Animal Fat Methyl Ester).

Before it can be processed, **used cooking oil** (UCO) must be collected by tanker truck **from agri-food businesses and commercial or institutional catering kitchens**. **Animal oils and fats** are collected **from rendering plants,** which collect **animal waste from slaughtering**, meat processing and point-of-sale butchering activities, and then **process this waste, in some cases extracting its constituent fats and proteins**.

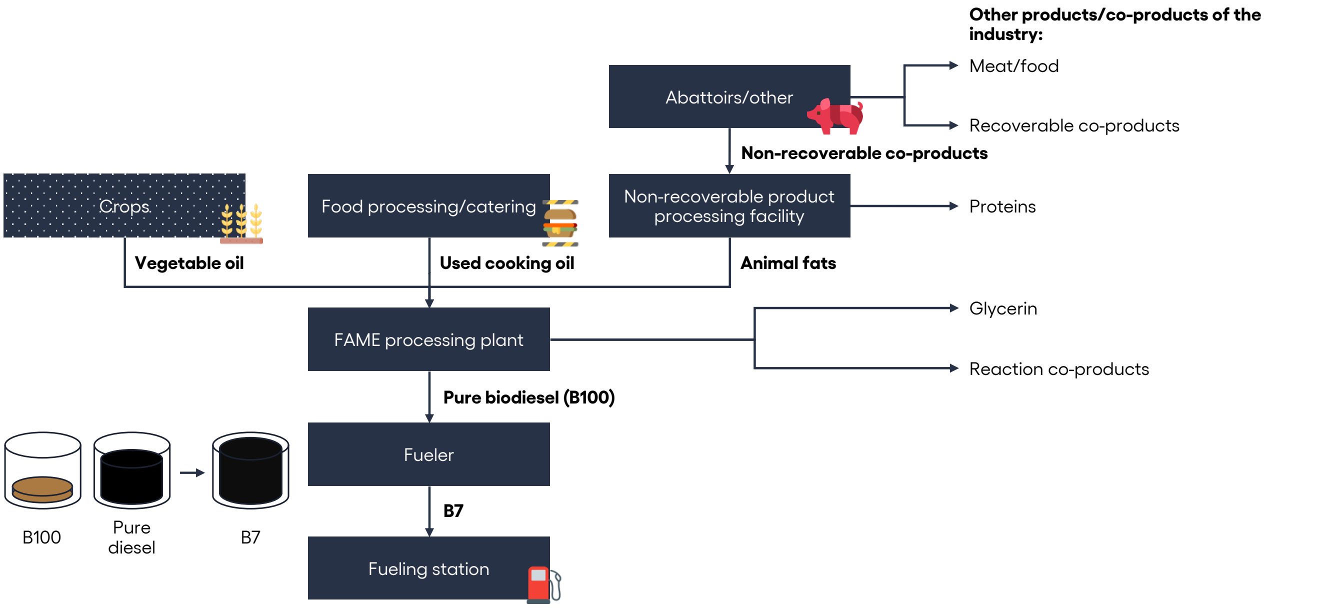


Figure 2 – Industry diagram

Once this feedstock has been collected, **fatty acid methyl esters are obtained by "transesterification"**: as animal oils and fats cannot be used untreated in engines, they are converted into fatty acid esters by having their triglycerides react with an alcohol (a diagram showing the various steps of the conversion process is included in the Appendix).

CATEGORIZATION OF ANIMAL BY-PRODUCTS: NOT ALL AFMES ARE CREATED EQUAL!

Animal fats deemed to be **'animal by-products'** under Regulation (EC) No 1069/2009 are **classified in three categories**, according to the health risks they present:

- **Category 1 (C1) fats** pose a **significant risk to public health** and may only be **recovered as biodiesel or other fuels**, typically for generating steam at rendering plants or for conversion into fuel.
- **Category 2 (C2) fats** present a **lower risk to public health and may be recovered for a number of uses other than animal feed** (such as organic fertilizer, conversion to biogas, compost, etc.), as well as for technical applications (e.g. steam production) or fuels, like C1.
- **Category 3 (C3) fats** present **no risk** to animal health or public health. These fats, which are fit for human consumption but for commercial reasons are not used in that way, are the only category authorized for **use in animal feed**. When suitably processed, they also have applications in **pharmaceuticals, cosmetics, agronomics** (e.g. fertilizers, including compost and anaerobic digestates), **manufactured products, handicrafts and the energy sector**.

The choice of recovery pathway is dictated by this classification, but also by market demand and by the availability of suitable collection and processing infrastructures. **In principle, the goal is to maximize added value**.

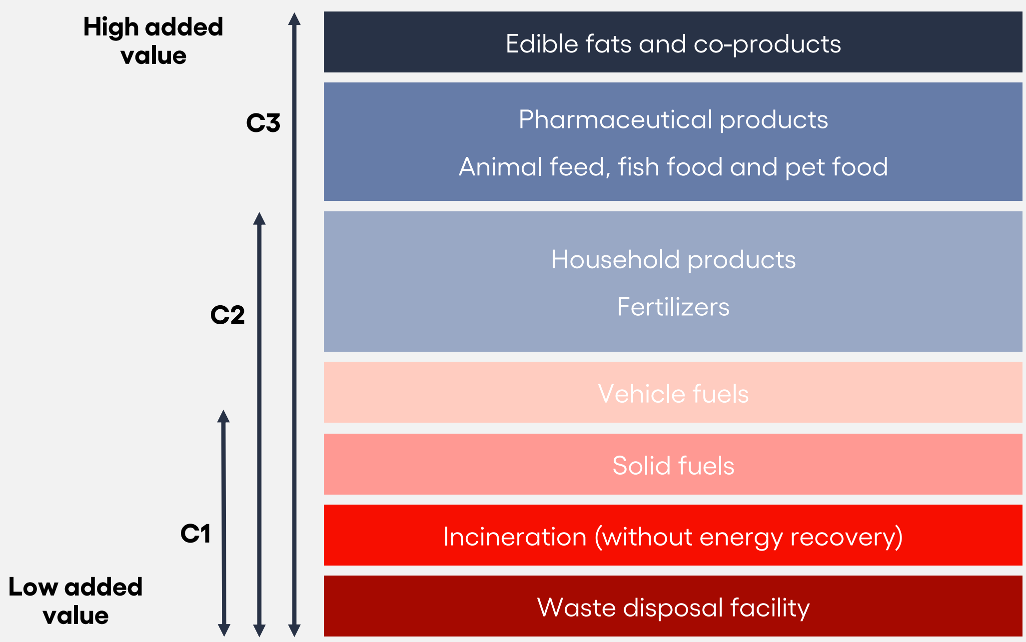


Figure 3 – Hierarchy of uses of products derived from meat industry co-products and by-products (adapted from the EFPRA Sustainability Charter)

In view of the differences in processing between the various categories, this study draws a distinction between **AFME derived from C1-C2 fats** and **AFME from C3 fats**. These are respectively referred to as "**C1 AFME" and "C3 AFME**".

In 2019, C3 AFME accounted for one quarter of all AFME incorporated in France[5].

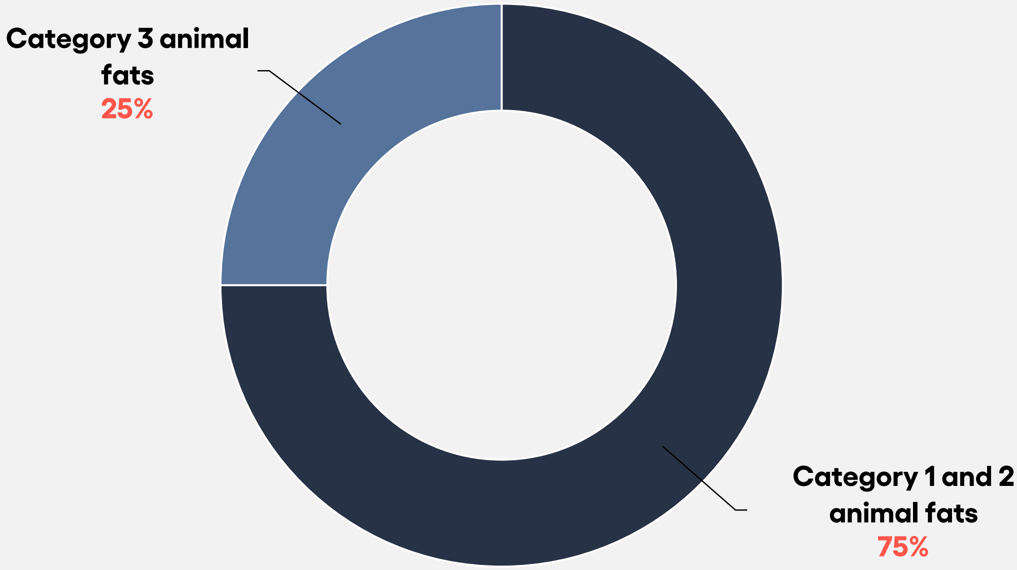


Figure 4 – Feedstocks used to produce AFME incorporated in France in 2020

[5]Source: French Ministry of Ecological Transition, *Panorama 2020 des biocarburants incorporés dans les carburants en France (2020 overview of biofuels incorporated into fuels in France), 2021*

2 – Are these biodiesels better for the climate?

PRODUCTION-RELATED CARBON FOOTPRINT

By convention, **burning biofuel is considered a zero-emissions activity**[6], as the CO_2 released during combustion was previously absorbed by the fuel's raw materials as they grew. This process is the natural short cycle of carbon. Any GHG emissions attributable to biofuels therefore relate to the phase upstream of their use.

Additionally, when **waste/residues are the raw materials** from which a biofuel is produced, the European Renewable Energy Directive (RED II) considers that they generate **no emissions prior to collection**[7]. In this respect, feedstock extraction for **biodiesel derived from used cooking oil or C1 and C2 fats is deemed by default to be a zero-emission activity.**

[6] Directive (EU) 2018/2011 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, Annex V, Part C, item 13: "Emissions of the fuel in use shall be taken to be zero for biofuels and bioliquids"
[7] Directive (EU) 2018/2011 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, Annex V, Part C, item 18: "Waste and residues, (...) and residues from processing, (...) shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials"

RENEWABLE ENERGY DIRECTIVE (RED) – A CONSTANTLY-CHANGING EUROPEAN FRAMEWORK

Issued in April 2009, the Renewable Energy Directive 2009/28/EC – also known as RED I – established targets for European Union member states in terms of incorporating renewable energy into final energy consumption, particularly in the area of transport.

The original Directive was revised in 2018, leading to the publication of RED II, which defined a number of new categories of renewable feedstocks. These categories are allowed to be counted for twice their actual energy value, as an incentive to industrial stakeholders to exploit resources that are harder to process but deliver greater climate benefits. This practice is known as double accounting (DA).

The eligible materials are specified in Annex IX of the Directive, organized in two separate parts:

- Part A presents so-called "advanced" feedstocks,
- Part B presents used oils and Category 1 and 2 animal fats, which are the focus of this study.

As these materials were known to be in limited supply, they were assigned specific incorporation targets for use in transport.
RED II came into effect in July 2021, and is already being revised for a planned RED III, which will be included in the "FitFor55" package aimed at achieving carbon neutrality by 2050.

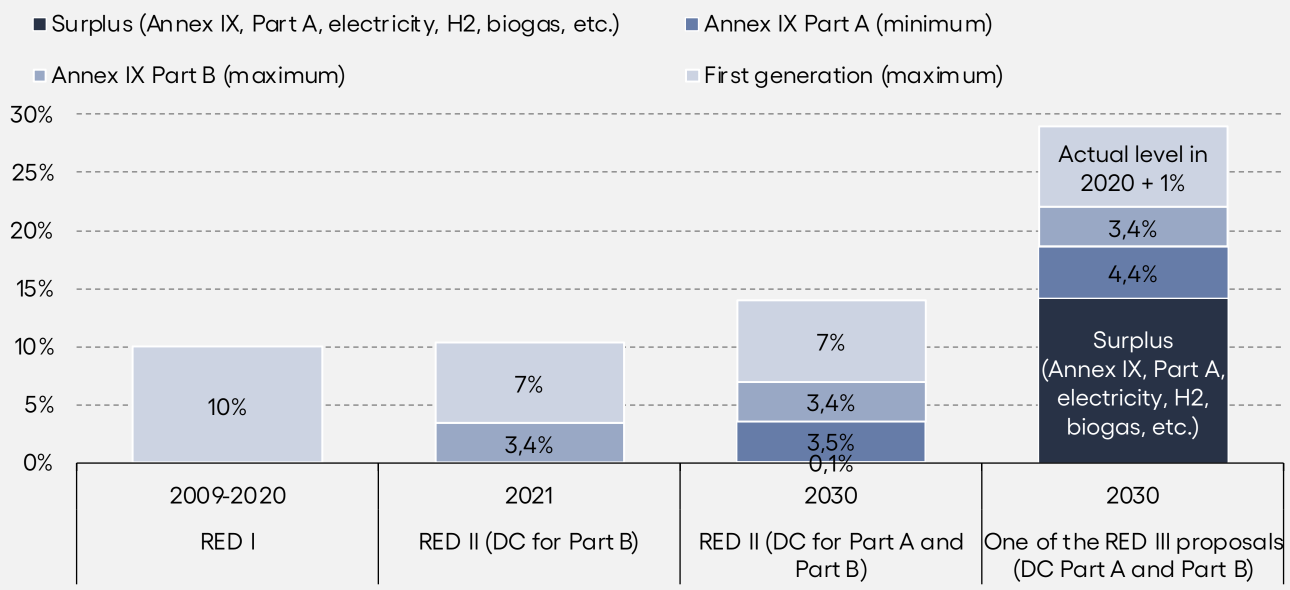


Figure 5 - Change in transport-related incorporation targets (stated as a % of NCV) in the EU Renewable Energy Directive (DA = double accounting)

The proposal for RED III, currently under discussion, would allow Member States to choose between a target of reducing GHG intensity by 14,5% **without double accounting** (not shown in the chart above) compared to a baseline value for fossil fuels, or alternatively, an overall incorporation rate of 29% in NCV[8], **with double accounting,** in both cases by 2030 (see chart above).

However, **the Directive is somewhat unclear** regarding biodiesels **from C3 fats,** which are not explicitly addressed. If waste and residues are considered to produce no upstream emissions, does the same apply to these fats, which have a **more ambiguous status** (as they do not pose a health risk and offer high added value through a wide range of possible uses)? **How should emissions from the meat industry be allocated[9] between meat intended for human consumption and the various co-products?** The specific nature of C3 AFME raises many methodological questions relating to GHG emissions, which we address in the section below.

The life-cycle carbon footprints of UCOME and C1 AFME include the transport and processing of their feedstocks, as well as their storage and distribution. According to data from French producers[10], these respectively amount to **9.8 and 15.7 gCO_2e/MJ[11]**, representing **emissions reductions of 90% and 83% relative to the baseline fossil fuel value**[12]. This data is shown in Figure 6 below.

[8] Net Calorific Value
[9] Emissions arising from production and transport of animal feed, digestive gases from cattle (enteric fermentation), animal manure, energy use on farms, etc.
[10] Data collected by Carbone 4
[11] These values are lower than the default values indicated in RED II, namely 14.9 and 20.8 gCO_2e/MJ, respectively.
[12] Directive (EU) 2018/2011 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, Annex V, Part C, item 19: the value for the baseline fossil fuel is 94 gCO2eq/MJ.
Notes:

- Converting FAMEs also generates energy co-products, typically bio heating oil (BHO) and glycerin, which are used to supply anaerobic digesters (in the case of glycerin) or cement kilns. In the calculations, greenhouse gas emissions are allocated between FAMEs and their co-products proportionally to their energy content, as indicated in Directive (EU) 2018/2011 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, Annex V, Part C, item 17.
- Co-production of BHO requires an additional distillation step, which has been included in the calculations, and the results obtained in terms of GHG emissions are therefore in principle conservative.

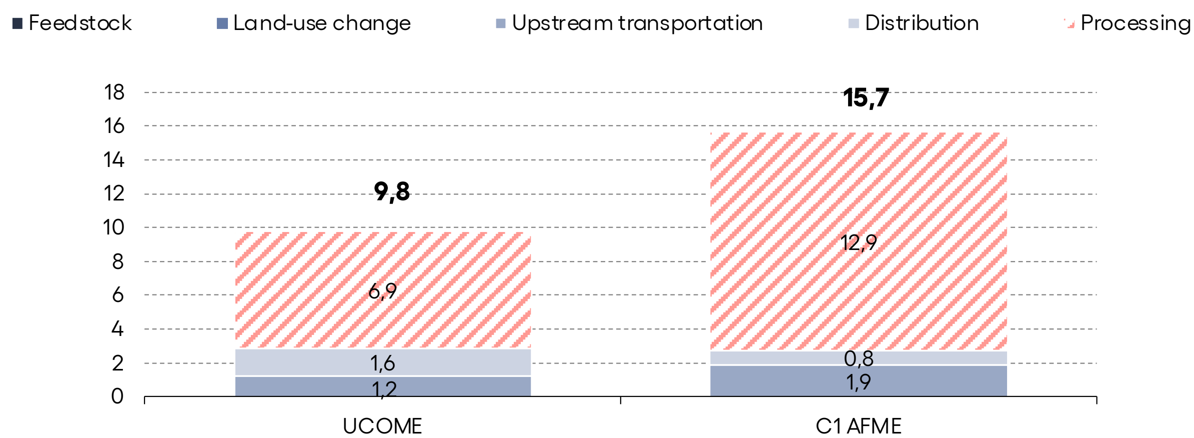


Figure 6 – Carbon footprints of UCOME and C1 AFME producers (gCO2e/MJ)

Note that these two "second-generation" FAMEs are obtained from the same process. The difference between their respective carbon footprints is attributable to the animal fat rendering stage upstream of the actual processing. It therefore appears that **more complex feedstock processing** (involving intermediate steps) **tends to result in a larger carbon footprint and higher production cost**. This observation seems **paradoxical** in light of the European Commission's proposal **to switch from a target (of at least 14%) for renewable energy as a share** of energy consumption in the transport sector **to a target for reducing the carbon intensity of energy in transport** by 14,5% by 2030[13]. Despite **these processes appearing to be harder to develop and less profitable, the new target could be less favorable to them.** In reality, the conclusions are anything but obvious: while it may be true that an advanced FAME requiring multiple processing steps will generally have a larger carbon footprint than a UCOME (i.e. FAME from used cooking oil), that footprint will probably still be smaller than for a first-generation FAME (i.e. FAME from virgin vegetable oil), after factoring in land-use change effects. Additionally, exclusions such as those already introduced for palm oil and its derivatives[14] might in the future impact a number of first-generation biofuel feedstocks.

[13] Relative to a benchmark level of fossil fuel emissions
[14] Biofuels produced from food and feed crops with a high risk of inducing indirect land-use changes

EMISSIONS ATTRIBUTED TO CATEGORY 3 ANIMAL BY-PRODUCTS

An agricultural system typically **produces multiple** products, co-products and by-products **concomitantly**. **How should the environmental impacts of this system be apportioned** between these outputs?

This methodological question (which will be familiar to LCA specialists, as it applies to many "systems") is often hotly debated, as the answer to it **can shape the future of the industries concerned**, depending on the figures obtained.

In the case of biofuels, the European Commission's new 'Fit for 55' climate package proposes to **replace the current target of increasing the share of renewable energy** in transport energy consumption to at least 14% **with a target in terms of decreasing the carbon intensity of energy** by 14,5% by 2030, relative to a benchmark level for fossil fuel emissions. In this context, the **emissions attributed to the various co-products**, and by extension the allocation rule applicable to feedstocks, is clearly a **crucial issue for the industries in question**.

By default, the European Directive RED II assigns no emissions to category 1 and 2 animal fats or used cooking oil. The reason for this appears to stem from the guideline according to which "***waste and residues (...) and residues from processing (...) shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials***, *irrespectively of whether they are processed to interim products before being transformed into the final product*" (Part C of Annex V). This guideline **is debatable, however**: the energy value — and thus the economic value — of these materials might justify a share in the responsibility for the carbon footprint of their respective industries. Nevertheless, **this guideline has the merit of ranking the desirability and utility of the various by-products**. **Clearly defining waste and residues** in the context of this guideline is therefore **very important**.

Category C3 animal fats are not covered by the Directive, and their status is ambiguous. They have **multiple applications** (in animal feed, cosmetics and pharmaceuticals, for example) and should therefore **not be treated as waste.** In addition, they are **increasingly sought after by energy producers for use in biofuels**, and this trend is likely to intensify if they help to achieve the European Commission's proposed new target. A **fair means of allocating emissions must therefore be devised, with due consideration for decarbonization targets and systemic substitution effects.**

Multiple methods of allocating environmental impacts exist, but there is no consensus among industry stakeholders and experts. These methods all have **strengths and weaknesses on different criteria**, making it difficult to establish one rule as objectively better than the others for the meat industry[15].

[15] For more information on this subject, see the IFIP study report *Allocations pour l'affectation de l'impact environnemental entre les produits et co-produits* (Guidance for allocating environmental impacts between meat products and co-products), which reviews allocation recommendations found in a number of methodological guides, standards, terms of reference and research papers on the subject.

In the specific case of C3 fats, for example, the possible options include:

- **Allocating emissions among meat products and by-products proportionally to their mass**. This method is easily applicable, but appears largely unsuitable for products with different functions and markets.
- **Distributing emissions between meat products and by-products proportionally to their market value**. This method makes it possible to assign the environmental impacts to the products for which the production activity was originally undertaken and which have a utility and a market; however, the accessibility and reliability of the relevant data (such as fluctuations in market prices, changes to applicable regulations and taxation, or variability between countries) make it difficult to apply.
- **Assigning them the emissions of substitute products**: using C3 fats for biodiesel production competes with other existing outlets (in cosmetics, animal feed, etc.), forcing the affected industries to switch to alternative inputs. Although this approach **accounts for indirect emissions associated with substitution effects**, multiple substitute products often exist, and these can change over time, making them difficult to identify. Given the availability of plentiful volumes of competitively-priced **palm oil with a fat profile similar to C3 animal fats**, it is likely that this **transfer of use would be to palm oil,** potentially indirectly generating a risk of land-use competition and possible deforestation. While assigning the emissions corresponding to virgin rapeseed oil would still deliver a climate benefit compared with pure diesel, **allocating those of palm oil would result in a 77% increase in overall emissions**. The choice **of alternative oil is therefore crucial in this allocation method**, due to its **direct impact on the ability of C3 AFME to contribute to the goal of cutting the carbon intensity of energy** by 14,5% by 2030, as proposed by the European Commission.

The results of the carbon footprint calculation for C3 AFME vary significantly according to the method chosen, as illustrated in the figure below. Assigning meat industry emissions to C3 fats proportionally to their market value or assigning them the emissions from rapeseed oil shows the use of C3 AFME to be more beneficial to the climate than pure diesel. A very different conclusion is reached if they are assigned meat industry emissions based on their mass, or if they are assigned the emissions generated by palm oil.

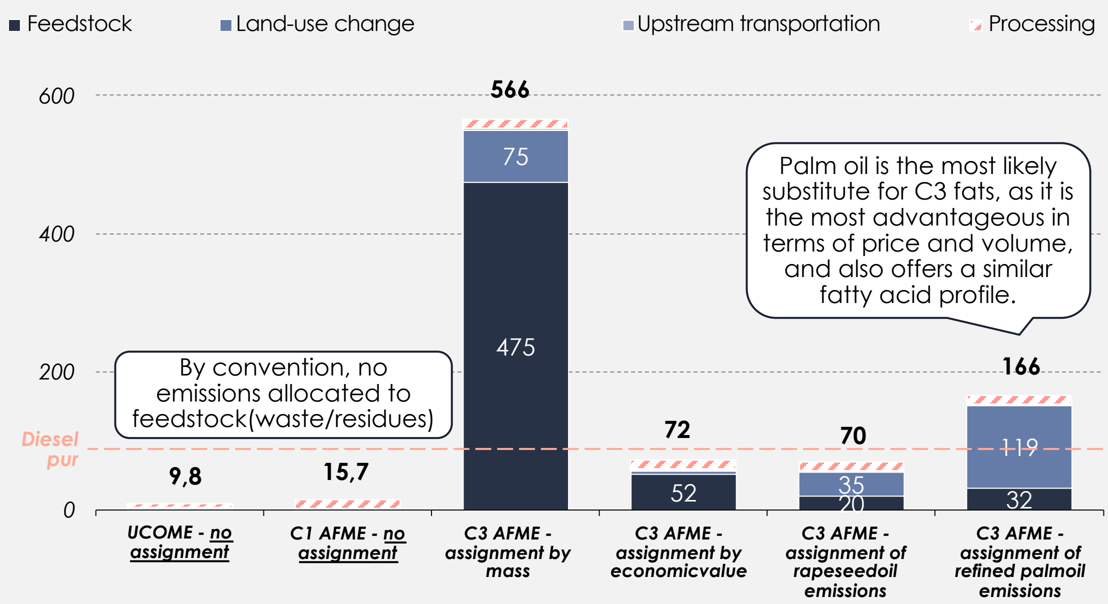


Figure 7 – Comparison of the carbon footprints of FAMEs according to the emissions assigned to their feedstocks (gCO2e/MJ)

Considerable uncertainty therefore surrounds the true carbon impact of C3 AFME.

HOW DOES FAME MEASURE UP TO THE ALTERNATIVES FOR 19T TRUCKS?[16]

When comparing different engine configurations within a particular vehicle category, it is important to **evaluate the carbon footprint for the vehicle's full life cycle, including its manufacture, operation and end-of-life phase**, taking all greenhouse gases into account. With this global <*energy vector + energy converter*[17]> approach, **the efficiency of a vehicle's engine** can be taken into account (for example, internal combustion engines are far less efficient than electric motors), as well as any **vehicle-related specificities** (for instance, the manufacturing and end-of-life phases of internal combustion-engined vehicles generate fewer emissions than battery electric vehicles). The carbon footprint can then be **expressed relative to a standard functional unit**: the distance traveled by the vehicle over its lifetime.

[16] A 19 t cargo truck is fairly representative of the target market for second-generation FAME biofuels
[17] Truck power plant

Figure 8 below illustrates the comparison between various alternatives for a 19 t cargo truck entering operation in France in 2022. The emission factors and main assumptions are given in the Appendix

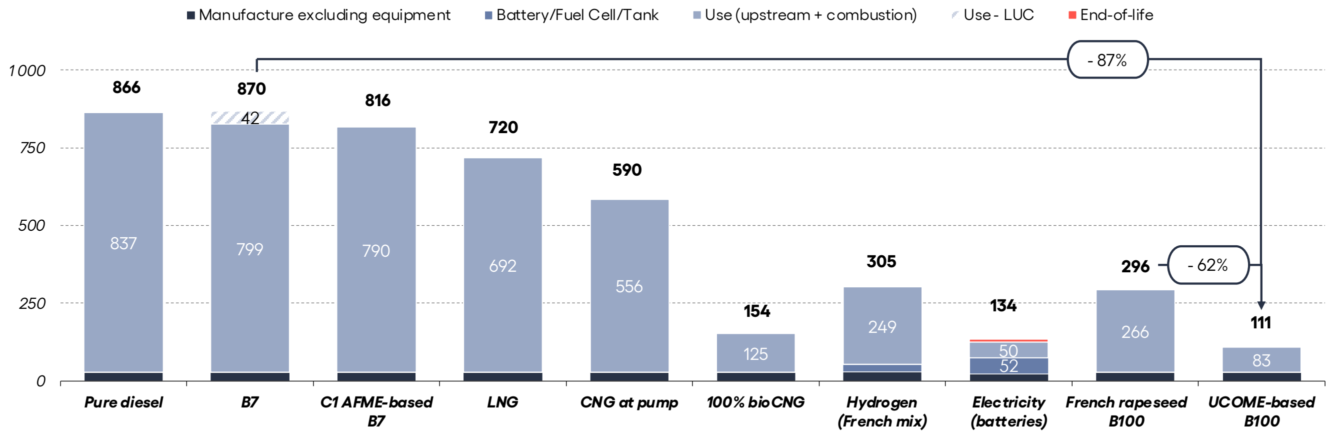


Figure 8 – Average life-cycle carbon footprint of a 19t truck sold in 2022 in France – 600,000 km (gCO2e/km)

Notes:

- Emissions associated with direct and indirect land use changes are taken into account in the study, unlike in current European regulations. For example, biofuel production may require deforestation (direct land-use change), or it may displace food production to previously uncultivated areas (indirect land-use change).
- The B7 and B100 diesel formulas respectively contain 7 and 100% biofuel (by volume). In 2022, the biofuel incorporated into B7 at the pump in France consisted of 80% rapeseed oil (some of which was imported), 14% palm oil, 5% soybean oil, and less than 1% "advanced" oils. The share of advanced oils in this composition is gradually increasing.
- The biofuel content of C1 AFME-based B7 is exclusively C1 AFME.
- By convention, no emissions are assigned to UCO used to produce UCOME-based B100, or to C1 fats used to produce C1 AFME.
- In 2022, CNG at the pump contained 19.6% biomethane (source: AFGNV figures for the bio-CNG incorporation rate of CNG distributed in France in 2021); this incorporation rate is assumed to increase by 1% per year.
- For the purposes of this study, bioCNG is assumed to consist exclusively of biomethane.

This analysis reveals that a **biofuel produced entirely from used cooking oil** (UCOME-based B100) cuts **emissions by 87%** over the life cycle of a 19t truck, **compared to diesel at the pump (B7)**. This drastic reduction **is largely attributable to the fact that no emissions are assigned to the feedstock** (as explained above). This biodiesel would appear to be the best alternative from a climate perspective, but its carbon footprint, which is of the **same order of magnitude** as that of an **electric-powered or bioCNG[18]-fueled 19 t truck**, is not the only criterion of choice. As the **supply of used cooking oil is limited,** we should **(i) direct it towards the uses most difficult to decarbonize** (for example for construction equipment, maritime transport or air transport, for which alternatives to fossil fuels will be harder to find), and **(ii) treat it as a transitional decarbonization tool over the coming years.**

[18] 100% biomethane

In addition, AFME biodiesels produced from **animal fats behave more poorly at low temperatures**. As a result, they are only suitable for use in blended fuels. Thus, assuming that the 7% of biofuel contained in diesel sold at the pump (B7) consists entirely of C1 AFME, a 19t carrier would emit about **6% less GHG** over its lifetime **than it would using "average" diesel sold at the pump in France**.

3 – GHG emissions are only part of the story!

C3 ANIMAL FATS – COMPETITION BETWEEN USES COULD INDIRECTLY LEAD TO LAND-USE CHANGES

The historically recent use of category 3 animal fats for biodiesel production **competes directly with existing industries, prompting them to switch to substitute products such as palm oil** (see previous section). And palm oil consumption is **responsible for deforestation of primary forests and the destruction of peatlands in Indonesia and Malaysia** (which together account for 85% of global production)[19]. Emissions arising from indirect land-use changes are **very difficult to estimate** but **are certainly significant and therefore cannot be ignored**.

As mentioned in the 2020 report[20], considerable uncertainty still surrounds the absolute level of emissions generated by land-use changes. Emission factors vary enormously according to the case under consideration. These factors include the plantation age (deforestation already "paid back" or not), soil type (mineral or peatland), and the released carbon payback period (between 20 and 30 years). Nevertheless, estimating the order of magnitude of these emissions makes it possible to **properly account for the climate impact of producing these crops**.

Indirectly, therefore, using C3 AFME may produce the **same effects as using biodiesel derived from "first-generation" virgin vegetable oils**.

LIMITED SUPPLY

Over its operating life, **the carbon footprint** of a 2022-registered 19 t truck running exclusively on UCOME[21] is of the **same order of magnitude** as that of an equivalent **electric-powered or bioCNG[22]-fueled truck**. Are these three solutions equivalent in every respect?

In addition to the climate impacts, a number of other criteria must be considered, including the abundance of supply and the maturity of the technologies in question. The **rollout of battery electric vehicles is still in its infancy** and this type of propulsion will undoubtedly **never be suitable for some purposes** (such as power-intensive transportation over long distances in areas poorly equipped with charging stations, for example). Additionally, **as for bioCNG, the**

[19] Carbone 4: *Transport routier : quelles motorisations alternatives pour le climat ?* (Road transportation: what alternative motorisations are suitable for the climate?), 2020
[20] Carbone 4: *Transport routier : quelles motorisations alternatives pour le climat ?* (Road transportation: what alternative motorisations are suitable for the climate?), 2020
[21] B100 based on FAME produced from used cooking oil
[22] 100% biomethane

total supply of used cooking oil and C1-C2 animal fats in France is **very limited.** In 2015, the available supply of C1-C2 animal fats in France totaled around 100,000 metric tons[23], representing approximately 90 million liters of C1-C2 AFME, and supplies of used cooking oil were estimated at 1.7 – 3.6 million metric tons in Europe in 2019[24], representing approximately 1.5 – 3.2 million liters of UCOME. In comparison, 2,740 million liters of VOME[25] were incorporated in France in 2019[26]. However, there is little reason to believe that these quantities could increase in the future, as dietary trends in Europe are shifting towards fewer meat products.

UCOME and C1 AFME do have a **role to play in the short term,** as a substitute for fossil diesel **in the existing fleet**, delivering **an immediate reduction in emissions**. However, as they are likely to remain niche solutions, due to the aforementioned supply limitations, they should **ultimately be redirected to address the uses most difficult to decarbonize** (such as construction machinery, long-distance road freight, maritime transport and air transport, for which it will be harder to find alternatives to fossil fuels).

USED COOKING OIL: INADEQUATE TRACEABILITY TO DATE

Encouraging the development of biofuels derived from cooking oil could lead to a collateral windfall effect, with used cooking oil becoming more valuable than virgin oil. In such a scenario, it might **become more profitable to misrepresent and sell unused oil as UCO**, **potentially leading to abuse.**

In 2019, a biofuel industry source informed EURACTIV that one third of all UCO used in the European biofuel market was more than likely fraudulent[27]. In addition to the **threat to the virtuous AFME and UCOME industries posed by such practices[28]**, these lower-cost imports **may not always fully comply with the industry's sustainability criteria**, due to the absence of a mandatory traceability system[29] [30].

The European Commission should create **an EU database to ensure transparency and traceability** of renewable fuels.

---

[23] Institut de l'économie circulaire, *L'ester méthylique d'huile animale (EMHA), un biocarburant inscrit dans l'économie circulaire* (Animal Fat Methyl Ester (AFME), a biofuel for the circular economy), 2015
[24] EWABA and MVaK (2021), *Conversion Efficiencies of Fuel Pathways for Used Cooking Oil*
[25] FAME from virgin vegetable oils
[26] French Ministry of Ecological Transition, *Panorama 2020 des biocarburants incorporés dans les carburants en France (2020 overview of biofuels incorporated into fuels in France)*
[27] EURACTIV, *Industry source: one third of used cooking oil in Europe is fraudulent*, 2019
[28] which are based on recovering under-exploited resources at the national and European levels
[29] Institut de l'économie circulaire (2016) : *L'ester méthylique d'huile animale (EMHA), un biocarburant inscrit dans l'économie circulaire* (Animal Fat Methyl Ester (AFME), a biofuel for the circular economy)
[30] System other than the sustainability schemes recognized and approved by the European Commission (ISCC, 2BV, RetCert, etc.)

WHAT ABOUT OTHER POLLUTANTS?

Despite offering a number of climate benefits, second-generation FAME are still fuels that **emit pollutants** when burned. A 2020 study by the distributor Martin Brower, Fraikin, CRMT and ADEME found that **adding biodiesel to fuel** reduces emissions of carbon monoxide (CO) and unburnt hydrocarbons (HC), but **increases emissions of nitrogen oxides (NO_x)**[31], which are **particularly harmful to human and animal respiratory tracts**. Regarding fine particle emissions, research conducted by IFPEN in 2016 appears to indicate a decrease of a few tens of percent by mass and number on vehicles not equipped with particle filters. No such biofuel effect was observed on vehicles fitted with filters.

Using biodiesel **does not therefore offer a comprehensive solution for suppressing air pollution**. This implies that these fuels should at this stage only be used in sparsely populated areas, typically for long-distance transport.

A PATHWAY FOR (SLIGHTLY) REDUCING OUR ENERGY DEPENDENCY?

In 2020, the **C1-C2 animal fats** used to produce AFME incorporated in fuels in France were mainly sourced in **France (43%,** and up to 100% for some manufacturers), the **United Kingdom (27%)** and **Spain (26%).** The majority of C3 animal fats came from France (60% on average) and other European countries[32,33]. Incorporating AFME in fuels **contributes to energy security** as it is a **local energy source, replacing fossil diesel imported** mainly from Saudi Arabia, Kazakhstan, Russia, Nigeria and Algeria[34].

This is less true for UCOME, as **only half of the volumes** released for consumption in France in 2020 were produced **from used cooking oil sourced in Europe**, with the rest coming mainly **from Asia (36%)**.

The table below summarizes the strengths and weaknesses of the various alternatives.

[31] IFPEN : *Évaluation de l'impact du biodiesel pour les véhicules légers sur les émissions polluantes et particulièrement les suies* (*Assessment of the impact of biodiesel on soot and other pollutant emissions from light vehicles*) 2016

[32] French Ministry of Ecological Transition: *Panorama 2020 des biocarburants incorporés dans les carburants en France (2020 overview of biofuels incorporated into fuels in France), 2021*

[33] The FAME market is driven by price, product grades/specifications and national traceability regulations. Note that not all of the FAME produced in France is incorporated in fuel in France

[34] UFIP, *Un approvisionnement en pétrole et en gaz fortement dépendant des importations* (Oil & gas supplies heavily dependent on imports) 2022

	Strengths	Weaknesses/Negative externalities
UCOME	• Does not compete with food production • Increases non-fossil fuel resources • Recovers a resource with no other outlets	• Limited supply • Risks of fraudulent feedstock imports
C1 FAME	• Does not compete with food production • Avoids waste processing emissions • Recovers a resource with no other outlets • Relatively low cost	• Very limited supply • Usable only when incorporated into diesel (not suitable for use directly in B100) • High filterability temperature, which restricts applications
C3 FAME	• Does not compete with food production • Increases non-fossil fuel resources	• Limited supply • Strong competition with other existing uses (pet food, oleochemistry), potentially generating indirect emissions through substitution effects • Usable only when incorporated into diesel (not suitable for use directly in B100) • High filterability temperature, which restricts applications
C3 HVO	• Does not compete with food production • Increases non-fossil fuel resources • Suitable for direct (unblended) use	• Limited supply • Strong competition with other existing uses (pet food, oleochemistry), potentially generating indirect emissions through substitution effects • More energy-intensive process than FAME, reducing the potential GHG savings • Production cost somewhat higher than for FAME
BioCNG	• Avoids farming and waste processing emissions • Decreases emissions of fine particles and NOx in use	• Highly variable estimates of biomethane supply potential in France and Europe • Strong competition with other, potentially more suitable uses (industry, construction) • Risk of gas leaks, with a significant climate impact • Currently a more costly technology, partly for safety reasons
Fossil LNG/CNG	• Cheaper than pure diesel	• Low GHG savings potential relative to diesel • Volatile prices, driven by geopolitical tensions, speculation, severe winters, incidents in producing countries, etc. • Direct dependence on fossil fuels and producing countries (principally Russia, Norway and Algeria in Europe) • Risk of gas leaks, with a significant climate impact • Currently a more costly technology, partly for safety reasons
H2	• Mitigates the intermittency of renewable energies • Co-benefits in terms of noise and air pollution	• Strong competition with potentially more economically appropriate uses (industry) • Relatively high cost of hydrogen • Embryonic supply and infrastructure • Risk of leaks, possibly with negative climate effects (research pending)

Figure 9 – Overview of the strengths and weaknesses of the studied energy vectors

4 – Assessment of abatement costs for the various alternatives

The cost per ton of avoided CO_2e emissions, also known as the "abatement cost", is an average marginal cost over a given period. In this context, it represents the ratio between the additional cost of producing a particular alternative rather than pure diesel and the emissions avoided by using said alternative instead of pure diesel.

This study of abatement costs adopts a "producer-focused" approach, covering only the "ex-factory" cost of the energy vector[35]. At this stage, this approach is not suitable for comparing solutions from the user's perspective. Just as the various alternatives should be ranked based on their climate impact, **a systemic <*energy vector + energy converter*[36]> *approach should be adopted*** to take into account the **power plant efficiency** and **cost of the vehicles**. This is also the reason why hydrogen has not been included in this survey: the cost and engine efficiency of a hydrogen vehicle are very different from those of a diesel-powered vehicle.

These calculations take into account the feedstock extraction and product processing costs, as well as the cost of distribution to fueling stations (except for FAME, the distribution cost of which is unknown).

The study was conducted for the **period 2013-2020** and for **January-April 2022**, to account for **price volatility** and the **recent increase in energy prices**. The results are shown in Figure 10 below.

---

[35] Only the costs of extracting and processing the feedstock are taken into account, along with the related supply infrastructures in the case of bioCNG/CNG/LNG (see calculation methodology and assumptions in the Appendix)

[36] Vehicle power plant

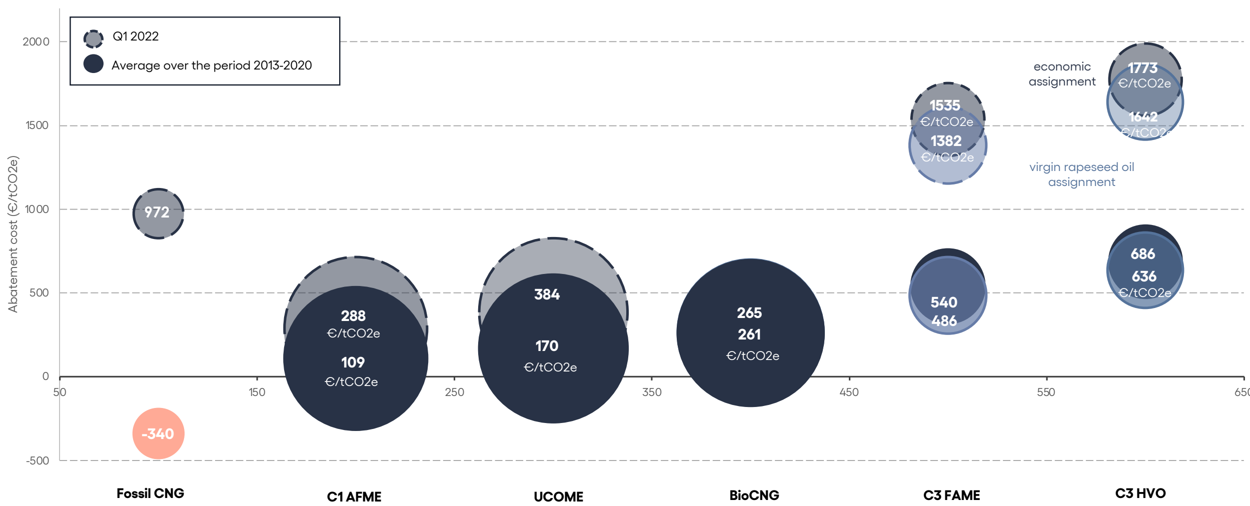


Figure 10 – Abatement cost of the various alternatives

Notes:

- *Bubble sizes are representative of the GHG emissions reduction potential per MJ.*
- *For the purposes of this study, bioCNG is assumed to consist exclusively of biomethane.*
- *HVO stands for hydrotreated vegetable oil, which is a biodiesel obtained by a different process than that used for FAME. Referred to somewhat inaccurately herein as "C3 HVO", this fuel is a hydrogenated oil derived from category 3 animal fats.*

The **C3 AFME** to which the emissions for virgin palm oil are assigned (based on the substitution assumption) are not shown in the graph above, as they **do not avoid any CO_2e emissions**. Only the economic and substitution assignments for rapeseed oil yield emission reductions.

Over the period 2013-2020, **fossil CNG had a negative abatement cost**, meaning that this alternative to pure diesel **not only made it possible to reduce CO_2e emissions, but also cost less**. **C1 AFME was the alternative with the second-lowest abatement cost**, followed by UCOME, bioCNG, C3 AFME and C3 HVO[37].
The recent rise in energy prices **has made the abatement cost of bioCNG more competitive, followed by C1 AFME, UCOME and C3 AFME.**

This analysis points to **broadly similar abatement costs for C1 AFME and bioCNG**, whereas the abatement cost of **C3 AFME is approximately four times higher.**

[37] HVO stands for hydrotreated vegetable oil, which is a biodiesel obtained by a different process than that used for FAME. Referred to somewhat inaccurately herein as "C3 HVO", this fuel is a hydrogenated oil derived from category 3 animal fats

Note that the **abatement cost**, i.e. the ratio between additional cost and climate benefit, **masks the absolute climate benefit**. Although the abatement cost of **fossil CNG is lower than the other alternatives** over the period 2013-2020, this alternative to pure diesel does not yield **CO_2e emission reductions on a scale commensurate** with the challenge of decarbonizing the transportation sector!

Additionally, depending on the type of transport, not all alternatives may be valid. For example, an air carrier will always have to pay more per ton avoided than a road carrier because it can only use HVO and not FAME (due to technical limitations such as the filterability temperature limit).

Conclusion

The use of FAME produced from **used cooking oil (UCOME) and animal fats that present health risks** (C1-C2 AFME) can significantly **reduce greenhouse gas emissions**. Considering the case of a 19 t cargo truck configured with various types of engine, **the climate benefits of using an all-UCOME biodiesel would reduce per-mile emissions by 87% compared to pure diesel**. This reduction is of the same order of magnitude as with a battery electric truck or one running exclusively on bioCNG (biomethane). This comparison cannot be replicated with a biofuel containing only C1-C2 AFME (i.e. from animal fats posing health risks) as this biodiesel's physicochemical characteristics are such that it can only be used in a blended fuel.

This **very positive result** is due in particular to the fact that **no emissions are assigned to the AFME** prior to collection. Note that this **does not apply to FAME derived from animal fats that do not present health risks** (i.e. C3 AFME). This category of fat **has many competing uses** (particularly in the animal feed and cosmetics industries) and using it for biofuel can generate indirect greenhouse gas emissions as a result of substitution effects. The carbon footprint of C3 AFME is harder to assess (being heavily **dependent on the emission assignment method**), but is **potentially much larger** (by a factor 5 to 10) than that of C1-C2 AFME.

A natural consequence of this is that the **method of assigning upstream emissions to the various "second-generation" feedstocks** is a fiercely debated topic. This choice is all the more crucial inasmuch as **it may significantly influence the outlook for the various biofuel industries**, in view of the European Commission's proposal **to switch from a target (of at least 14%) for renewable energy as a share** of energy consumption in the transport sector **to a target for reducing the carbon intensity of energy in transport** by 14,5% by 2030[38].

When the analysis is expanded to include the economic dimension, we observe that the abatement costs[39] associated with **C1-C2 AFME and bioCNG production** are **broadly similar**, whereas that of **C3 AFME** is **approximately four times higher**. It should nevertheless be borne in mind that from a biofuel end user's perspective, the abatement cost calculation should also factor in the cost of the vehicle and its power plant, which was not the case in this study.

---

[38] Relative to a benchmark level of fossil fuel emissions
[39] cost per metric ton of CO_2e avoided

Despite their climate benefits and their **(modest) contribution to energy sovereignty**, advanced FAME from used cooking oil and C1-C2 animal fats suffers from a number of drawbacks:

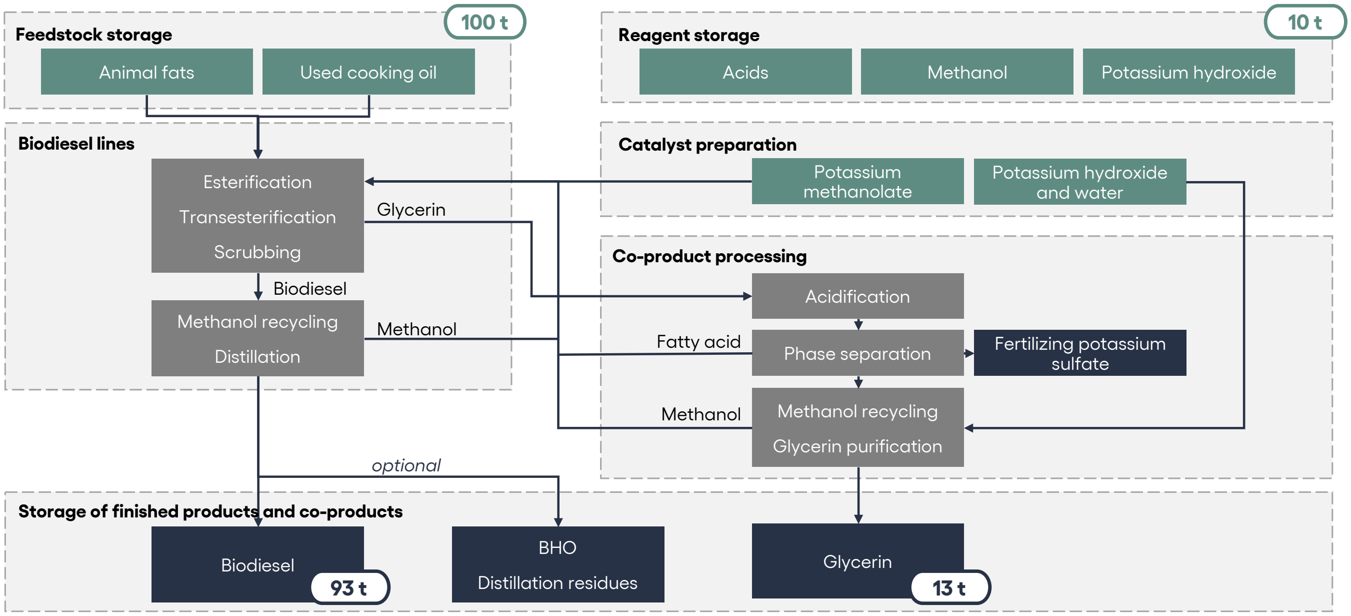
- The **available supply is very limited**, and not likely to increase,
- These fuels still generate **exhaust pollutants** (NO_x, CO, HC, etc.),
- The combination of strong demand for used cooking oil and currently inadequate traceability has led to **fraudulent imports** of virgin oils that do not always comply with sustainability criteria.

In conclusion, UCOME and C1-C2 AFME clearly have a **role to play in the short term,** as a substitute for fossil diesel **in the existing vehicle fleet**, contributing to an **immediate reduction** in transport-related greenhouse gas emissions. For most road uses, this should be considered only as **a transitional solution** (until the 2030s), as alternative, equally decarbonizing solutions suitable for **large-scale deployment** become increasingly available (including bioNGV and battery electric vehicles). Looking ahead, these fat-based processes, which are likely to remain niche solutions due to the aforementioned limitations, should **ultimately be redirected to the uses most difficult to decarbonize** (i.e. non-electrified or hard-to-electrify heavy land transport, aviation and inland waterway transport).

Appendices

FIGURES

FLOWCHART OF THE FAME CONVERSION PROCESS



Converting FAMEs also generates **co-products,** typically **BHO**[40] and **glycerin**, which are used to supply **anaerobic digesters** (in the case of glycerin) or **cement kilns**. The **conversion yield is very good**: for every 100 tons of feedstock and inputs, almost 93 tons of FAME leaves the plant.

RED II METHODOLOGY FOR CALCULATING GREENHOUSE GAS EMISSIONS FROM BIOFUEL PRODUCTION AND USE

Annex V of the RED II European Directive defines the rules for calculating the greenhouse gas impact of biofuels. Greenhouse gas emissions arising from biofuel production and consumption are calculated according to the following formula, as shown in the figure below:

[40] Bio Heating Oil, a renewable equivalent of domestic heating oil

Total emissions from fuel use:

$$E = eec + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr}$$

- emissions from **raw material extraction or cultivation**
- annualized emissions from changes in carbon stocks due **to land-use changes**
- emissions from **processing**
- emissions from **transportation and distribution**
- emissions from **fuel at the time of use**
- emission reductions due to **soil carbon sequestration** achieved through improved farm management
- emission reductions due to CO2 **capture and geological storage**
- emission reductions due to CO2 **capture and substitution**

The calculation rules also stipulate that *"waste and residues (…) and residues from processing (…) shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials, irrespectively of whether they are processed to interim products before being transformed into the final product"*.

RED therefore considers the e_{ec} and e_l emissions for biodiesels produced from used cooking oil or from Category 1 and Category 2 rendered fat to be zero by default. As a result, the only emissions considered for these products derive from the terms e_p and e_{td}:

$$E = 0 + 0 + e_p + e_{td} + 0 - 0 - 0 - 0$$

RED II does not cover biodiesel produced from Category 3 rendered fats. This results in some ambiguity in terms of accounting for emissions associated with the feedstock.

EMISSION FACTORS AND MAIN ASSUMPTIONS USED TO CALCULATE THE CARBON FOOTPRINT OF A 19 T TRUCK FOR VARIOUS POWER PLANT CONFIGURATIONS

19 t truck *Power plant*	*Invariable over time* Weight	 Service life	*Variable over time*	*2022*	*2032*
ICEV - Diesel	3,066 kg	600,000 km 10 years	**Actual cons. (MHEV)**	26 L/100 km (9 mpg)	22 L/100 km (10.7 mpg)
			Biodiesel share in B7	7%	7%
ICEV - CNG	3,325 kg *of which tank: 324 kg*	600,000 km 10 years	**Actual cons. (MHEV)**	22 kg/100 km	19 kg/100 km
			BioGNC share	19.6%	19.6%
ICEV - LNG	3,100 kg *of which tank: 99 kg*	600,000 km 10 years	**Actual cons. (MHEV)**	22 kg/100 km	19 kg/100 km
			BioLNG share	19.6%	19.6%
BEV	4,707 kg *of which battery: 1,943 kg*	600,000 km 10 years	**Actual consumption**	100 kWh/100 km	95 kWh/100 km
			Battery capacity	311 kWh	432 kWh
HEV (electrolysis)	3,962 kg *of which battery+tank: 680 kg*	600,000 km 10 years	**Actual consumption**	6.6 kg/100 km	6.0 kg/100 km
			Tank size	43 kgH_2	43 kgH_2

Figure 11 – Main assumptions specific to 19 t trucks

Energy vector	*Underlying assumption*		*2022*	*2032*
Diesel at pump	Conventional in France: 80% rapeseed / 14% palm / 5% soy / 2% advanced Advanced: waste & residues	**Incorporation rate**	69% B7 7% B10	51% E10 44% E20
		Share of advanced biodiesel	5.5% convent. 0.1% advanced	5.7% convent. 2.2% advanced
LNG at pump	Biogas[1]: 46% onsite ag. / 33% regional ag./ 12% landfill / 6% WWTP / 3% biowaste (75% sorted at source)	**BioLNG incorporation rate**	19.6%	21.9%
		Fossil LNG & biomethane emission factors	3.68 gCO_2e/kg 0.59 gCO_2e/kg	3.64 gCO_2e/kg 0.52 gCO_2e/kg
CNG at pump	Biogas*: 46% onsite ag. / 33% regional ag./ 12% landfill / 6% WWTP / 3% biowaste (75% sorted at source)	**BioCNG incorporation rate**	19.6%	21.9%
		Fossil CNG & biomethane emission factors	3.00 gCO_2e/kg 0.59 gCO_2e/kg	2.98 gCO_2e/kg 0.52 gCO_2e/kg
Electricity	Electricity mix forecasts based on IEA and SNBC studies	**Emission factors in France**	54 gCO_2e/kg	142 gCO_2e/kg
Hydrogen	Centralized steam reforming	**Electrolysis emission factors in France**	4.15 gCO_2e/kgH_2	3.05 gCO_2e/kgH_2

Figure 12 – Energy assumptions

	Chassis manufacturing EF[1]		Tank/battery manufacturing EF				End-of-life EF	
	ICE vehicle $kgCO_2e/kg$	Electric vehicle $kgCO_2e/kg$	Hydrogen[2] $kgCO_2e/kg$	CNG $kgCO_2e/kg$	LNG $kgCO_2e/kg$	Battery $kgCO_2e/kWh$	Vehicle $kgCO_2e/kg$	Battery $kgCO_2e/kWh$
2022	5.0	4.6	410	10.8	5.0	97	0.4	15
2032	4.2	3.9	370	10.0	4.2	81	0.4	15

- [1]Emission factor from manufacturing the vehicle, excluding its tank and battery
- [2]Same carbon footprint for Type III (350 bar) and Type IV (700 bar)

Figure 13 – Emission factors adopted when calculating vehicle manufacturing and end-of-life emissions

CALCULATION METHOD, DATA AND MAIN ASSUMPTIONS USED TO CALCULATE ABATEMENT COSTS

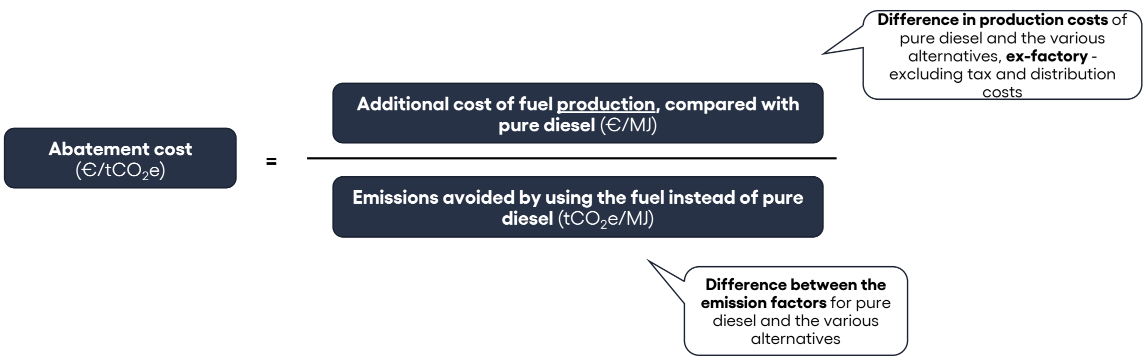


Figure 14 – Calculation method for "ex-factory" abatement costs

	Data used	Data sources	Assumptions - 2013-2020 period	Assumptions - Q1 2022
Pure diesel	Price of diesel on the Rotterdam market	UFIP	2013-2020 average	Jan-April 2022 average
FAME	Feedstock price and processing cost	Industry player	2013-2020 average	Jan-April 2022 average
C3 HVO	Feedstock price and processing cost (deduced from the average production cost of UCO HVO)	ICCT, *The potential of liquid biofuels in reducing ship emissions*, 2020 EWABA and MVaK, *Conversion efficiencies of fuel pathways for Used Cooking Oil*, 2021	Average feedstock prices over the period 2013-2020 Processing cost deduced from the average production cost of UCO HVO	Average feedstock prices in Jan-Apr 2022 Processing cost estimated by Carbone 4
BioCNG	Production and infrastructure costs	Jacques Wiart (ADEME), *Feuille de route réduction des coûts : où en sommes-nous ?* (Cost reduction roadmap - How are we doing?), 2022 Research & Innovation Days French Ministry of the Ecological Transition, *Bilan énergétique de la France pour 2019 (2019 national energy review)* 2021	Average production cost of biomethane injected over the period 2015-2020 Average infrastructure cost over the period 2013-2020	Processing cost estimated by Carbone 4 Average infrastructure cost over the period 2013-2020
Fossil CNG	Supply and infrastructure costs	Comité National Routier, *2022 monthly gas prices* (PEG) French Ministry of the Ecological Transition, *Bilan énergétique de la France pour 2019 (2019 national energy review)* 2021	2013-2020 average Average infrastructure cost over the period 2013-2020	Average supply cost in Jan-Apr 2022 Average infrastructure cost over the period 2013-2020

Figure 15 – Data and main assumptions used to calculate the abatement costs of alternative energy vectors to pure diesel

Note: HVO stands for hydrotreated vegetable oil, which is a biodiesel obtained by a different process than that used for FAME. Referred to somewhat inaccurately herein as “C3 HVO” and “UCO HVO”, these fuels are hydrogenated oils derived respectively from category 3 animal fats and from used cooking oil.

BIBLIOGRAPHY

General concepts and assumptions:

- **ADEME, CRMT, Fraikin and MARTIN BROWER**, *Mesures de performances environnementales sur un porteur MAN 26 tonnes EURO VI step C alimenté successivement en gazole et B100 en région lyonnaise* (Environmental performance measurements on a 26 t MAN EURO VI Step C cargo truck, successively supplied with diesel and B100 in the Lyon region of France), 2020
- **Carbone 4,** *Transport routier : quelles motorisations alternatives pour le climat ?* (Road transportation: what alternative motorisations are suitable for the climate?), 2020
- **EURACTIV**, *Industry source: one third of used cooking oil in Europe is fraudulent*, 2019
- **EWABA and MVaK**, *Conversion efficiencies of fuel pathways for Used Cooking Oil*, 2021
- **FranceAgrimer**, *Allocations pour l’affectation de l’impact environnemental entre les produits et co-produits carnés* (Guidance for allocating environmental impact between meat products and co-products), 2017
- **IFPEN,** *Évaluation de l’impact du biodiesel pour les véhicules légers sur les émissions polluantes et particulièrement les suies* (Assessment of the impact of biodiesel on soot and other pollutant emissions from light vehicles), 2016
- **Institut de l’économie circulaire,** *L’ester méthylique d’huile animale (EMHA), un biocarburant inscrit dans l’économie circulaire* (Animal Fat Methyl Ester (AFME), a biofuel for the circular economy), 2015
- **French Ministry of Ecological Transition:** *Panorama 2020 des biocarburants incorporés dans les carburants en France* (2020 overview of biofuels incorporated into fuels in France), 2021
- **UFIP,** *Un approvisionnement en pétrole et en gaz fortement dépendant des importations* (Oil & gas supplies heavily dependent on imports), 2022
- **European Union**, *Directive (EU) 2018/2011 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources*, 2018
- **European Union**, *Regulation (EC) No 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal By-products Regulation)*, 2019

Carbon footprint calculations and comparisons:

- **ADEME**, *Base Carbone (carbon database)*
- **Agribalyse**
- **AFGNV**, *Part de bio-GNC dans la consommation totale de carburant (2014 à 2020)* (BioCNG as a share of total fuel consumption (2014-2020), 2022

- **AFHYPAC**, *Applications de la pile à combustible et de l'hydrogène dans le transport routier* (Fuel cell and hydrogen applications in road transport), 2018
- **Committee on Climate Change**, *Hydrogen in a low-carbon economy*, 2018
- **Fraunhofer Institute**, *Greenhouse gas emissions for battery electric and fuel cell electric vehicles with range over 300 km*, 2019
- **Gas for climate**, *The optimal role for gas in a net-zero emissions energy system*, 2019
- **GFLI EFPRA**, EFPRA Rendered Animal By-Products LCIA, 2021
- **Globiom**, *The land use change impact of biofuels consumed in the EU*, 2015
- **ICCT**, *A methodological comparison for estimating renewable gas potential in France*, 2019
- **ICCT**, *What is the role for renewable methane in European decarbonization?*, 2019
- **IEA**, *Electricity Information*, 2021
- **IEA**, *Outlook for biogas and biomethane*, 2020
- **IEA**, *Technology Roadmap Hydrogen and Fuel Cells*, 2015
- **IFP energies nouvelles**, *Bilan transversal de l'impact de l'électrification par segment* (Review of the impact of electrification by market segment), 2018
- **IFP energies nouvelles,** *Étude ACV de véhicules roulant au GNV et bioGNV* (LCA study of vehicles running on NGV and bioNGV), 2019
- **IFP energies nouvelles – E4T**, *Analyse de la consommation énergétique des véhicules routiers (du réservoir à la roue)* (Analysis of (tank-to-wheel) energy consumption of road vehicles), 2018
- **IVL Swedish Environmental Research Institute**, *Lithium-Ion Vehicle Battery Production*, 2019
- **JEC**, *Well-to-Tank Database v5a*, 2018
- **Les Comptes des Transports en 2018** (2018 transport review), 2019
- **National Renewable Energy Laboratory**, *Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs*, 2014

Abatement costs:

- **Carbone 4**, Data from an industrial customer
- **Comité National Routier**, *2022 monthly gas prices* (PEG)
- **EWABA and MVaK**, *Conversion efficiencies of fuel pathways for Used Cooking Oil*, Final Report, 2021
- **ICCT**, The potential of liquid biofuels in reducing ship emissions, 2020
- **Jacques Wiart (ADEME)**, *Feuille de route réduction des coûts : où en sommes-nous ?* (Cost reduction roadmap - How are we doing?), 2022 Research & Innovation Days
- **French Ministry of the Ecological Transition**, *Bilan énergétique de la France pour 2019 (2019 national energy review)* 2021
- **UFIP,** *Tableau de bord de l'évolution des prix des produits pétroliers (Price trends for petroleum products)*, 2022
- **European Union**, *Directive (EU) 2018/2011 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources*, 2018

Carbone 4 is the leading independent consultancy specializing in low-carbon strategy and climate change adaptation.

Constantly alert to weak signals, we deploy a systemic vision of the energy-climate constraint, harnessing our discipline and creativity to transform our customers into leaders equipped for the climate challenge.

Contact: contact@carbon4.com