Desk Study on Technical Corn Oil

Final Report

Project #402063

E4tech Sàrl for the Dutch Ministry of Infrastructure and Water Management

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Contents

List of Abbreviations

CCO: Crude Corn Oil (extracted from corn wet milling)

DCO: Distiller Corn Oil (US synonym of technical corn oil).

DDGS: Distillers' Dried Grains and Solubles

FAME: Fatty Acid Methyl Ester (Biodiesel)

FAPRI: Food and Agricultural Policy Research Institute (University of Missouri)

GHG: Greenhouse Gas

LUC: Land-Use Change (can be direct or indirect)

RED/RED II: Renewable Energy Directive (RED will be enforced until the end of 2020, then replaced by RED II)

RFS: Renewable Fuel Standard (US). RFS2 is used to designate the second rule of the program, which was brought in in 2010.

RIN: Renewable Identification Number (US)

TCO: Technical Corn Oil (extracted from corn dry milling)

TRL: Technology Readiness Level

1 Introduction

1.1 Background and objectives

Technical corn oil (TCO) is made during the processing of corn into ethanol. It is extracted from the Distillers' Dried Grains and Solubles (DDGS) and can be used directly as feedstock for biodiesel production. It can also be used as feed ingredient.

A possibility exists for certain biofuel feedstocks to be included in Annex IX of the recast Renewable Energy Directive or RED II (European Commission, 2018), which has important consequences, including specific inclusion sub-targets and the possibility for member states to double count the contribution of such feedstocks against renewable energy targets. The decision to include new feedstocks to Annex IX can only be made by the European Commission through delegated acts, as detailed in Article 28, paragraph 6 of RED II.

Through this study, the Dutch Ministry of Infrastructure and Water Management would like to assist the European Commission in understanding the case for considering TCO as a waste or residue, and/or potentially include as a feedstock within Annex IX part A or B of the. Considering TCO as waste or residue would reduce the scope of compliance with RED II, e.g. compliance with land-use criteria would no longer be required, greenhouse gas would only be considered from the first collection point onward and the chain of custody (traceability) would be reduced. Including TCO in Annex IX would in turn place TCO outside the 7 % cap for food/feed-based biofuels and the phase-out obligation for high-iLUC feedstocks.

This study provides the technical and material elements needed by the European Commission to evaluate whether sufficient evidences exist for the inclusion of TCO in RED II Annex IX (Part A or part B). The following sections address the following key questions:

- What is TCO and how is it made (Section 2.1)?
- What are the other sectors competing with biodiesel for the use of TCO (Section 2.2)?
- What are the economics of TCO (Section 2.3)?
- Can TCO be considered a waste or a residue rather than a co-product, as per RED II definitions (Sections 3.1.1 and 3.1.2)?
- Should the production of TCO-derived biodiesel be considered as a mature or advanced technology (Section 3.2.1)?
- Is the use of TCO for biodiesel in line with a circular economy approach (Section 3.2.2)?
- How likely is TCO-based biodiesel to meet RED II land-use criteria (Section 3.2.3), minimum GHG savings (Section 3.2.5) and minimise other environmental impacts (Section 3.2.6)?
- Could the use of TCO for biodiesel production create market-driven effects such as indirect land-use change (Section 3.2.4)?
- Given these considerations, what is the case for inclusion of TCO as an Annex IX A or B feedstock (Section 4)?

2 Introduction to Technical Corn Oil (TCO)

2.1 The TCO supply chain

According to the US Department of Agriculture (2018), more than 1.1 billion metric tonnes of corn were produced globally in 2016-2017, including more than a third in the United States. Corn grains are primarily used as animal feed (60% of world consumption), as well as human food and ethanol production. During the corn milling process (to produce food, feed or ethanol) small amounts of corn oil can be extracted from the germ. According to Engels (2017), corn oil represents about 3.3% of a bushel of corn by weight.

Two processes exist for corn processing: dry milling and wet milling. Dry milling is primarily used to produce both ethanol and feed, whereas wet milling tends to be primarily used to produce food ingredients (incl. sweeteners, starch and corn oil) and feed, although about 10% of US corn ethanol comes from the wet milling process. In general, “Technical Corn Oil” (TCO) is the term used specifically to designate the corn oil extracted through the dry milling process, whereas corn oil produced through the wet milling process is generally called “crude corn oil” (CCO).

2.1.1 The corn dry milling process

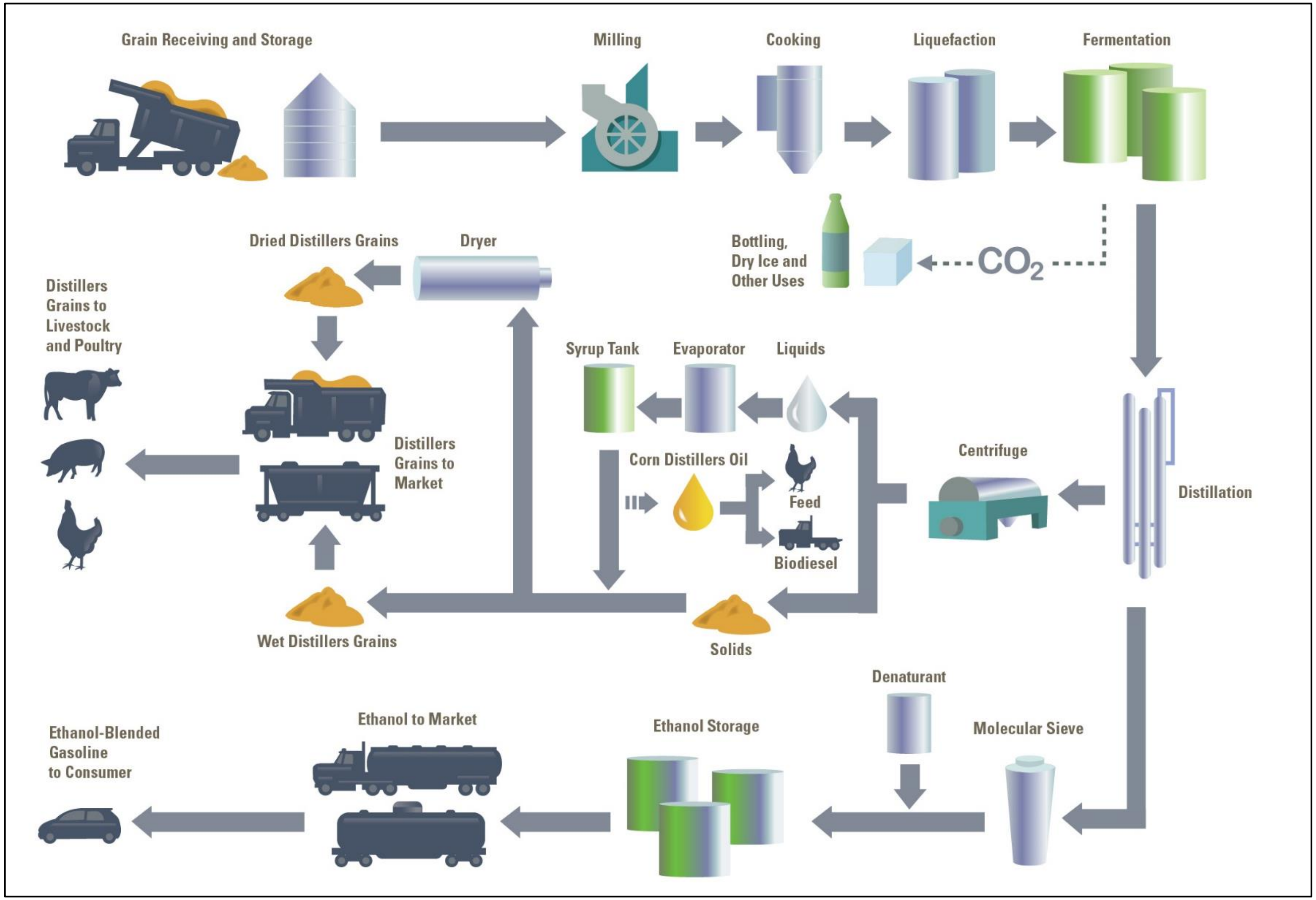
In the dry milling process (Engels, 2017), corn grains are cleaned and ground directly to obtain a fine corn flour. This flour is then mixed with water, enzymes and other ingredients (cooking and liquefaction) to convert starch into simple sugars, then into glucose (saccharification). This glucose is fermented to produce ethanol, which is then removed by distillation and purified by dehydration. The remaining stillage (called distillers grain) is then processed further to expel technical corn oil (generally called “distillers corn oil” in the United States) through centrifugation. The remaining “de-oiled” stillage is mixed with nutrient-rich effluents from the liquefaction stage and dried into “Dry Distillers Grain and Solubles”, which is used as animal feed. Between 0.23 and 0.45 kgof oil per bushel can be extracted through the dry milling process (Riley, 2016). Figure 1 summarises the corn dry milling process (note that TCO is called distillers corn oil in the figure).

2.1.2 The corn wet milling process

The main difference in the wet milling processes, compared with dry milling, is that the corn germ is separated from the rest of the grain earlier in the process, i.e. before the grinding or any other bioprocessing (e.g. enzyme addition or fermentation) . Corn oil is then expelled from the germ by pressing in presence of a solvent (hexane or alcohol) and the remaining corn germ is processed as animal feed. The rest of the corn grain is further separated into its different components, mainly fibre, gluten and starch. Gluten is used to produce a protein-rich meal whereas starch is processed into several co-products, including food ingredients (e.g. sweeteners) and/or bio-based products. To date, wet milling has not been used for the production of bioethanol in the European Union[1]. In the United States, about 10% of corn ethanol comes from wet milling.

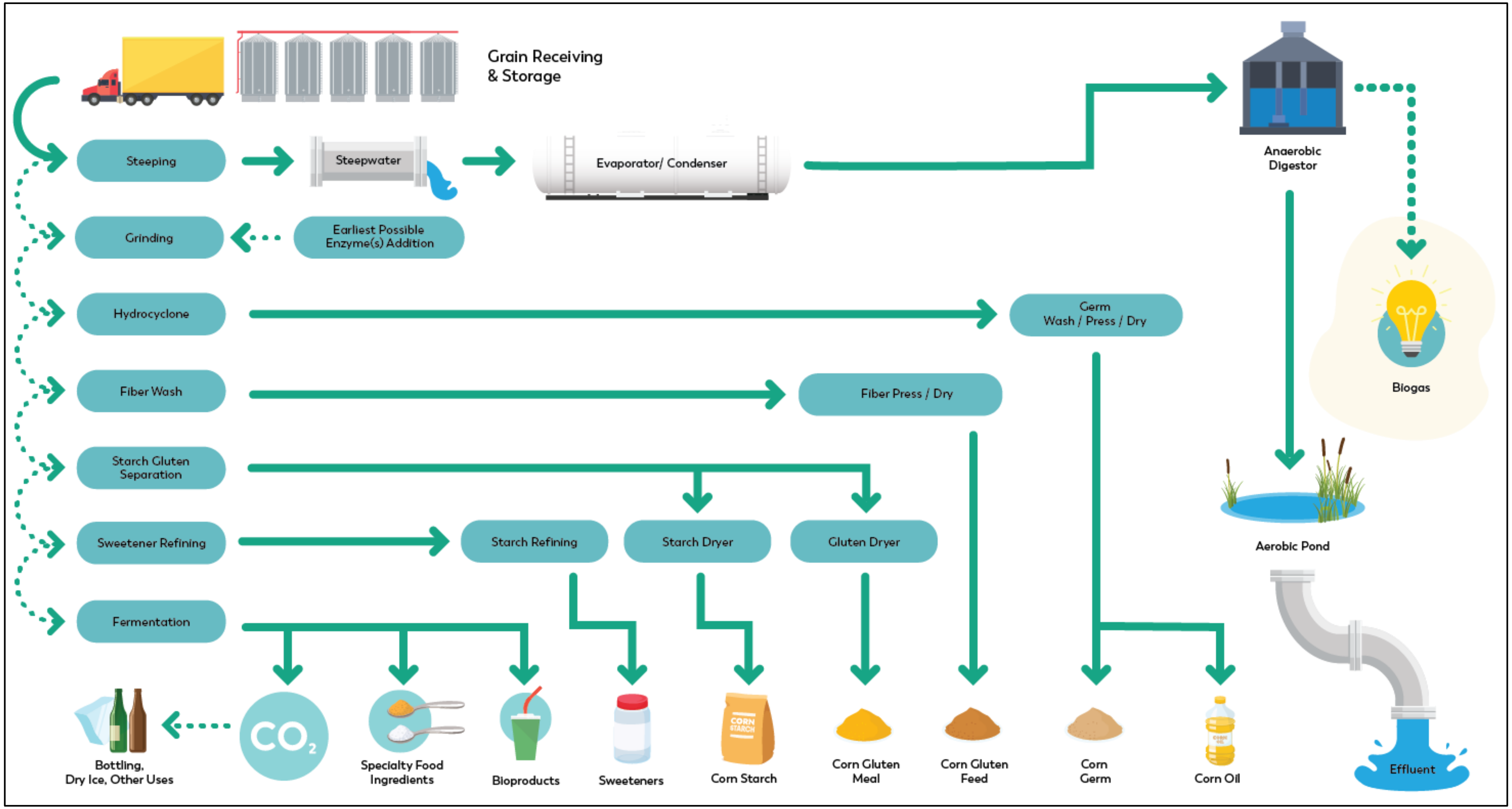
[1] Personal communication from industry stakeholder.

Figure 1: The Corn Dry Milling Process



Source: Renewable Fuel Association

Figure 2: The Corn Wet Milling Process



Source: Corn Refiners Association (www.corn.org)

2.1.3 Differences between technical corn oil and crude corn oil

Differences are found in the literature regarding the terminology used to designate different grades of corn oil derived from the dry and wet milling processes. Engels (2017) highlights some of the physico-chemical differences between TCO (dry milling process) and CCO (wet milling process), based on specifications from the American Fats and Oils Association, as shown in Table 1.

Table 1: Differences in physico-chemical specifications for TCO and CCO

	Technical Corn Oil	Crude Corn Oil
Free Fatty Acid (FFA) Content	Max 20%	Not specified. Typical value around 3%
Moisture	Max 1%	Max 1%
Insoluble Impurities	Max 0.5%	Max 0.8%
Unsaponifiables	Max 2.5%	Max 2%
Flash point	Not specified	Min 250°F (approx. 121°C)

Source: Engels (2017)

In theory, any corn oil may be used as biodiesel feedstock, but the physico-chemical characteristics of CCO, which can be further refined to reduce its free fatty acid (FFA) and impurity content, make it suitable for use as a human food ingredient unlike TCO, which is only suitable for use as biodiesel feedstock or animal feed. Therefore, the scope of this study will focus on technical corn oil (TCO), which can be defined as the corn oil directly produced out of the dry milling process without further processing.

2.1.4 Technological and commercial maturity

Both the dry and wet milling processes are technically and commercially mature technologies. While the wet milling process theoretically allows the extraction of all the oil contained in the corn germ, oil extraction yields are significantly lower in the dry milling process (Engel, 2017). Specialised companies are developing and selling corn oil extraction aids, which achieve significant increases in oil yield. Corn oil production is a side process to the production of ethanol and can therefore not be promoted at the expense of ethanol yield. Extraction aids must therefore take into account the specificities of individual ethanol facilities, as well as the particularities of crops, oil content and extractability being variable from year to year. Companies like Novozymes, Solenis or Nalco have developed and commercialised enzymes, which are added to the corn oil extraction process. As an example, Nalco claims to increase corn oil yields by up to three times, while reducing the need for post-extraction treatment by enhancing purity of the extracted oil[2]. Therefore, additional progress may be expected in the specific corn oil extraction stage through enzymes and other extraction aids, added to the current mature dry milling process.

2.2 Uses of TCO

According to Riley (2016) and Malins (2017), biodiesel and feed are currently the two main markets using TCO. Although TCO could theoretically be upgraded to match food or cosmetic specifications,

[2] https://www.ecolab.com/nalco-water/offerings/corn-oil-recovery

no evidence was found that such practice is being implemented. This is likely to be because it would probably not prove cost-effective compared to other vegetable oils.

United States

In the US, TCO is traditionally left in distillers grains and so adds to the overall nutritional value of DDGS; corn oil may also be extracted and added back to the feed rations. The recent increase in extraction of corn oil was essentially driven by the decreasing profits in the ethanol industry, due to a surge in feedstock price (Wisner, 2013). As a result, corn ethanol producers started extracting TCO to add an extra revenue stream. Between 2011 and 2016, the share of corn ethanol plants equipped to extract TCO increased from 15% to 90%. Therefore, the proportion of TCO used for biodiesel in the United States went up from 30% in 2015 to 50% in 2017 (McKeany-Flavell, 2018). With the steady increase in the mandate for biomass-based diesel as part of US Renewable Fuel Standards and California's Low Carbon Fuel Standard, TCO production and consumption has been continuously increasing over the past few years (Figure 3). As of September 2019, TCO is the second biodiesel feedstock in the US after soybean (EIA, 2018). In 2018, about 3.7 million tonnes of soybean biodiesel were produced in the US (i.e. approx. 135 PJ), out of 6.2 million tonnes of FAME in total (59%).

This increased use of TCO as biodiesel feedstock primarily impacts the feed industry, as TCO extraction reduces the nutritional value of corn DDGS to that of wheat DDGS (Agri-Facts, 2011). This loss in dietary content is compensated by increasing the amount of DDGS fed to cattle or by adding wet or dry corn to rations (Rutherford B., 2014). Malins (2017) suggests that the missing fats in cattle feed would likely be substituted by other virgin vegetable oils.

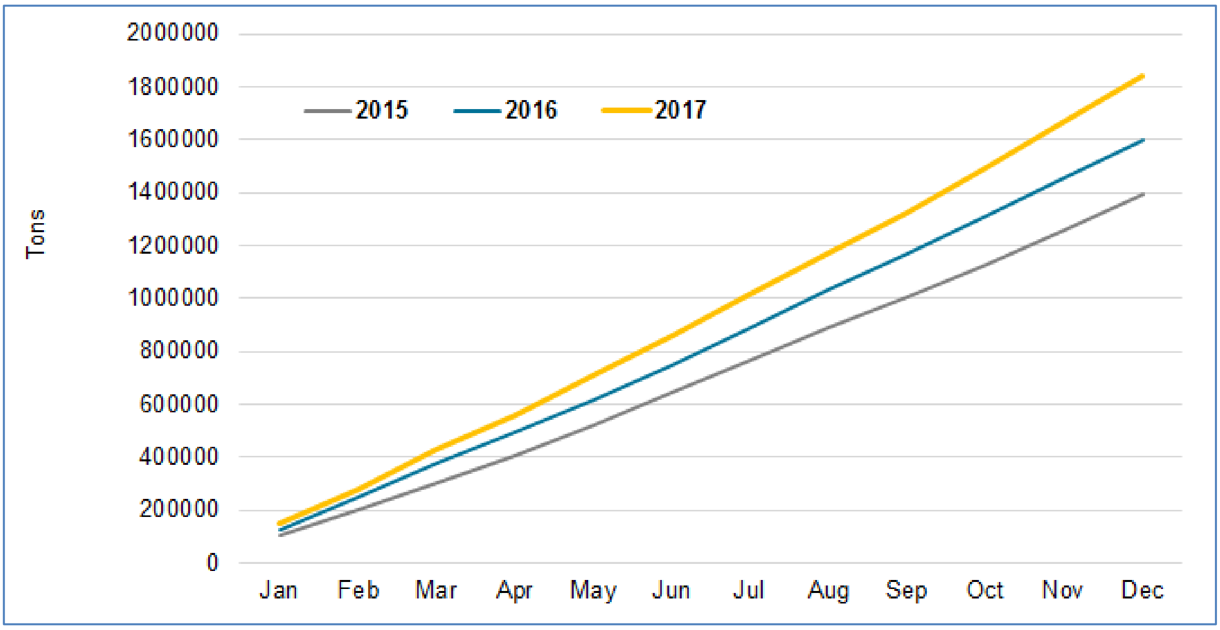


Figure 3: Yearly production of technical corn oil in the US (2015 to 2017) - Source: USDA (via McKeany-Flavell)

European Union

According to Malins (2017), TCO (referred to as "Distiller's Corn Oil") is seldom extracted in the EU to be used as a biodiesel feedstock. Neste successfully obtained an approval from the Finnish Energy

Ministry for TCO to be considered as a residue for biodiesel production, but Malins (2017) suggests that Neste exports its TCO-based biodiesel to the United States to benefit from D4 RINs, as per Neste's own press release from 2013[3]. The EurObserv'ER Biofuels Barometer[4] does not list corn oil as a biodiesel feedstock being used in the European Union in 2017.

Pannonia[5] and Ethanol Energy[6] are among the few European ethanol companies advertising corn oil supply, mostly for use as animal feed (although biodiesel is also mentioned as a potential end-use). It can be therefore assumed that other ethanol producers do not extract corn oil out of DDGS, possibly to ensure a higher nutritional value for their feed.

The exact benefits of TCO in cattle nutrition is not extensively documented, besides being an additional energy source, thus allowing to feed smaller rations than with lower fat feeds. Malins (2017) assumes that should TCO be increasingly used as biodiesel feedstock, it would most likely be substituted by other vegetable oils for feed purpose, rather than with higher cereal rations, thus creating a risk of indirect land-use change. No other publications could be found, which confirm this assumption.

2.3 Overview of TCO economics

The United States is currently the largest producer of TCO. As of 2016, Engel (2017) estimates that 1.4 million tonnes of TCO was recovered by US ethanol producers, accounting for 13.7% of US biodiesel production (approx. 32 PJ). As of December 2018, corn oil price in the US ranged between USD 550 and 584 per tonne (USDA, 2018b), but historic highs (above USD 800/t) were reached in 2015/2016 when corn oil prices were higher than soybean oil, thus increasing the attractiveness of TCO.

At the corn milling level, TCO adds to the profitability of ethanol production. Riley (2016) reports an extra USD 0.015 to 0.037 per gallon of ethanol produced in sales. In turn, FAPRI (2016) assumes an extra USD 0.1 per gallon of ethanol for corn oil, when weighted by share of dry mills de-oiling DDGS, representing about 4% of the total income of the ethanol plant. TCO therefore adds a significant revenue stream to corn ethanol production.

According to USDA (2017), about 165,000 tonnes of corn oil were expected to be produced as by-product from corn ethanol in the European Union in 2017. According to our calculations, this figure tends to assume that corn oil is systematically extracted from the corn ethanol process (dry milling), which is contradiction with the limited TCO production reported in the EU, as mentioned in the previous sections. Therefore, this figure should be regarded as a potential, rather than an actual amount produced. Pannonia, which claim to be the largest TCO producer in Europe[7], announces a yearly production of 15,000 tonnes, i.e. 9.1% of the total TCO potential in Europe.

[3] https://www.neste.com/neste-oil-adds-technical-corn-oil-feedstocks-used-producing-nexbtl-renewable-diesel
[4] https://www.eurobserv-er.org/biofuels-barometer-2017/
[5] https://pannoniabio.com/products/corn_oil/
[6] http://www.novyethanolenergy.cz/krmiva-a-oleje
[7] Private communication

The estimated potential 165'000 tonnes of corn oil would represent approximately 163'350 tonnes of biodiesel per year (approx. 6.1 GJ)[8], which could only fulfil a very limited share of biodiesel consumption in the European Union (about 13.5 million tonnes in 2017 as per USDA (2017)).

No data could be found regarding TCO production at global level. Based on global corn ethanol production, we can estimate a global TCO potential (should TCO be systematically extracted from corn ethanol process and all of it used for biodiesel production) of approximately 4.3 million tonnes annually (Table 2), which would represent 4.26 million tonnes (160 PJ) of biodiesel (FAME). Actual EU and US TCO production appears well below this estimate.

Table 2: Estimated global TCO production potential

2017 Global bioethanol production	102bn Liters
Estimated share of corn in global ethanol production	58%
Estimated 2017 global corn bioethanol production	59.4 bn Litres
Estimated ratio TCO/ethanol	0.0721 kg/L
Estimated 2017 global TCO production potential	4.3 million tonnes
Estimated 2017 global TCO-based FAME production potential	4.26 million tonnes

(Source: Renewable Fuel Association, E4tech)

3 Eligibility of TCO for inclusion in RED II – Annex IX

This section explores the different criteria found in RED II, which could potentially lead to the inclusion of TCO in Annex IX, including the status of TCO as co-product, residue or waste.

3.1 Feedstock categories in RED II

RED II includes several biofuel feedstock categories, for which compliance with sustainability and traceability criteria differ.

Table 3: Summary of applicable criteria in RED II

Status	Land-use criteria	GHG calculation	Chain-of-custody	Cap /Phase-out
(Co-)product	Applicable	Full life-cycle Energy allocation	Full supply chain	7% cap for food/feed crops Phase-out for high iLUC feedstocks
Residue (other than agricultural and forestry)	Not applicable	Starting at collection point	Starting at collection point (optional audit of suppliers)	1.7% cap if in Annex IX B
Waste	Not applicable	Starting at collection point	Starting at collection point (possible audit of suppliers)	1.7% cap if in Annex IX B

Regardless of whether feedstocks are considered a residue/waste, inclusion in Annex IX determines whether these feedstocks will benefit from additional incentives or restrictions:

- Annex IX A feedstocks have a specific sub-target, increasing from 0.2% to 3.5% (2022-2030).
- Annex IX B feedstocks have a specific cap at 1.7% of transport fuels (this percentage may be modified by member states, upon approval by the Commission).

[8] Based on Biograce's FAME:veg oil ratio and LHV for FAME.

- Both Annex IX A and B feedstocks are double-counted against set targets.

It should be noted that a given feedstock may be considered a residue without necessarily being included in Annex IX (e.g. tallow category 3). Similarly, some feedstocks included in Annex IX are not necessarily considered a residue (e.g. algae). Therefore, the status of TCO as a co-product, a waste or a residue needs to be evaluated separately from its possible inclusion in Annex IX.

3.1.1 Could TCO be considered as a waste?

RED II definition

RED II uses the definition in Directive 2008/98/EC, which defines waste as "*any substance or object which the holder discards or intends or is required to discard",* excluding substances that would have been intentionally modified or contaminated in order to meet this definition.

Evaluation

No evidence exists that Technical Corn Oil would ever be discarded or required to be discarded. TCO, whether as oil or contained in DDGS, has a market value, either for the feed or the biodiesel sectors.

Conclusion

Under no circumstances can TCO be considered as a waste under the RED II definition.

3.1.2 Could TCO be considered as a residue?

RED II definition

RED II defines a residue as a "*substance that is not the end product(s) that a production process directly seeks to produce; it is not a primary aim of the production process and the process has not been deliberately modified to produce it*."

This definition is not clear and may be interpreted as follows:

1) Following the production of the main product, any additional process required to extract another product could be considered as deliberate modification; or
2) Deliberate modifications could be restricted to processes aiming at an increase in the yield of the second product at the expense of the main product.

Evaluation

Corn oil is not a direct by-product of ethanol production. Corn dry milling produces a glucose-rich syrup, which is fermented into ethanol, leaving an oil-rich stillage. This stillage is centrifuged to produce DDGS, out of which TCO is eventually expelled.

According to the first interpretation above, TCO would therefore be considered a co-product, not a residue, given that two additional processing steps are required to transform corn stillage into TCO. However, according to the second interpretation, TCO would be considered a residue, as the drying of the stillage to produce DDGS and further extraction do not modify the corn ethanol yield.

One may as well argue that DDGS is one of the '*end product(s) that a production process directly seeks to produce'*. Therefore, the process to produce DDGS can be seen as deliberately modified to produce TCO i.e. less and lower nutritional value DDGS has been produced due to TCO extraction.

Therefore the extraction of TCO could be deemed a deliberate additional step, compared to business-as-usual (i.e. producing oil-rich DDGS).

Finally, country regulators such as UK's RTFO appear to consider other potential uses and the economic value of the product in their evaluation of feedstocks, leading them to consider technical corn oil as a co-product, given its high market value and use as feed.

Conclusions

Since TCO is not directly produced along with corn ethanol (additional drying and extraction are required) and DDGS production is deliberately modified to produce TCO, considering TCO as a co-product could appear justified. In addition, TCO carries a significant market value and may be used as feed, which is the main reason why UK classifies it as a co-product.

As an alternative interpretation, however, the extraction of oil out of DDGS does not impact corn ethanol yields, meaning TCO could also be considered as a residue.

Additional investigations and consultations of EU officials and member state regulators would be required to take a fully informed decision on this matter. Following the precautionary principle, we suggest considering TCO as a co-product for the time being.

3.2 Compliance with criteria for inclusion of TCO in Annex IX

The possibility to include TCO in Annex IX (Part A or B) of RED II depends on the fulfilment of several criteria listed in Article 28, par. 6 of the Directive (European Commission, 2018), which are evaluated in the following subsections.

3.2.1 Conversion technologies

RED II categorises feedstocks that can be added to Part A of annex IX as those feedstocks that 'can be processed only with advanced technologies' and 'technology (that) is more innovative and less mature and therefore needs a higher level of support'. Feedstocks that are to be included in Part B of Annex IX are those that 'can be processed into biofuels, or biogas for transport, with mature technologies'. Whilst RED II doesn't explicitly define what constitutes an advance technology, Article 28(6) states that these technologies should 'effectively stimulate innovation and ensure greenhouse gas emissions savings in the transport sector'.

There are two methods by which vegetable oils, such as TCO, can be processed into biodiesel. The first uses a transesterification reaction between the triglyceride molecules present in vegetable oils and low molecular weight alcohols (e.g. methanol or ethanol) to generate longer chain fatty acid methyl esters (FAME). This reaction is performed in the presence of an alkaline catalyst, such as sodium hydroxide, and generates glycerol as a co-product.

The second method uses hydrogenation and subsequent isomerisation reactions to convert the vegetable oil triglycerides into longer chain hydrocarbons with the end product being hydrotreated vegetable oil (HVO). The first hydrogenation reaction is used to saturate double bonds in the unsaturated triglycerides with the fatty acids undergoing further hydrogenation to generate a mixture of straight chain, branch chain and cyclic paraffinic hydrocarbons. This mix of hydrocarbons is then catalytically isomerised to give longer chain hydrocarbons that meet or exceed the specifications for conventional fuels.

Both of these processes have been developed to commercial scale and can be considered at TRL 9. Due to the well-established commercial presence of the technologies used to produce FAME and HVO from plant oils, biodiesel production from TCO should be considered a mature technology. As such it is highly unlikely that TCO would be included on the list of feedstocks in Annex IX Part A. As to whether it is included on Annex IX Part B would be dependent on whether it met the other criteria set out in RED II, which are evaluated in the following section.

3.2.2 Is TCO in line with the circular economy concept and waste hierarchy?

As part of the EU circular economy package, the European Parliament (2016) states the following:

"In a circular economy, products and the materials they contain are valued highly, unlike in the traditional, linear economic model, based on a 'take-make-consume-throw away' pattern. In practice, a circular economy implies reducing waste to a minimum as well as re-using, repairing, refurbishing and recycling existing materials and products. What used to be considered as 'waste' can be turned into a valuable resource."

In other words, the EU approach to the circular economy can be summarised as a commitment to reduce waste and prolong the material use of products as much as possible before being recycled, disposed of and/or used for energy recovery. The extraction and use of TCO increases the value of the corn ethanol production process, reduces waste and displaces additional fossil fuels, which are typical examples of linear economy.

Although TCO could not be considered as a waste (See Section 3.1.1), its evaluation against the waste hierarchy may not be required. Should this criterion remain valid for future evaluation of TCO, its use for biodiesel production broadly appears in line with the waste hierarchy (Table 4). The two existing uses for TCO are feed (incl. when TCO is still contained in DDGS) and biodiesel. In both cases, no further use can be made out of TCO through reuse or recycling, as TCO will exit the circle via cattle metabolism or engine combustion. In theory, TCO could also be used to produce bio-based chemicals and/or plastics, which can be considered a material use. Aside from experimental setups, no large-scale use of TCO to produce plastic is being reported, which makes the possibility to use TCO for material production limited. Consequently, the possibility to recycle TCO appears limited too. Given the limited possibilities of material use, re-use and recycling of TCO, its use as biodiesel feedstock can generally be considered not to be in contradiction with the circular economy approach described above and the waste hierarchy.

Table 4: Evaluation of TCO against the waste hierarchy (Circular economy)

	Hierarchy Steps	**Applicability to TCO**
	1. Prevention	Not applicable. TCO is contained in corn and remains contained in corn stillage or DDGS, whether extracted or not.
	2. Reuse	Only applicable to bio-based chemicals. No material use possible with TCO
	3. Recycling	Limited. Recycling conditions unknown.
	4. Energy Recovery	Applicable
	5. Disposal	Applicable

3.2.3 Compliance of TCO biodiesel with the Union sustainability criteria (RED II, Article 29, par. 1-7)

The recast of the Renewable Energy Directive ("RED II") includes several environmental criteria for biofuels to comply with, in order to count against EU targets for renewables in transport. Those environmental criteria can generally be split into land-use criteria and greenhouse gas savings.

RED land-use criteria (Art. 29, par 1-7) regard the use of certain types of lands with high biodiversity value, high carbon stock or an important value for ecosystem services. No-go areas include:

- Land with high biodiversity value, including primary forest and natural wooded land;
- Protected areas;
- Highly biodiverse grasslands (natural and non-natural);
- Wetlands;
- Continuously forested areas;
- Peatlands.

As any crop, corn cultivation may involve land-use change if natural or urban land is converted to agriculture. Such conversion may bring about environmental damage such as the loss of biodiversity or ecosystem services, although this risk seems limited in the European Union and the United States, due to strict rules for land conversion for agriculture. Corn grains imported from countries with less strict rules could be at risk, but overall, compliance with RED II land-use criteria should not be a major obstacle to the use of corn oil as biodiesel feedstock, due to the fact all biofuels entering the European Union must be certified to an EU-approved sustainability standard including land-use criteria.

Land-use criteria do not apply to biofuel feedstock considered as waste or residue, other than those directly produced from agriculture (i.e. crop residues), forestry or fisheries. Therefore, should TCO be eventually recognised as a processing waste/residue (See Sections 3.1.1 and 3.1.2), only GHG requirements would apply.

3.2.4 Potential distortive market effects of TCO biodiesel (by-products, waste and residues)

As described in Section 2.3, large amounts of TCO can be extracted out of DDGS in the European Union (165,000 t/year) and globally (4.3 Mt/year). Aside from the United States, a limited number of countries appear to be currently using TCO as biodiesel feedstock, thus representing an important potential feedstock source for biodiesel to tap into.

An important limitation exists, however, to a significant increase of TCO extraction, given the importance of corn oil as part of the nutrients sought in DDGS fed to cattle. Corn oil contained in DDGS provide a higher energy content, among other benefits for animals and cattle ranchers[9]. Therefore, the systematic extraction of TCO out of DDGS will likely trigger market effects by forcing cattle ranchers to increase the rations and therefore increase the demand for DDGS or other feed sources, which could create indirect land-use change (iLUC) and contribute to threatening food security. This effect would be further amplified if double counting for TCO-derived biodiesel was to

[9] https://www.drovers.com/article/feeding-corn-more-corn-oil

be implemented by some EU member states, thus creating additional economic incentives, which could change current economic patterns for TCO.

Malins (2017) attributes a high iLUC factor to corn oil, based on the assumption that it is substitutable with other virgin vegetable oils (primarily soy oil) and, therefore, carries a similar risk of indirect impacts. ILUC Factors for TCO-based FAME (biodiesel) vary between 74 and 141 g CO_2 eq/MJ, according to the approach used to calculate the iLUC factor (RED II or GLOBIOM).

As a consequence, market-driven effects of an increased use of TCO produced in the EU for biodiesel production are likely to occur, unless significant changes in cattle diet are observed. Controversies exist over the use of grains to feed cattle (rather than grazing) due to a deficit in fibre. In addition, climate change and animal welfare concerns led the European Union to steadily reduce its meat consumption[10], which may reduce the demand for DDGS and leave a share of TCO to be exploited for biodiesel.

Projections for the consumption of TCO in the US are an important parameter to evaluate the potential market effects of an increased use of TCO for biodiesel production in the European Union. As of today TCO-derived biodiesel has been granted "biomass-based diesel" status by US EPA (RIN D.4)[11], which means that it competes directly with soy-derived biodiesel. Given the increasing RFS2 mandate (See Table 5) for biomass-based diesel, it is expected that US domestic consumption of corn oil for biodiesel production will increase over the next decade, as confirmed by FAPRI's projections (Figure 4). Two notable consequences of this evolution are:

1) A stagnation in corn oil exports. Therefore, no extra TCO supply from the US is to be expected for the European Union, compared to current levels.
2) The share of corn oil used for feed will decrease, which may affect feed markets and create knock-on impacts (e.g. indirect land-use change) by driving more feed production out of other biomass sources.

Table 5: RFS2 Mandates as of 2017

Final Volume Requirements [a]				
	2017	**2018**	**2019**	**2020**
Cellulosic biofuel (million gallons)	311	288	418	n/a
Biomass-based diesel (billion gallons)	2.0	2.1	2.1[b]	2.43
Advanced biofuel (billion gallons)	4.28	4.29	4.92	n/a
Renewable fuel (billion gallons)	19.28	19.29	19.92	n/a

Notes:

[a]All values are ethanol-equivalent on an energy content basis, except for biomass-based diesel (BBD) which is a biodiesel-equivalent.

[b]The 2019 BBD volume requirement was established in the 2018 final rule (82 FR 58486, December 12, 2017).

[10] https://data.oecd.org/agroutput/meat-consumption.htm
[11] https://www.epa.gov/renewable-fuel-standard-program/approved-pathways-renewable-fuel

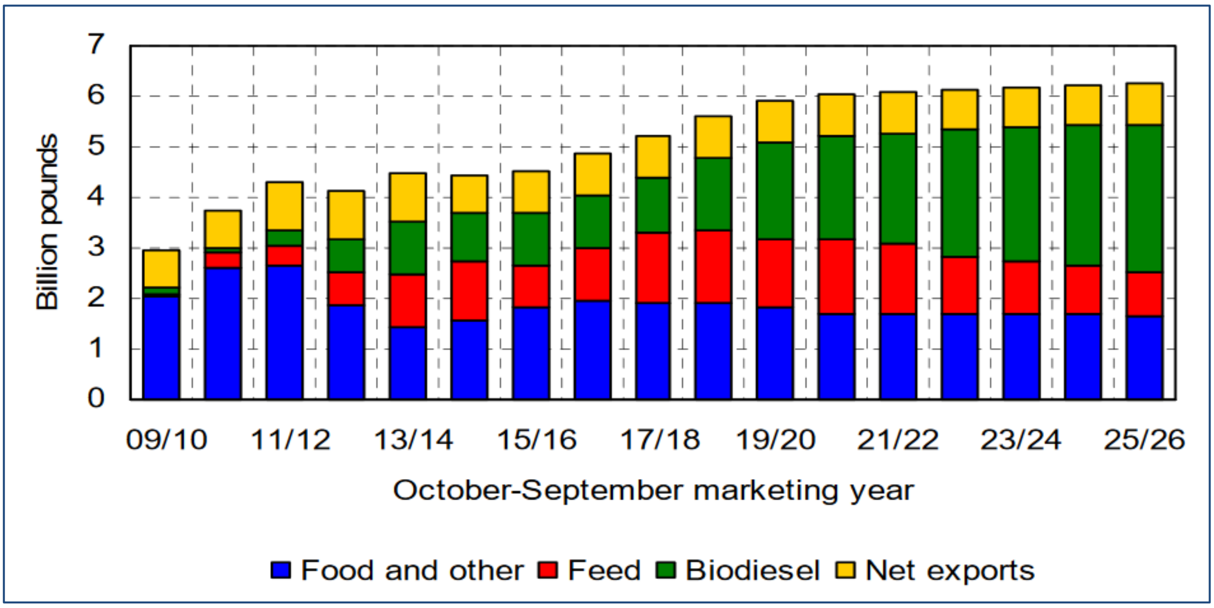


Figure 4: Projected use of corn oil in the United States (Source FAPRI, 2016)

Data for the rest of the world are scarce. It can be assumed, however, that a large share of corn oil is currently being used as nutrient while contained in DDGS. Therefore, the exact availability and the risk of market effects due to an increase in imports to the EU remains difficult to evaluate.

3.2.5 Potential greenhouse gas savings from TCO biodiesel (RED II, Art. 29, par 10)

Minimum greenhouse gas savings in EU RED II are set as follows:

- At least 50 % for biofuels produced in installations in operation on or before 5 October 2015;
- At least 60 % for biofuels produced in installations starting operation from 6 October 2015 until 31 December 2020;
- At least 65 % for biofuels produced in installations starting operation from 1 January 2021;

GHG emissions are allocated between co-products on an energy basis. However, whenever a feedstock is considered a waste or a residue, its GHG intensity is calculated starting at the first collection point, which means that crop cultivation and processing are entirely attributed to the main product and nothing is allocated to the waste or residue.

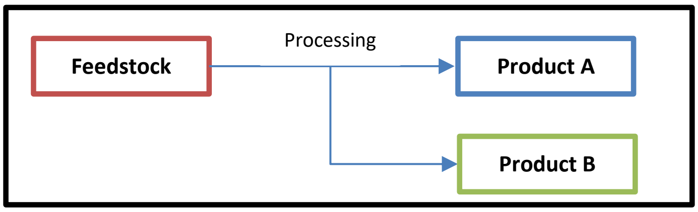


Figure 5: Flowchart of co-product allocation

As displayed in Figure 5, if Product A (e.g. corn ethanol) and Product B (e.g. DDGS or corn oil) are considered co-products, they will get a share of the GHG intensity of feedstock production and processing allocated on the basis of their respective energy content. In contrary, if Product B is considered a waste or a residue, Product A gets the entire GHG intensity of feedstock production and processing allocated to it.

The GHG intensity of TCO biodiesel is linked to the life-cycle GHG emissions of corn ethanol, the former being a by-product from the latter. There are no specific default values for corn oil biodiesel in RED II. As per RED II, the default GHG intensity of corn ethanol ranges between 30.3 and 56.8 g CO2/MJ, depending on the process energy used (natural gas, lignite or biomass), which represents between 40% and 68% GHG savings, compared to fossil fuels. Should TCO be eventually considered a co-product (See Section 3.1.2), its GHG intensity would be calculated on the basis of its energy content relative to corn ethanol and DDGS. According to Wang et al. (2015), the typical life-cycle GHG intensity of technical corn oil would vary significantly according to the allocation methodology used: by using an energy allocation approach (as required in RED II), Wang et al. (2015) obtain a life-cycle GHG intensity of 45g $CO_{2\ eq}$/MJ, which only represents a 52% savings, compared to the fossil fuel comparator included in RED II (94 g $CO_{2\ eq}$/MJ).

It should be noted that methodological differences may exist between the LCA conducted by Wang et al. (2015) and the GHG calculation methodology included in RED II. Nevertheless, TCO-biodiesel could be at risk of not passing the RED II GHG threshold, unless produced in an installation operating on or before 5 October 2015. Should TCO be considered a residue, its GHG intensity would only be calculated starting at the first collection point, which would likely considerably reduce its GHG intensity below the GHG minimum saving threshold.

3.2.6 Impacts on the environment and biodiversity

Although not part of RED II compliance obligations, other environmental impacts may be brought about by corn cultivation and processing, such as the use of fertilisers and pesticides, which may induce water and soil contamination. Risks of water depletion may exist in drought-prone areas. Finally, a large share of corn crops cultivated worldwide (esp. in the US) are genetically modified, which may bring about risks of genetic contamination. Should TCO be considered a co-product of corn ethanol, a share of corn cultivation impacts would be assigned to TCO. However, if TCO is considered as a residue, those impacts would entirely be assigned to corn ethanol.

3.2.7 Additional demand for land

Since TCO is produced during the dry milling process used to produced corn ethanol, no additional land is directly required for TCO production. As described in Section 3.2.4, however, market-driven effects may exist, following a significant increase in the use of TCO for biodiesel production. As a result of the lower nutritional value of DDGS, cattle ranchers may either increase the rations of DDGS or cereals fed to cattle, or substitute TCO with other vegetable oils, thus creating a risk of indirect land-use change, as laid out in Malins (2017).

4 Conclusions and recommendations

As summarised in Table 6, the potential for inclusion of TCO in Annex IX largely depends on whether it actually qualifies as a residue or if it should rather be considered as a co-product of corn ethanol. Section 3.1 explores the different possible interpretations of the RED II definition of residues and their implication on the status and scope of compliance for TCO. In light of the elements gathered throughout this study, a precautionary approach would lead to consider TCO as a co-product.

Table 6: Summary of the evaluation of TCO against RED II criteria

RED II criterion	Compliance assessment (TCO)	
Qualifies as a waste?	No. TCO has a significant economic value, even when contained in DDGS, and is not being discarded.	
Qualifies as a residue?	Depends on the interpretation of RED II residue definition.	
Conversion technology	Mature	
Relation to the circular economy strategy and waste hierarchy	Overall in line (assuming a limited use of TCO to produce bio-based plastics)	
	If TCO is considered a residue	If TCO is considered a co-product
Land-Use Criteria	Not applicable	The likelihood of TCO complying with Land-Use Criteria is high.
Market effects	Insufficient evidences to conclude on limited market effects. Risk of iLUC by substitution with other veg. oils or additional cereal production.	Insufficient evidences to conclude on limited market effects. Risk of iLUC by substitution with other veg. oils or additional cereal production.
GHG Criteria	TCO biodiesel will likely be above the minimum GHG savings	TCO biodiesel is at risk of not complying with RED II minimum GHG savings, unless produced in an installation in operation on or before October 5, 2015.
Environment and biodiversity	Not applicable	Limited risks
Demand for Land	Not applicable	No direct additional demand. Risk of indirect land-use change.

As mentioned above, the potential case for inclusion of TCO hinges on the interpretation of the RED II definition of residues, in particular:

1. Considering DDGS as a co-product, whether extracting a valuable part of DDGS makes that product (TCO) also a co-product. If a co-product then, TCO is considered to drive additional demand, and be partially responsible for impacts of corn production itself;

2. Whether TCO has an impact on the use of DDGS i.e. whether it reduce nutritional value and so requires farmers to add more/another feed, as suggested by various publications reviewed in this study.

The answers to the above questions would influence potential compliance of TCO with some of the criteria used to determine the potential inclusion of feedstocks in Annex IX, namely:

- Compliance with land-use criteria;
- GHG savings;
- Other environmental impacts;
- Direct demand for land.

In addition to the above, potential market-driven effects might be observed as a result of an increasing use of TCO as biodiesel feedstock, regardless of whether it is considered as a residue or a by-product. Important amounts of TCO are available in the EU and worldwide, which are extracted after corn ethanol production, but TCO is primarily used as a cattle nutrient, either as single product or as a component of DDGS. As described in this study, market-driven effects may occur as cattle ranchers compensate for the lower nutritional value of de-oiled DDGS. In this regard, evidence is lacking to demonstrate the absence of distortive market effects related to the use of TCO for biodiesel production.

Should the European Commission consider Technical Corn Oil as a co-product, following the example of UK, the case for inclusion in Annex IX would be extremely limited, as TCO would be at risk of non-compliance with several RED II criteria.

Should the European Commission consider TCO as a residue, a limited case may exist for inclusion in Annex IX B (given the maturity of FAME or HVO technologies), pending additional evidences of limited indirect market-driven effects, which are currently lacking.

Appendix A References

Agri-Facts (2011). *Feeding Distillers Dried Grains with Solubles (DDGS) to Pigs.* Available at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex13760/$file/440_68-1.pdf?OpenElement (Last consultation on December 4, 2018)

Beltranena Eduardo (2011). *Feeding Distillers Dried Grains with Solubles (DDGS) to Pigs.* Agri-Facts. Alberta Agriculture and Rural Development. Available at: https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex13760/$file/440_68-1.pdf?OpenElement (Last consultation on January 21, 2019).

Engels Brian (2017). *Technical Corn Oil Review.* Proceedings from ISCC stakeholder meeting for Canada and the USA (5 December 2017). Available at: https://www.iscc-system.org/wp-content/uploads/2017/08/Brian-Engel_Technical-Corn-Oil-Review_TC-Las-Vegas-2017-.pdf (Last consultation on December 4, 2018)

European Commission (2018). *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).* Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN (Last consultation on January 22, 2019)

European Parliament (2016) *Circular economy package, Four legislative proposals on waste.* Available at: *http://www.europarl.europa.eu/EPRS/EPRS-Briefing-573936-Circular-economy-package-FINAL.pdf* (Last consultation on January 22, 2019)

FAPRI (2016). *U.S. Baseline Briefing Book - Projections For Agricultural And Biofuel Markets.* Available at: https://www.fapri.missouri.edu/wp-content/uploads/2016/03/FAPRI-MU-Report-02-16.pdf (Last consultation on January 22, 2019)

Malins Chris (2017). *Waste not want not: Understanding the greenhouse gas implications of diverting waste and residual materials to biofuel production.* Cerulogy and the International Council on Clean Transportation. Available at: https://www.theicct.org/sites/default/files/publications/Waste-not-want-not_Cerulogy-Consultant-Report_August2017_vF.pdf (Last consultation on December 11, 2018)

Riley Joe (2016). *Overview of Distillers Corn Oil and Feed Fat.* Presentation given in 2016. FEC Solutions. Available at: http://www.biodieselsustainability.com/wp-content/uploads/2016/04/3._riley_distillers-corn-oil.pdf

Rutherford Burt (2014). *The nutritional value of distiller's grains is changing.* Beef Magazine. Available at: https://www.beefmagazine.com/nutrition/nutritional-value-distiller-s-grains-changing (Last consultation on December 18, 2018)

US Department of Agriculture (2017). *EU Biofuels Annual 2017.* (Currently not available due to US Government Shutdown).

US Department of Agriculture (2018a). *World Agricultural Supply and Demand Estimates*. Available at: https://www.usda.gov/oce/commodity/wasde/latest.pdf (Last consultation on December 4, 2018)

US Department of Agriculture (2018b). *USDA Daily Ethanol Report (Friday Dec 14, 2018).*

US Energy Information Administration (2018). *U.S. Inputs to biodiesel production.* Available at: https://www.eia.gov/biofuels/biodiesel/production/table3.pdf (Last consultation on December 18, 2018)

Wisner Robert (2013). *Feedstocks Used for U.S. Biodiesel: How Important is Corn Oil?* AgMRC Renewable Energy & Climate Change Newsletter. April 2013. Available at: https://www.agmrc.org/renewable-energy/biodiesel/feedstocks-used-for-us-biodiesel-how-important-is-corn-oil (Last consultation on December 18, 2018)

Wang Z., Dunn J., Han J. and Wang M. (2015). *Influence of corn oil recovery on life-cycle greenhouse gas emissions of corn ethanol and corn oil biodiesel.* Biotechnology for Biofuels (2015) 8:178. DOI 10.1186/s13068-015-0350-8. Available at: https://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/s13068-015-0350-8 (Last consultation on January 22, 2019)