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1. LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviation	Definition
DoA	Description of Action
EC	European Commission
H2020	Horizon 2020
RG	Refined Glycerol
CG	Crude Glycerol
CAGR	Compound Annual Growth Rate
HVO	Hydrotreated Vegetable Oil
GMO	Genetically modified organism
FOB	Free On Board
CIF	Cost Insurance Freight
DDP	Delivered Duty Paid
CFR	Cost and Freight

2. EXECUTIVE SUMMARY

This deliverable provides an overview about the current and historic situation of the global glycerol market, the relevant demand and production volumes of refined and crude glycerol, its historic price progressions, the contribution of different industries on the glycerol market and other important factors. Furthermore, different glycerol feedstocks are investigated from suppliers around Europe as well as alternative biogenic feedstocks which are compared with glycerol.

For the analysis of the global glycerol market different marketing reports were used together with information which could be found online as well as at Argent Energy. Due to the high fragmentation of the glycerol market, it was decided that the market report is divided into geographical sections having the most impact: Europe, North America and International (primarily China, Indonesia and Brazil).

The results show a high dependency of the glycerol market on the biodiesel industry which is by far the largest contributor to the generation of crude glycerol. Depending on the biodiesel producer, different grades of refined glycerol can be produced which have associated limitations in their usage. The COVID-19 pandemic hit the biodiesel market hard which led to a decrease in production volumes and prevented increases of biodiesel mandates. It is expected that the biodiesel market will rise again after the pandemic. Nevertheless, a volatility in the crude and refined prices was observed throughout 2020 in different markets.

The report concludes with an outlook on different variables influencing the glycerol market such as sources, application areas and industries. In general, a steady increase is expected due to the population growth which triggers growth in other areas as well. Nevertheless, some problems remain for the glycerol market. Alternative biofuel producers who developed new techniques which don't generate by-product glycerol and threaten the position of traditional biodiesel producers, the pressure from the international community to refrain from edible vegetable oil sources due to ethical reasons and also general price pressure. The two latter issues are pushing biodiesel producers towards more lower cost waste-based feedstocks which has a positive effect on crude glycerol as material for pure technical applications such as in GLAMOUR due to its regulatory restrictions. Alternative biofuel producers will in the long run reduce glycerol availability and will therefore most likely increase the crude glycerol prices to a certain level.

3. INTRODUCTION

Glycerol is a relevant product in our daily lives. It is a major component in the personal care and pharmaceutical industry due to its antimicrobial and antiviral properties, used as a sweetener in the food industry and also interesting for technical applications such as hydrogen production and others.

In this report feedstock specifications for the GLAMOUR project are presented. GLAMOUR is a H2020 research project to produce sustainable fuels for the aviation and marine industry from bio-waste feedstocks such as by-product glycerol.

The report provides a comprehensive overview about the current and historical state of the glycerol markets and presents different glycerol compositions of different European suppliers, grades which are defined in the industry and the consumption areas of glycerol. Starting with a brief history of glycerol and its importance during the 1st world war, different grades which are used in the industry and consumption areas are discussed. A closer look is taken at glycerol production and consumption volumes, imports and exports as well as inventories, ending with a brief outlook. Special consideration is taken regarding the COVID-19 pandemic and how it affected the market throughout 2020, especially the third quarter of 2020. Finally, a closer look is taken on different possible oleochemical-based feedstocks which are low priced and suitable for the production of sustainable fuels as well.

4. BACKGROUND

Early in the 20th century glycerol was produced primarily as a by-product of the saponification of fats and was used as a raw material for the production of nitro-glycerine. During the 1st world war glycerol became a strategic resource and therefore the demand exceeded the supply leading to the first synthetic plants for the production of glycerol by microbial sugar fermentation. Furthermore, the replacement of natural soaps with synthetical washing detergents has led to an increase in glycerol demand which accelerated the shift towards competitive petrochemical (synthetic) production routes. German, I.G. Farben used the high-temperature chlorination of propene to allyl chlore process to produce glycerol from a petroleum feedstock (Figure 1).

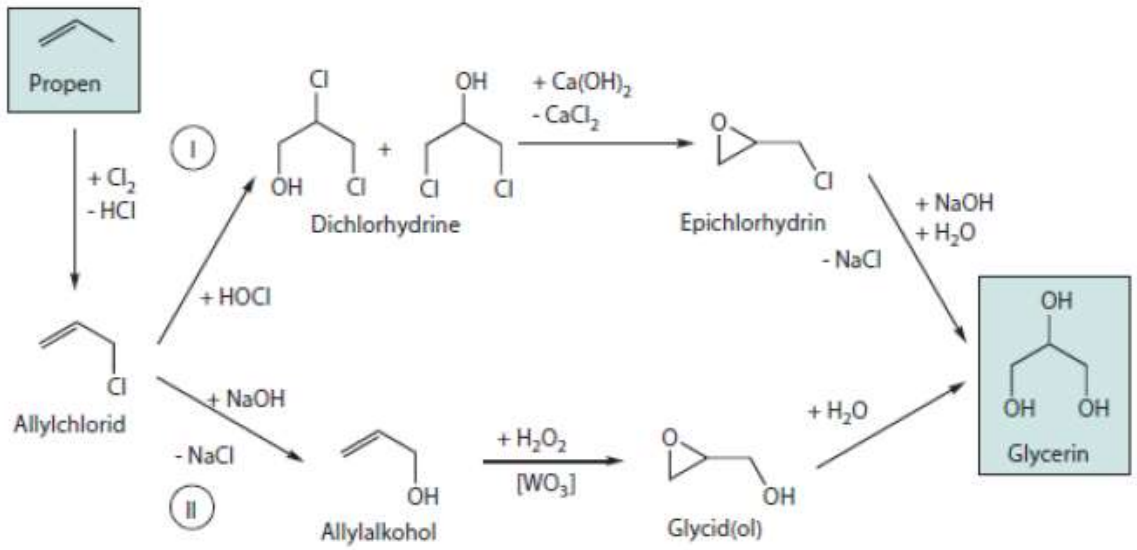

Figure 1: Two different production routes for the synthetic production of glycerol based on propene as feedstock. [1]

About 25% of the global glycerol demand was met by the petrochemical synthesis from propylene before the introduction of Biodiesel into the market in the early 2000s. The other 75% was obtained by the saponification of fats.

The increase in supply of glycerol was due to increased biodiesel production (Figure 2). During the transesterification reaction of triglycerides with methanol approximately 10 wt.% of glycerol is produced as a by-product. Hence, the biodiesel industry became the main supplier of glycerol for the world market leading to a lack of interdependence between supply and demand of glycerol. This had a huge effect on the price of crude and refined glycerol which is discussed later.

Global biodiesel production rose from 200,000 tonnes in 2003 to 600,000 tonnes in 2006. In 2011, >2 million tonnes were produced. In 2019, 2.3 million tonnes were sold on the world market and for 2020 it was estimated that global biodiesel production would reach 2.6 million tonnes. Theoretically, this would yield an approximate amount of 260,000 tonnes of crude glycerol for the year 2020 not counting the glycerol share which is produced by other oleochemical sources. This has led to most of the traditional chemical players pulling out of the market. Today the only player in Germany producing synthetic glycerol, according to GMP, is Olin in Stade (pharmaceutical grade with a purity of 99.7 wt.%). Nevertheless, in 2014 only a small fraction, less than 5000 tonnes out of 2 million

tonnes, was synthetic glycerol. To cope with the oversupply of crude glycerol a different number of methods to valorise the glycerol through chemical synthesis was proposed. The amount of research papers which were published on the alternative usage of glycerol rose to more than 7000 during the years 2000 and 2007.

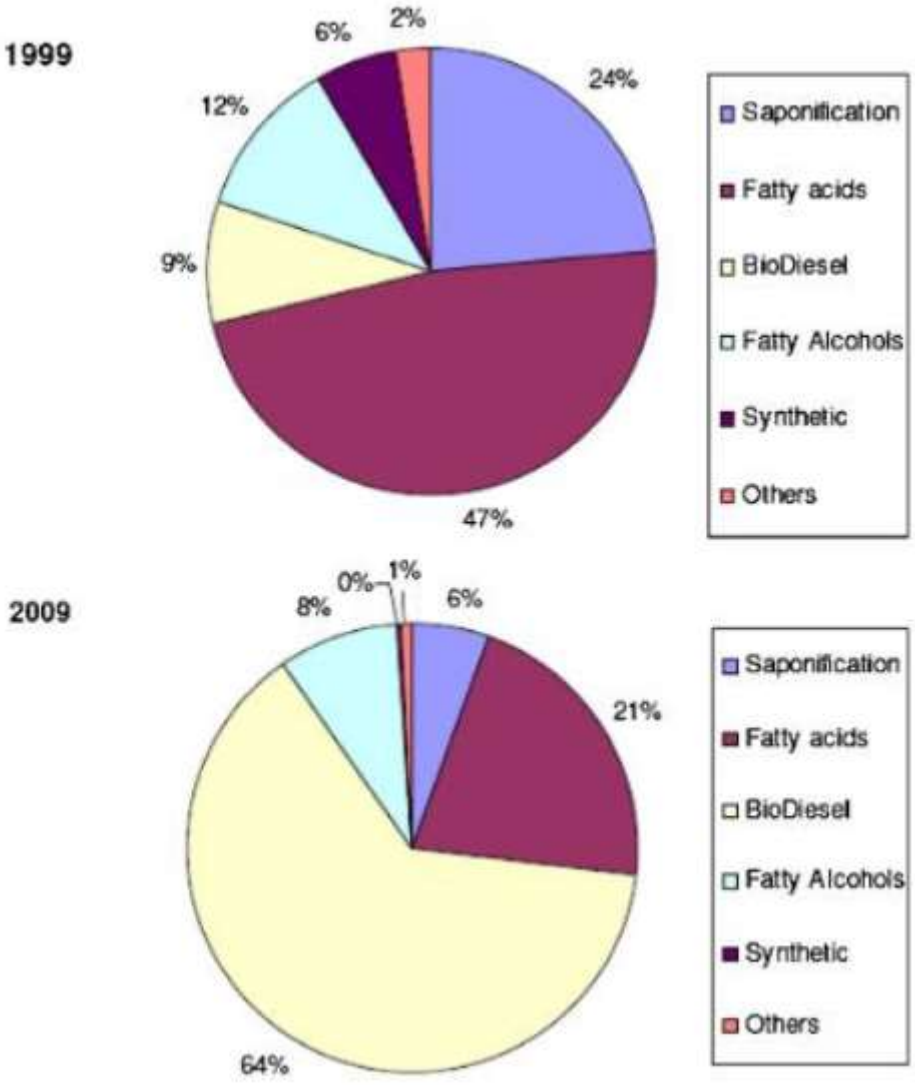

Figure 2: Shift in glycerol sourcing from 1999 to 2009. [2]

The problems associated with crude glycerol derived from biodiesel are the significant amount of impurities it contains, such as methanol, salts and free fatty acids (FFAs). Since the purification of crude glycerol is costly and is often not economical for small and medium sized biodiesel plants, the crude glycerol is usually regarded as a waste. This must be disposed of at cost or can be used as feedstock for anaerobic digestion.

4.1 COMPOSITION OF CRUDE GLYCEROL

The composition of the crude glycerol is highly dependent on the feedstock used. Typical impurities crude glycerol contain are water, ashes (inorganic salts) and MONG (Matter Organic Non-Glycerol) which usually consists of FFAs (Free Fatty Acids), FAME (Fatty Acid Methyl Esters), Glycerides (Mono-, Di- and Triglycerides), Alcohols such as methanol or ethanol and soaps (saponified fatty

acids, fatty acid salts) and other organic compounds. Typical average compositions of different crude glycerol production processes are given in Table 1.

Component	Transesterification [%]	Saponification [%]	Hydrolysis [%]
Glycerol	30-60	83-84	88-90
Ash	10-19	8.5-9.5	0.7-1.0
Water	≤10	6-7	8-9
MONG	≤40	3-4	0.7-1.0

Table 1: Average crude glycerol composition by different production processes.

The usual pH value of crude glycerol lies above 7 due to the usage of alkali catalyst such as sodium hydroxide, potassium hydroxide or even sodium methoxide. Most of the ash content is generated within the transesterification process due to the catalyst used for this reaction. Furthermore, a very high MONG content is being generated due to partially and unreacted glycerides. In the following subsections a detailed overview is made into different crude glycerol suppliers around Europe which use different feedstocks in the transesterification reaction yielding different compositions of glycerol as a by-product.

4.1.1 CRUDE GLYCEROL FROM UCO

Used cooking oil (UCO) is collected at many different points within countries which have the necessary infrastructure and is regarded as a sustainable resource. Its uptake is likely to increase in the future because it can be used for the production of other fuels as well. In Table 2 a typical average composition of different producers in Europe is presented.

UCO	Specifications [wt. %]		
Component	Ireland	Hungary	Germany
Water	10-25	0.3-5	0.5
Ash	5-9		30
Methanol	0-0.2	3-20	0.3
Glycerol	60-75	60	40
MONG	0-10	10-25	15

Table 2: Different average compositions of European crude glycerols derived from the transesterification of UCO.

4.1.2 CRUDE GLYCEROL FROM VEGETABLE OIL

Crude glycerol from vegetable oil is the most common source due to the mature technology of 1st generation biodiesel plants. The glycerol produced in these plants usually has a light colour and can be used in more end-user applications than crude glycerols from waste-based biodiesel producers. In Table 3 some average compositions of crude glycerols are given from different European producers. The lower value for Croatian glycerol is most likely due to an excessive usage of methanol in the transesterification as can be seen from the comparatively higher methanol content.

Vegetable	**Specifications [wt. %]**			
Component	**France**	**Slovakia**	**Croatia**	**Poland**
Water	13.4	<13	3-10	<12
Ash	4.6-5	<6	2.5-4.5	<8
Methanol	0.38-0.5	<0.2	3-22	<1
Glycerol	>80	>82	45-67	>80
MONG	0.4-2.5	<2.5	10-30	<4

Table 3: Different average compositions of European crude glycerol derived from the transesterification of vegetable oils.

4.1.3 CRUDE GLYCEROL FROM WASTE

The third most common feedstock for transesterification is waste such as tallow or sewage sludges. The by-product crude glycerol is usually highly impure, has a very dark colour and contains a high amount of MONG and ashes. Furthermore, crude glycerol from waste is not being used in pharmaceutical or personal care products due to its legal limitations. Wastes are category 1 feedstocks which are generally only used for energy generation.

Waste	**Specifications [wt. %]**	
Component	**United Kingdom**	**Netherlands**
Water	12	16
Ash	14	8
Methanol	-	-
Glycerol	45	66
MONG	30	12

Table 4: Different average compositions of European crude glycerol derived from the transesterification of waste-based feedstocks.

4.2 GRADES OF GLYCEROL

The industry distinguishes different grades of glycerol based on its purity (by wt.%). An overview of the different grades is given in Table 5.

Types of glycerol	Glycerol content [%]	Sources/applications
Crude glycerol	70-90	By-product of biodiesel production
Technical grade	95	Suitable for industrial applications
United States Pharmacopeia (USP)	96-99 USP (tallow-based) 96-99 USP (vegetable-based)	Used in cosmetic, pharmaceutical and food
Food Chemical Codex (FCC)	99.7 USP/FCC-Kosher	

Table 5: Different grades of glycerol. [3]

Glycerol grades for non-food applications are termed technical grade and usually have a purity of around 95 wt.%. USP (United States Pharmacopeia) grade glycerol has a purity of 96-99 wt.%. and is used for food and pharmaceutical applications. The highest purity has the USP/FCC (Food Chemical Codex) grade with a purity of 99.7 wt.%. The application area for this glycerol is mainly in kosher (and due to Islamic laws also halal) foods.

4.3 APPLICATION AREAS OF GLYCEROL

Glycerol has many different application areas. The application area of glycerol is dictated by whether the glycerol is crude or refined to a certain purity and also which feedstock is used in biodiesel manufacture. Usually, a distinction is made between crude, technical, USP and Kosher grade glycerol and all of them have different application areas. Furthermore, crude glycerol from waste-based sources can only be used for technical applications or energy generation due to the impurities such glycerol contains. Glycerol can be used as a platform feedstock for the production of fuels, chemicals, pharmaceuticals, detergents and the automotive and building industries. Nowadays, glycerol is used as a replacement feedstock for important chemicals such as epichlorohydrin, propylene glycol and biomethanol. New routes for the production of chemicals such as acrylic acid are being investigated. Traditional uses are applications in pharmaceutical and oral care or food. In Figure 3 the typical distribution of glycerol application/consumption which is purified to a certain stage is shown. As can be seen from the figure, about a third of the consumption is accounted for technical applications while at least about 40% is being used for pharmaceutical and hygienic applications. The rest is being used for resale and other uses which can be either technical or pharmaceutical applications.

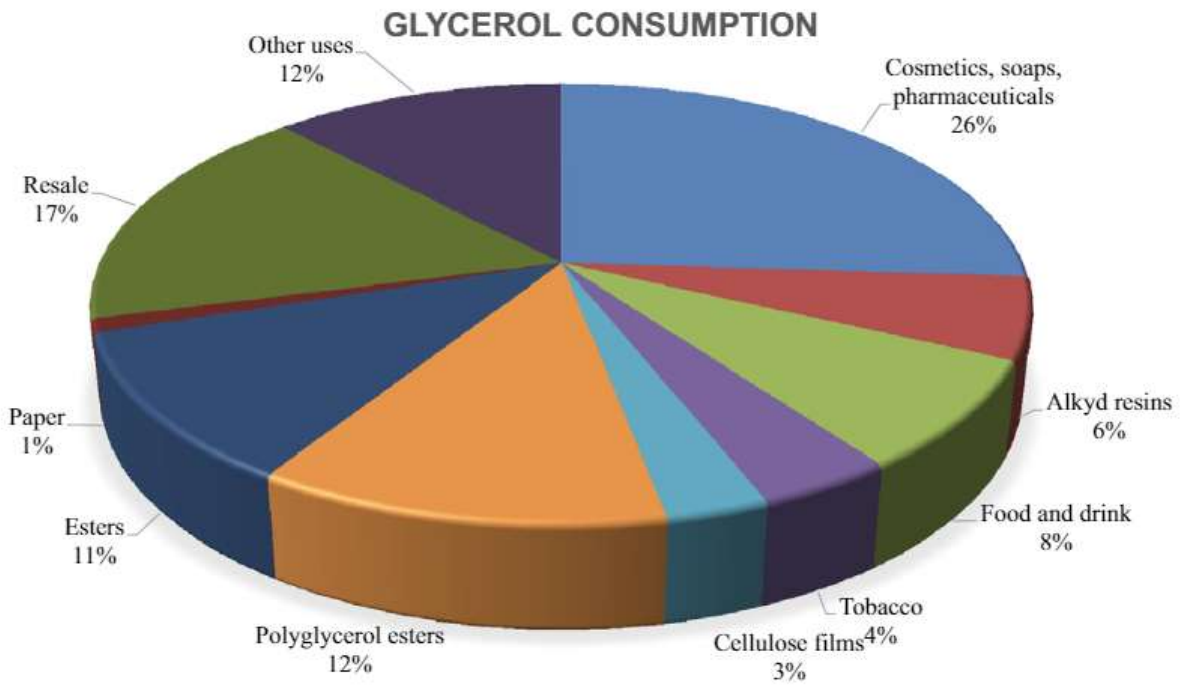

Figure 3: Distribution of glycerol application/consumption areas. [3]

5. GLYCEROL MARKET OVERVIEW

5.1 PRICE DEVELOPMENT OF CRUDE GLYCEROL

As already mentioned in the introduction, the oversupply in crude glycerol started in the year 2003 when significant increases in biodiesel production began, as can be seen in Figure 4.

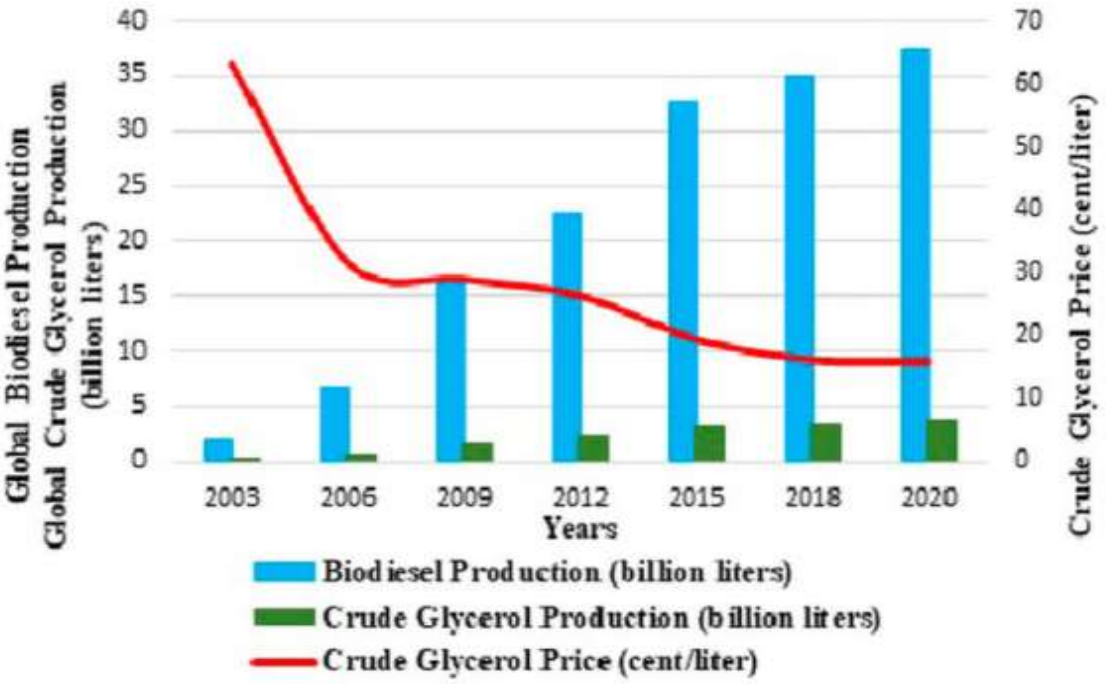

Figure 4: Global Biodiesel and by-product glycerol production with crude glycerol price course. [4]

The oversupply of crude glycerol led to a dramatic decrease of the crude glycerol price. The driving factor for the oversupply of glycerol was the biodiesel industry with an approximate share of 64% followed by the fatty acid industry with 21%. There are some contradictions regarding the price of crude glycerol due to the high fragmentation of the market with many different players in the biodiesel market. Some authors claim that bioglycerol shortly had no economic value [2] which is neglected by other authors [4]. In the year 2014 the price rose again to 240 $/tonne.

5.1.1 CURRENT PRICES OF CRUDE GLYCEROL

2020 was marked by the COVID-19 pandemic and an unprecedented demand for crude glycerol which is suitable for pharmaceutical areas such as disinfection. During the middle of 2020, a significant increase in the crude glycerol price of up to 500 EUR per tonne in Europe and 385 USD per tonne in China was observed. Table 6 depicts the crude glycerol prices for Europe and China for 2020.

Crude Glycerine Price per tonne	March 2020	June 2020	Sep 20	Dec 2020 est.
Europe kosher, non-GMO, DDP in bulk	€ 280 ($316)	€ 500 ($565)	€ 300 ($357)	€ 275 ($327)
China Vegetable, NaCl, CFR in flexibags	$210	$385	$280	$300

Table 6: Price development of European and Chinese crude glycerol during 2020.

5.2 RECENT DEVELOPMENT IN GLYCEROL MARKETS (Q3 2020)

In this section the historical and recent developments of glycerol markets are looked at from a global perspective. Sections are divided into, North America, Europe and International (focussing mostly on China, Indonesia and Brazil). A special focus is placed on the third quarter of 2020 as this was the most recent data available on the global glycerol market.

During the second quarter of 2020 glycerol prices increased for several reasons but any increases were lost in the third quarter. The prices in August were mostly the same as they were prior to March (low price level).

The supply of glycerol improved due to higher biodiesel profitability in the second half of 2020. While vegetable oil prices remained high a shift towards more sustainable feedstocks for production of biodiesel could be observed.

Furthermore, China ceased being the largest importer of refined and crude glycerol. The Q3 imports into China were the lowest seen in 2 years.

Additionally, the December lockdown increased the glycerol price in many markets due to lower production levels of biodiesel.

5.2.1 NORTH AMERICAN GLYCEROL MARKET

5.2.1.1 NORTH AMERICAN MARKET SUMMARY/Q3 2020

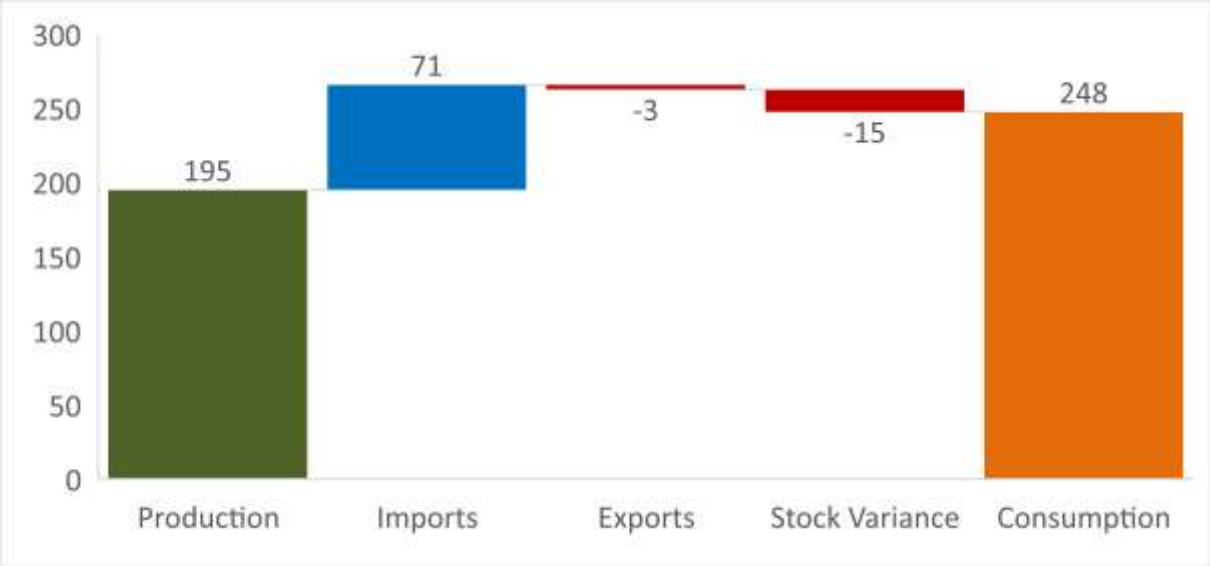

Figure 5: North American glycerol production to consumption bridge July - September 2020 ('000 tonnes).

The third quarter of 2020 showed the highest increase in glycerol production due to increased US biodiesel sales which were subsidised. Additionally, producers had to access much of their inventories (especially of CG) to respond to demand. The increase in supply has been offset by a correspondingly robust demand. Especially, imports for RG from Europe and SE-Asia increased by 25% compared to Q2. The waterfall diagram (figure) in combination with table 7 shows that about a third of the produced glycerol is accounted to crude glycerol while the rest is accounted to refined glycerol. Additionally, the imports have soared due to the demand for refined glycerol while exports almost declined to zero.

CG	70	1	3	-10	59
RG	123	70	1	-5	188

Table 7: Crude and refined glycerol distribution to Fig. 5.

5.2.1.2 NORTH AMERICAN GLYCEROL PRODUCTION: Q3 2020

Examining the contribution that different industries make to glycerol production it is obvious that biodiesel has by far the highest share. Compared to Q3 2019 biodiesel production has increased by 6%. Especially, also due to national governments mandating their use in transport applications. In Q3 2020 a total 195,000 tonnes of glycerol was produced – over two thirds as RG.

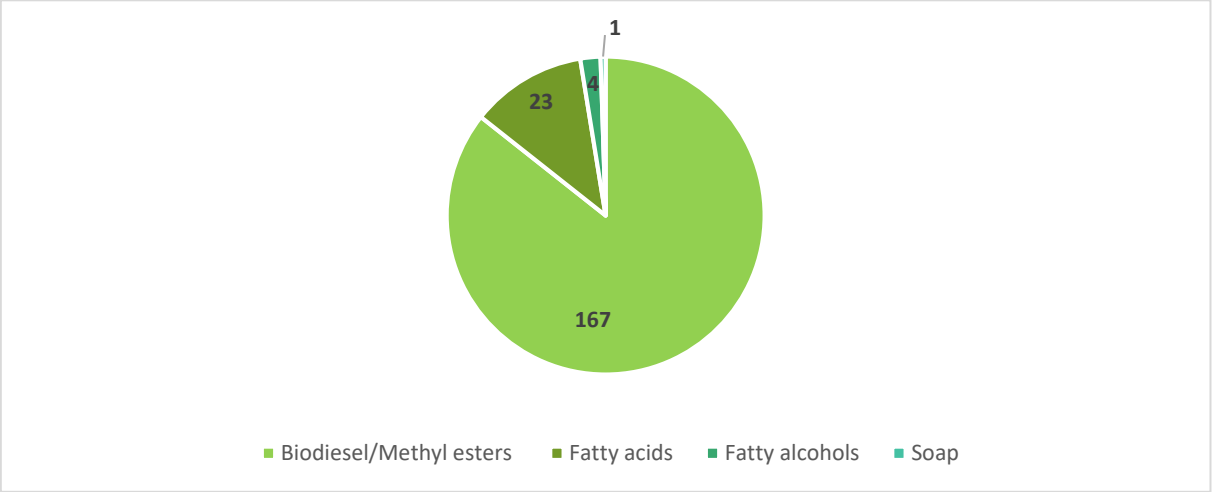

Figure 6: North American Glycerol production by industry ('000 tonnes).

5.2.1.3 NORTH AMERICAN PRODUCTION: OUTLOOK

As Biodiesel mandates have increased the amount of glycerol produced has increased also, see Figure 7. The amount of glycerol produced during the last three years has increased threefold and most likely will continue to follow this trend in the future. Improved sales in the US biodiesel market as well as a biofuel friendly policy of the Biden administration will likely further improve the situation. Nevertheless, this development has also drawbacks due to emerging technologies such as Renewable Diesel (HVO) which is becoming a widely used drop-in replacement for fossil-fuel derived diesel. However, renewable diesel does not produce glycerol as a by-product, instead propane is produced. The estimated total production level for glycerol from North America in 2020 is 745,000 tonnes.

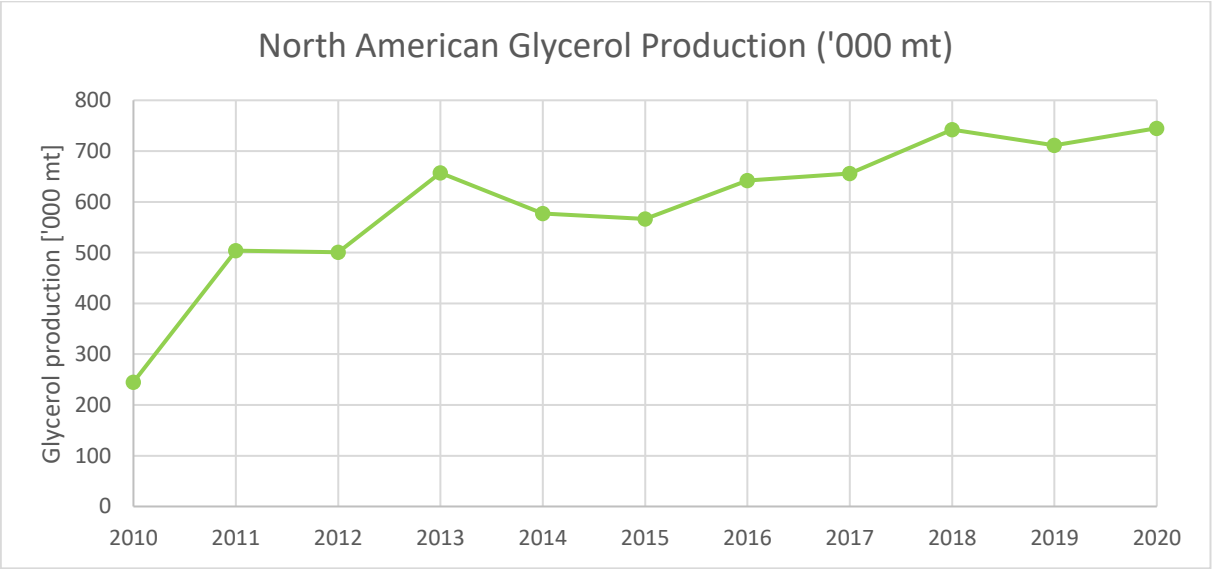

Figure 7: North American glycerol production from 2010-2020 est. ('000 tonnes).

5.2.1.4 NORTH AMERICAN CONSUMPTION Q3 2020

Glycerol consumption showed a strong demand in Q3 2020. This was due to increased activity in the construction industry and there was a shortage for use in the used car industry. Glycerol is used in the used car industry in the manufacture of polyols and polyurethanes which account for over 10% of US usage.

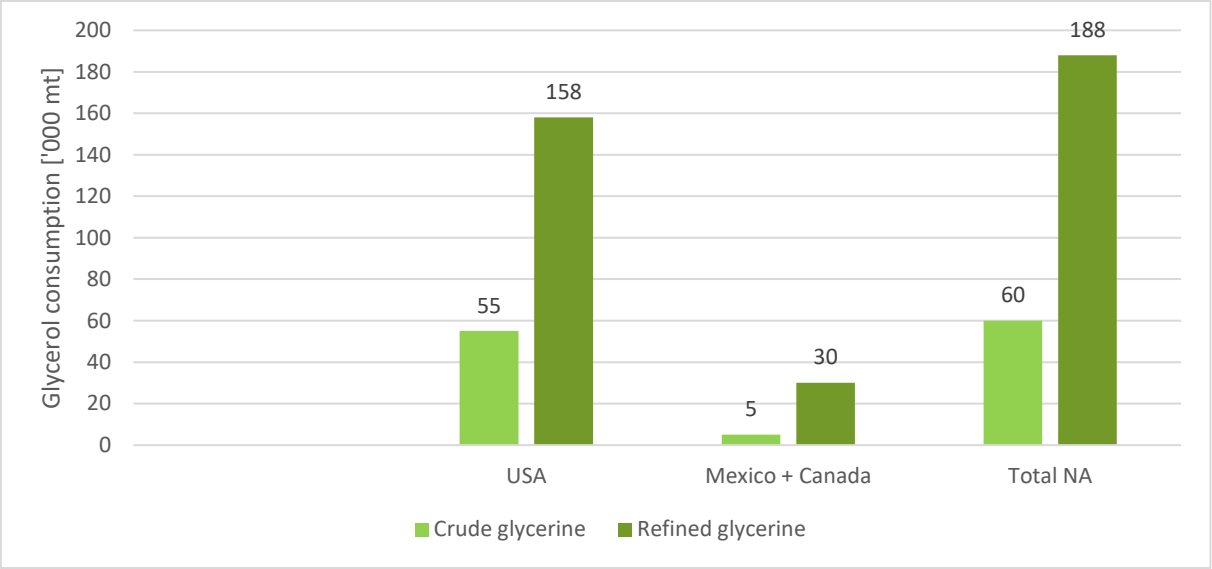

Figure 8: North American estimated glycerol consumption for Q3 2020 ('000 mt).

Furthermore, the competition for crude glycerol between animal feed, waste-water treatment and domestic refining industries has increased. In addition, exports of glycerol are also competing with these industries.

There is a strong demand in North American economies for household goods and cleaning products, especially due to the pandemic which has left most of the population stuck at home. This situation is benefitting the demand for glycerol and may stay like this throughout 2021 as well.

5.2.1.5 NORTH AMERICAN CONSUMPTION: 2020 OUTLOOK

Comparing the glycerol production of the last decade versus demand over the last decade, it is possible to observe a continuous increase in the demand of refined glycerol while the demand of crude glycerol remains more or less stable throughout.

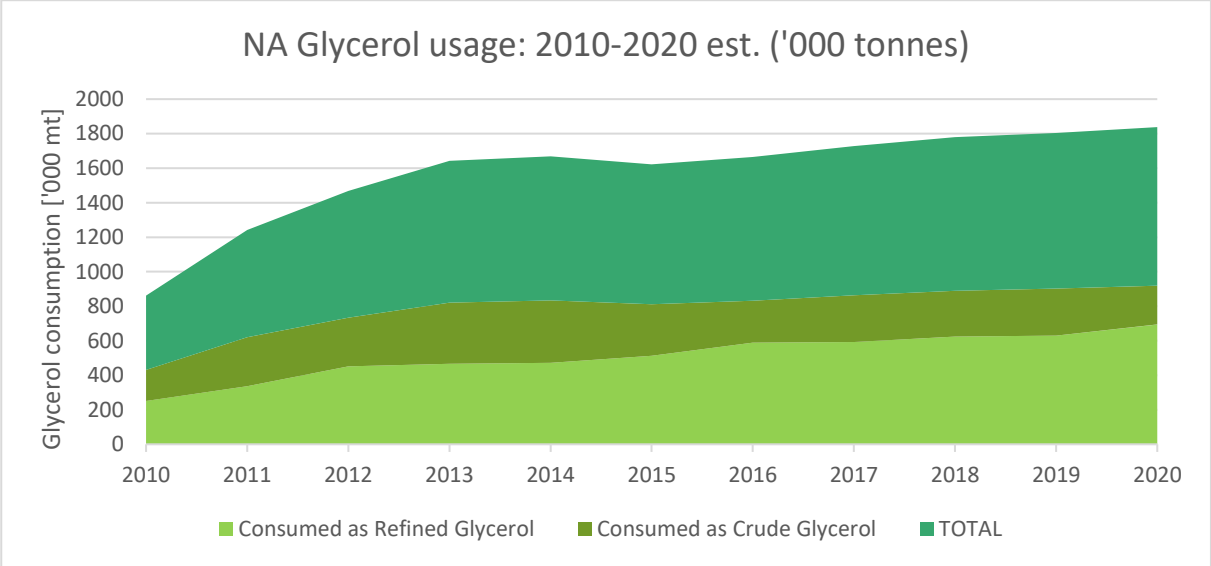

Figure 9: North American glycerol usage: 2010-2020 est. ('000 tonnes).

The reason for the increasing consumption of RG are household goods and cleaning products which have been very successful, particularly due to the pandemic as well as sufficiently large price ranges compared to CG which makes RG competitive for technical applications.

5.2.1.6 NORTH AMERICAN IMPORTS & EXPORTS

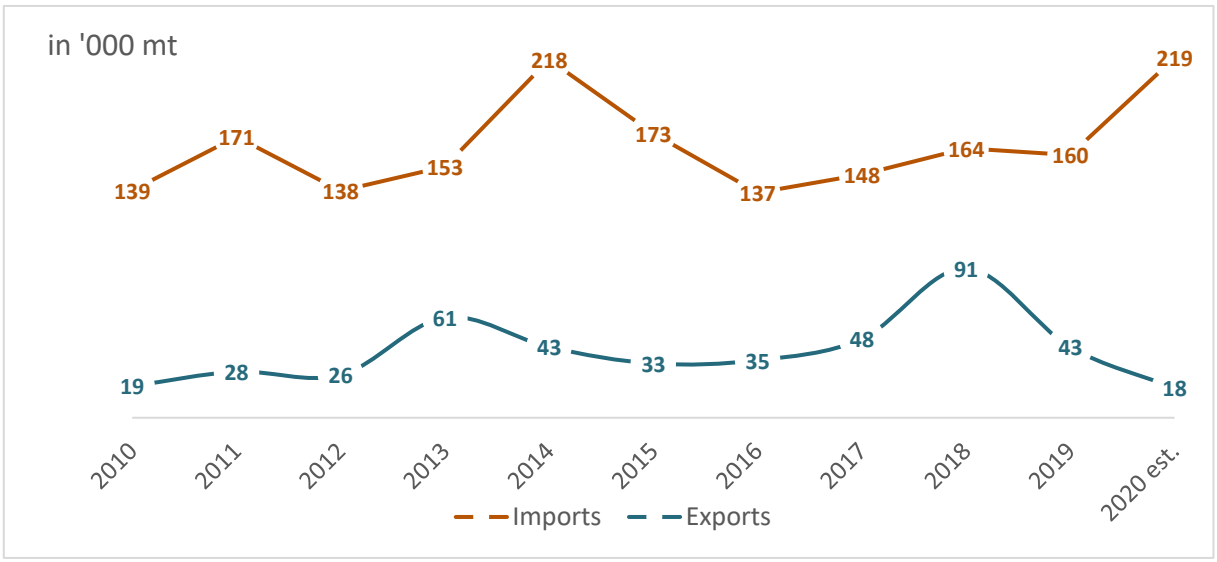

Figure 10: US Glycerol imports and exports 2010 - 2020 est. ('000 tonnes).

The import and export statistics are volatile throughout the entire last decade, as shown in Figure 10. Nevertheless, the drop in imports during the first half of 2020 was followed by a wave of imported

glycerol (approximately 70,000 tonnes from South East Asia into the USA during Q3). Most likely this value will decrease during Q4 due to limited availability from existing suppliers.

5.2.1.7 NORTH AMERICAN GLYCEROL INVENTORIES

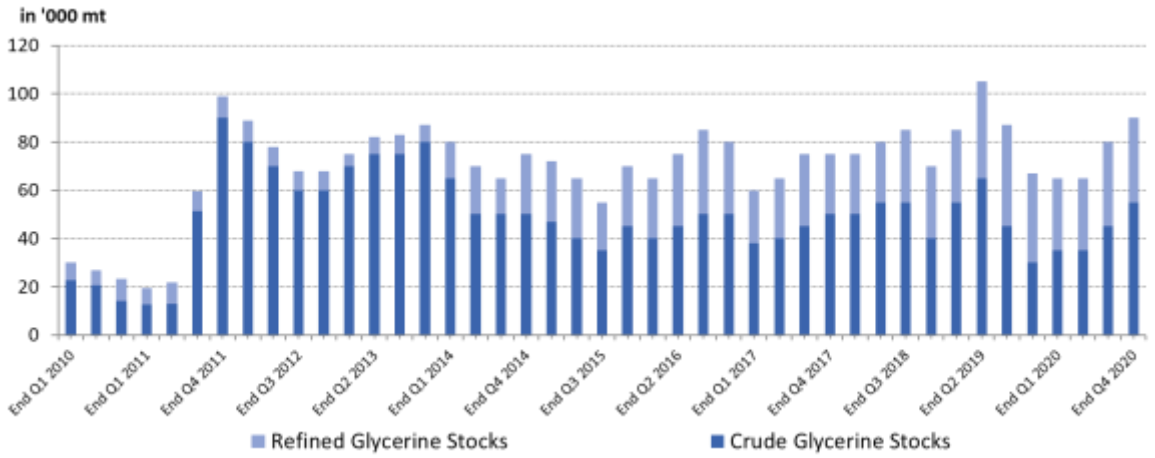

Figure 11: North American inventory levels from domestic production - 2010-2020 est.

Glycerol inventories increased by the end of Q4 2020 (as can be seen in Figure 11) due to production increases in Q3 while Biodiesel producers contracted longer term as from Q3. Stocks are expected to return to their average of about 2 weeks' production at most operators.

5.2.1.8 RG GLYCEROL PRICES: FROM Q3 2020

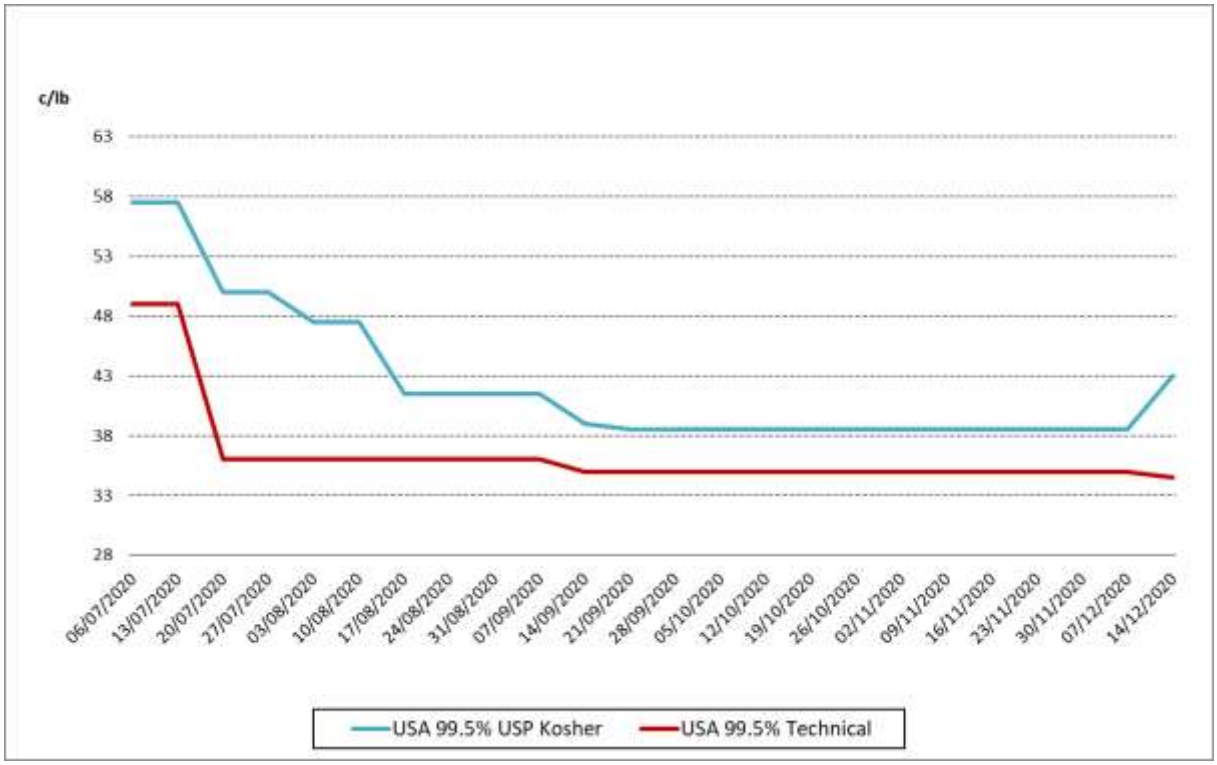

Figure 12: North American refined glycerol spot prices (cents/lb delivered in bulk).

As can be seen in Figure 12 the glycerol price dropped throughout the year due to the combination of high domestic production and significant imports as mentioned above. This led to an oversupply and hence to a price decrease. Pharma grade RG prices declined during July/August and stabilized just above 38 cents/lb delivered to customer in bulk.

5.2.2 EU GLYCEROL MARKET

5.2.2.1 EU MARKET SUMMARY/Q3 2020

European Biodiesel production had a less favourable year than the US market (except for UCO-based material) and imports from South-East Asia soared due to a strong Euro, simultaneously having a detrimental effect on exports. CG which was usually exported to China was mostly used in Northern Europe for Biogas production while RG consumption during Q2 and Q3 has been below the same period of 2019. Generally, RG has been on the low side.

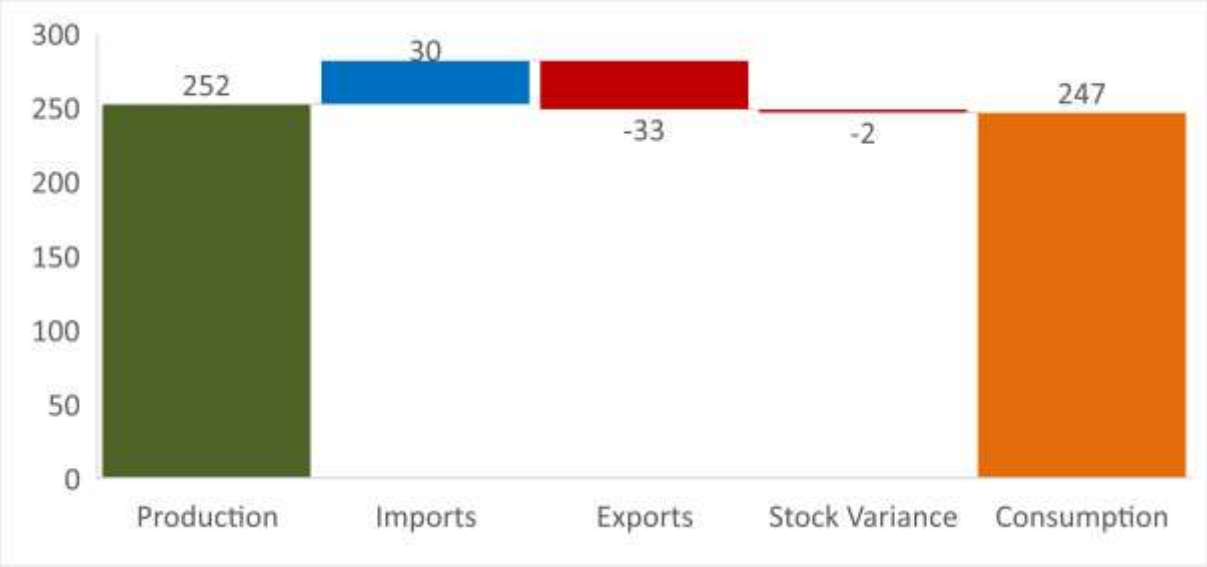

Figure 13: European glycerol production to consumption bridge Q3 2020 ('000 tonnes).

CG	137	6	23	3	123
RG	115	24	10	-5	124

Table 8: Crude and refined glycerol distribution to Fig. 6.

5.2.2.2 EU PRODUCTION: Q3 2020

The European production of glycerol is mainly driven by biodiesel production, as it is in the US. Nevertheless, the domestic glycerol production for Q3 2020 was higher compared to the US. Approximately, 80% of European glycerol has been generated by this industry as can be seen in Figure 14. Due to the expensive price of palm oil, UCO based biodiesel producers have enjoyed running at full capacity. Furthermore, the production of other oleochemical producers have soared e.g. in the domestic soap, fatty acid and fatty alcohols industry which generated about 46,000 tonnes of glycerol in Q3.

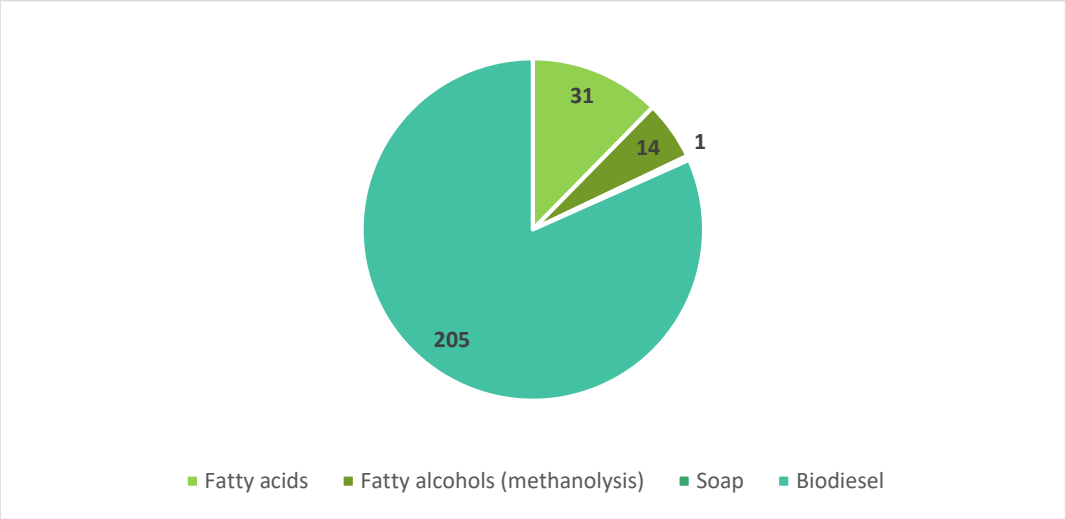

Figure 14: European Glycerol production by industry ('000 tonnes).

5.2.2.3 EU PRODUCTION OUTLOOK

As already seen in Figure 14 the European glycerol production is driven by the biodiesel industry mostly. The European wide lockdown for two months has truncated two months of production resulting in the lowest annual glycerol output of the past 10 years in Europe as can be seen in Figure 15. For Q4 2020 production of 240,000 tonnes of glycerol is expected and simultaneously distillation capacities are being ramped up which will cause a shortage in good quality crude glycerol.

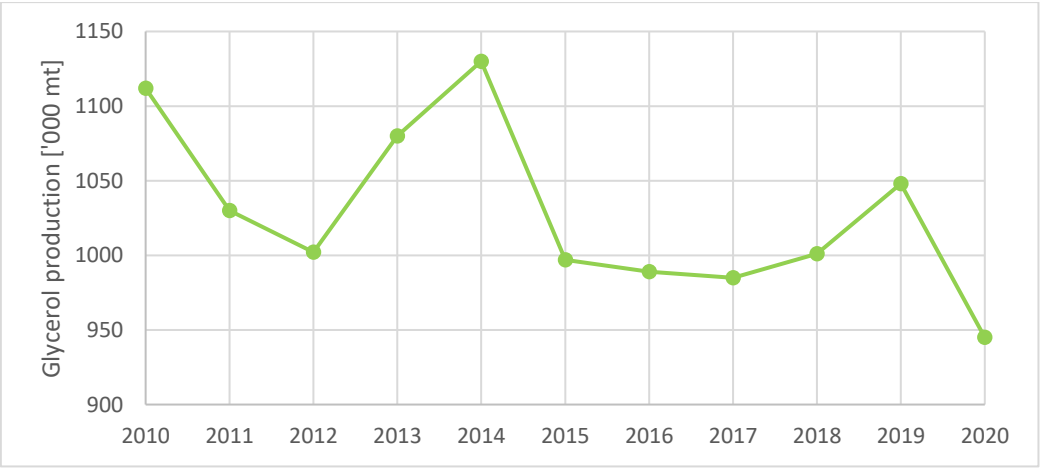

Figure 15: European glycerol production: 2010 - 2020 est. ('000 tonnes).

5.2.2.4 EU CONSUMPTION: Q1, Q2 AND Q3 2020

The European consumption of glycerol showed a significant increase in the consumption of crude glycerol of about 40%. Simultaneously, the consumption of refined glycerol decreased by approximately 17% compared to the previous year which can be seen in Figure 16. The reason for this effect is the shift to cheaper feedstocks for biodiesel production which lead to a higher increase of crude glycerol demand, especially in energy generation e.g. biogas rather than refining.

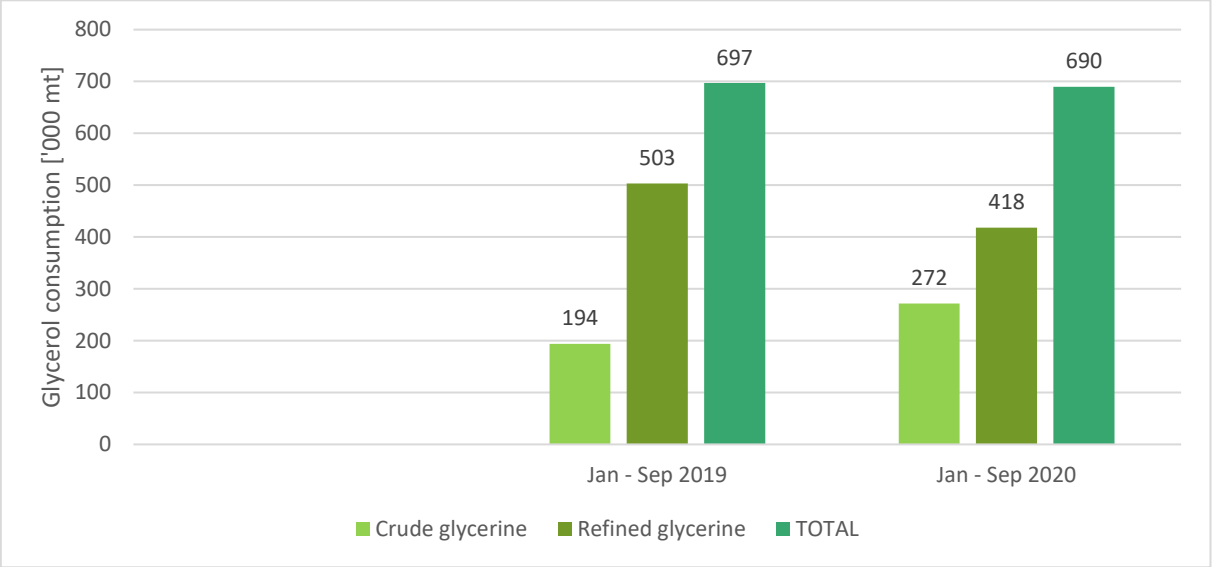

Figure 16: European glycerol consumption: ('000 tonnes).

5.2.2.5 EUROPEAN CONSUMPTION: FULL YEAR VIEW

European demand during the last decade increased by a small margin while crude glycerol demand decreased and compensated the loss of demand of technical refined glycerol by increasing sales of crude glycerol. For the year 2020 a total demand of 950,000 tonnes of glycerol is expected with 600,000 tonnes being refined glycerol.

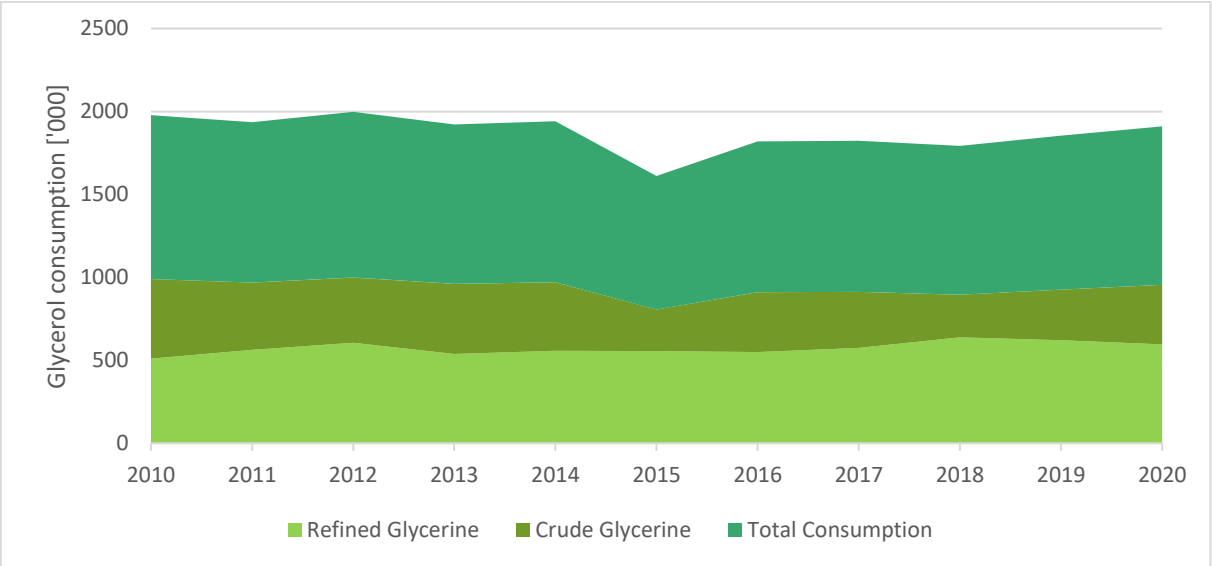

Figure 17: European glycerol consumption: 2010 - 2020 est. ('000 tonnes).

5.2.2.6 EU IMPORTS & EXPORTS

Exports have been dominating the European glycerol market over the last decade. 2020 was the first year where exports have plummeted, especially for crude glycerol during the first half of the year due to better domestic options available for producers. The European refined glycerol market is

facing massive competition from South-East Asia. Exports for Q3 and Q4 are expected around 33,000 tonnes each.

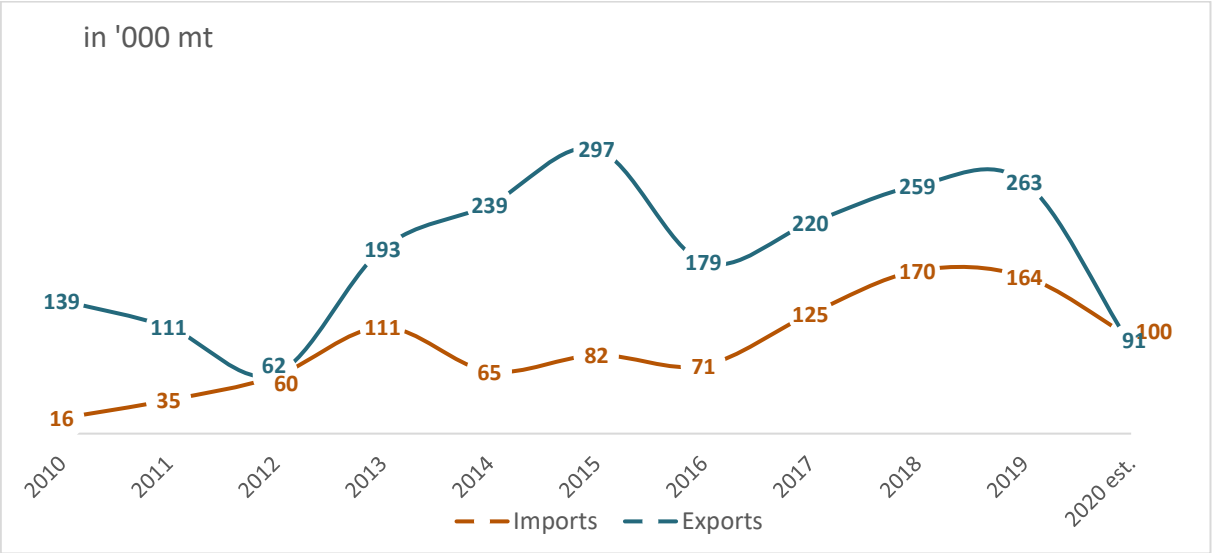

Figure 18: European glycerol imports and exports since 2010.

Furthermore, the importing trend from South-East Asia has been stopped due to a lack of material on the market. It is expected that Q3 imports will reach 28,000 tonnes and Q4 will be below 20,000 tonnes.

5.2.2.7 EU GLYCEROL STOCKS

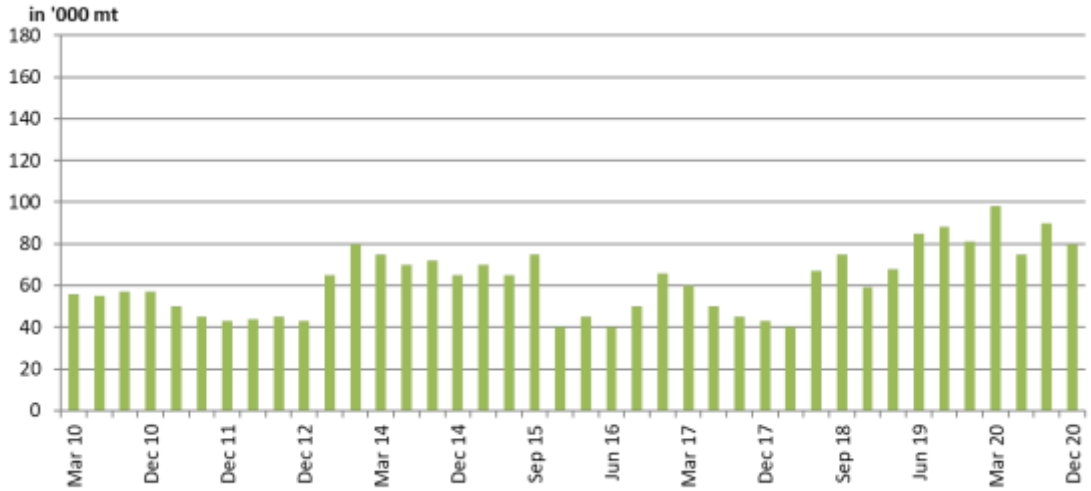

Figure 19: European inventory levels from domestic production - 2010 - 2020 est.

The European inventory levels from domestic production of the last decade are depicted in figure 19. It is obvious that by the end of September 2020, glycerol stocks accumulated again up to approximately 90,000 tonnes while crude glycerol stocks remained on the low side which will stay like this until the end of 2020.

5.2.2.8 GLYCEROL PRICES: RG DURING SECOND HALF 2020

The refined glycerol prices dropped during the summer in Europe due to declining demand on the spot market and additional supply which forced sellers to accept lower prices. Non-GMO kosher refined glycerol compared to technical grade glycerol was 50-85 EUR per metric tonne more expensive. As can be seen in Figure 20 the prices started to increase again by the end of the year but not reaching the previous level at the beginning of the second half of 2020.

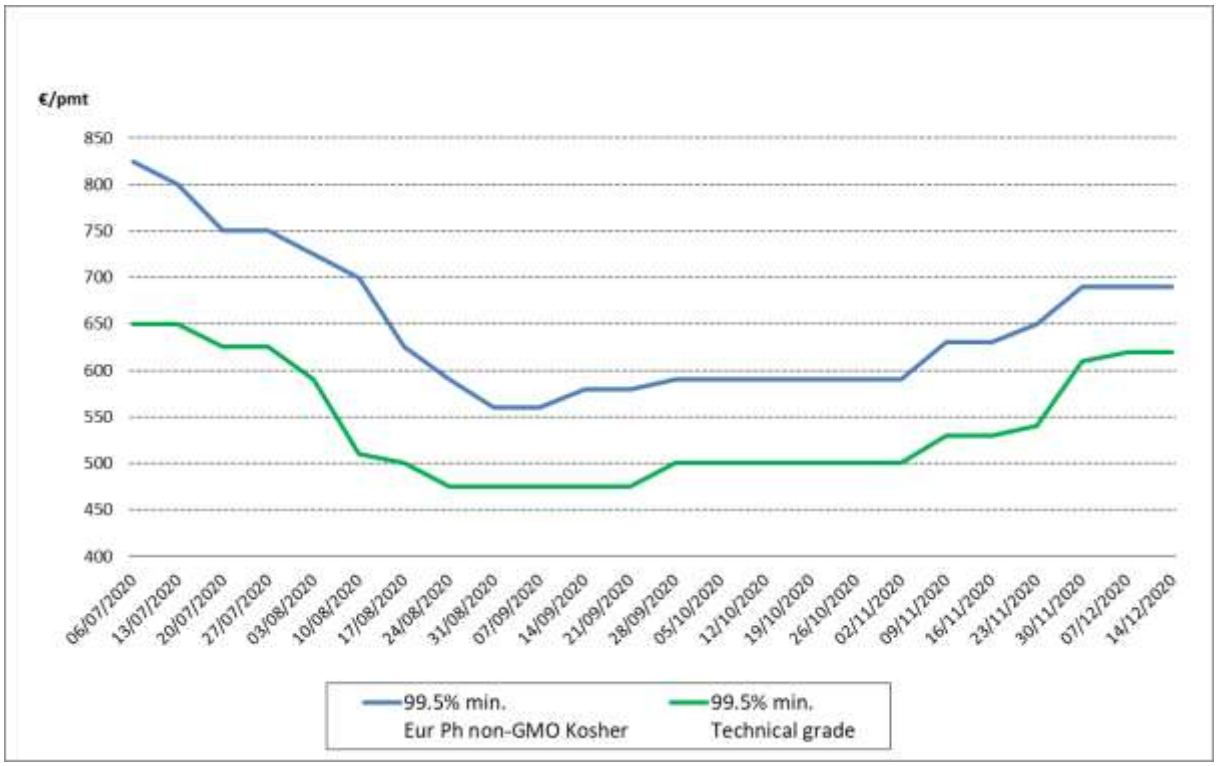

Figure 20: European refined glycerine spot prices in EUR per metric tonne delivered in bulk.

5.2.2.9 GLYCEROL PRICES: CG DURING SECOND HALF 2020

Comparing the values of the same period for crude glycerol a similar progression can be observed. Crude glycerol values eroded during Q3 and reached the bottom on the 15th of September. As with refined glycerol, crude glycerol prices started to increase during Q4 but not reaching the previous values of the year.

A good development of non-vegetable crude glycerol could be observed leading to a historical high of 220 EUR per metric tonne while the kosher quality non-GMO crude glycerol was low in demand during Q3.

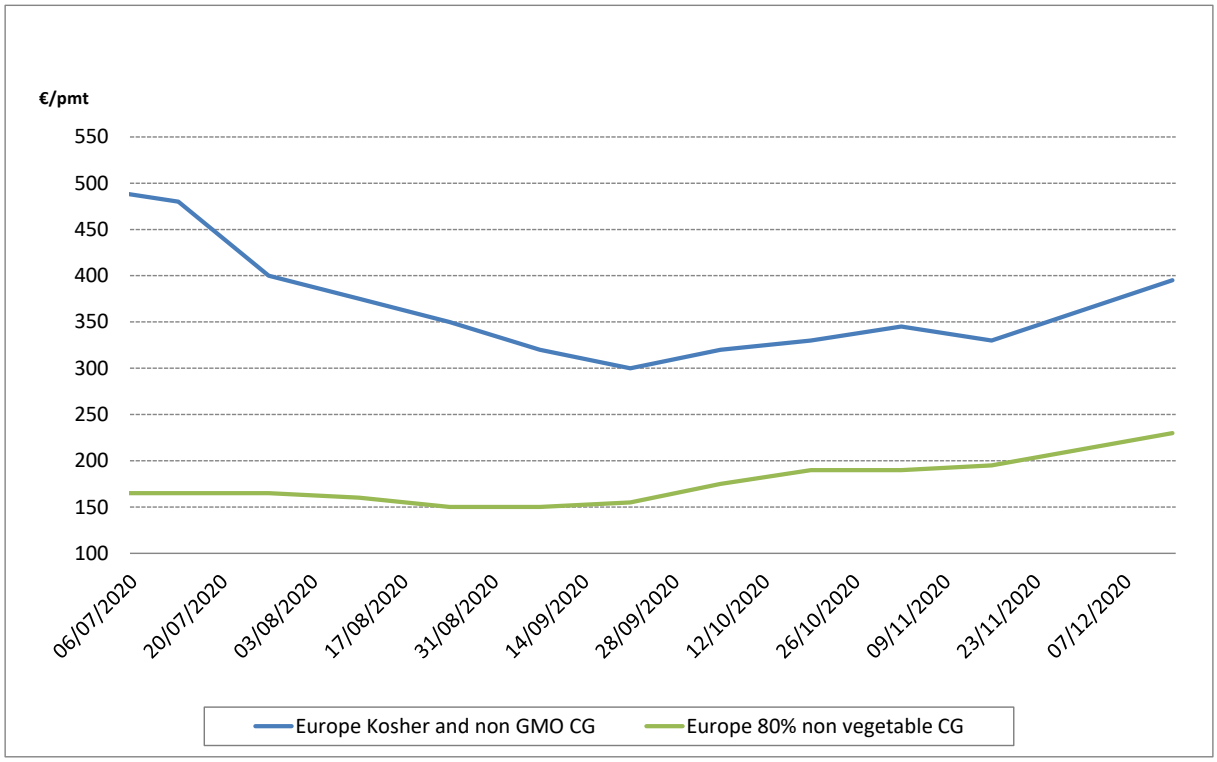

Figure 21: European crude glycerol spot prices in EUR per metric tonne delivered in bulk.

5.2.3 INTERNATIONAL

In the following section attention is given to the country of China and the countries of the continents of South America and South-East Asia.

5.2.3.1 BIODIESEL PROFITABILITY – SECOND HALF OF 2020

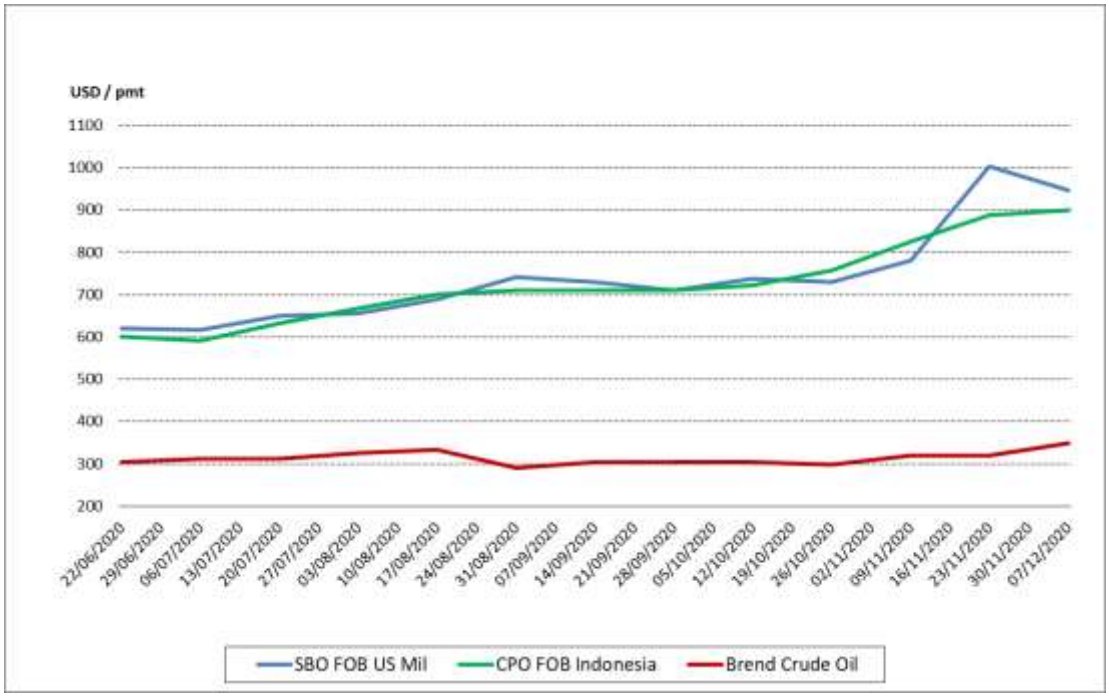

Figure 22: Soy and Palm Oil prices versus Mineral Oil.

Biodiesel profitability was highly problematic in the second half of 2020 due to the continuing high prices of vegetable oils compared to depressed mineral oil values which were abundantly supplied on the market. Consequently, biodiesel mandates were more expensive than ever to enforce and countries such as Indonesia, Argentina and Brazil have all relaxed their obligations.

5.2.3.2 GLYCEROL SUPPLY FROM BRAZIL AND INDONESIA

Brazil and Indonesia are important suppliers of glycerol for the world market due to their increasing biodiesel mandates. Brazil is of a similar order of magnitude to Indonesia. Indonesia is a larger supplier of glycerol in the world market due to the larger oleochemical industry developed there. In Brazil, the mandate was relaxed marginally. B10 for September and B11 for November and December replaced the actual planned B12. Officially, Brazil has produced 5.7 million tonnes of biodiesel for 2020 and large volumes of crude glycerol have not been offered on the world market but used for domestic distillation capacities.

In Indonesia, the ambitious plans of B30, which would mean a production of 9 million tonnes of biodiesel, was not implemented. It is estimated that 6.5 million tonnes will be produced. The glycerol is mainly sold on long-term contracts which has left the spot market dry. The additional refining capacities made the South-East Asian area a net buyer of crude glycerol.

5.2.3.3 THE CHINESE MARKET: THE END OF A CYCLE?

The Chinese market has been a great importer of glycerol for a long time. It seems that after a long time of importing glycerol into China this trend has now changed as can be seen in figure 23. Due to a lack of lower priced glycerol, imports into China were reduced. It is expected that China will import 1.2 million tonnes of glycerol in 2020, compared to 1.4 million tonnes in 2019.

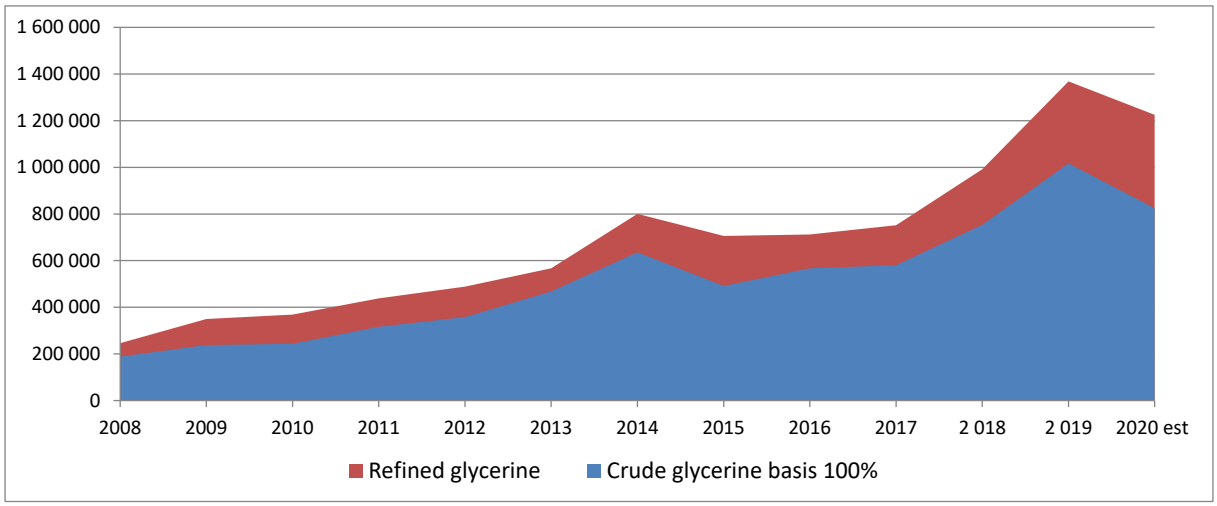

Figure 23: Imports of glycerol into China from 2010-2020 est. (tonnes).

5.2.3.4 CHINA RG PRICES: SECOND HALF 2020

Chinese refined glycerol prices (domestic 95% min. technical grade) were disconnected from South-East Asian 99.5% min USP kosher FOB (Free On Board: meaning that the seller is responsible for transportation of the goods to the port of shipment and the cost of loading) in flextanks until approximately June 2020. Following this, a lack in the Chinese market led Chinese buyers to cover material from other regions and prices surged up to USD 700 per metric tonne from USD 450 per metric tonne FOB Malaysian/Indonesian Ports. From this price point both glycerols started gradually to increase in clear correlation. The prices seem to have balanced around USD 700 per metric tonne FOB SEA. The crude glycerol spot import prices in USD per metric tonne and the value for domestic price of 95% min tech RG are shown in Figure 24.

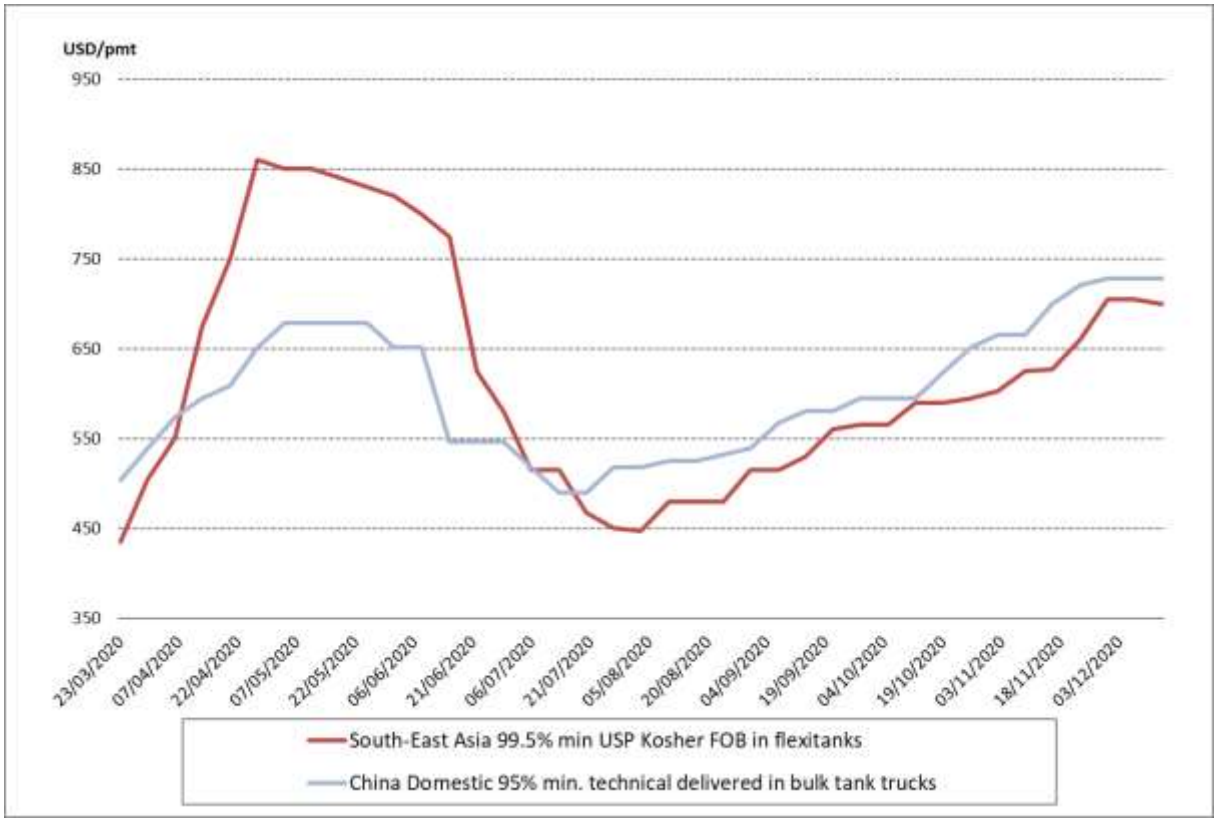

Figure 24: Chinese and South East Asian glycerol spot prices (in USD per metric tonne).

5.2.3.5 CHINA CG PRICES: SECOND HALF OF 2020

Crude glycerol prices in bulk flexibags have almost doubled during the second half of 2020 just below USD 400 per metric tonne CIF (Cost Insurance Freight: meaning that the seller will deliver the goods on board the vessel. As soon as the goods are on board the ship, the customer overtakes the responsibility of the goods) Chinese Main Ports in bulk. Compared to RG, CG is quite expensive and remains above 50% of RG value since September. The increased demand is most likely due to the preparation for the Chinese New year break.

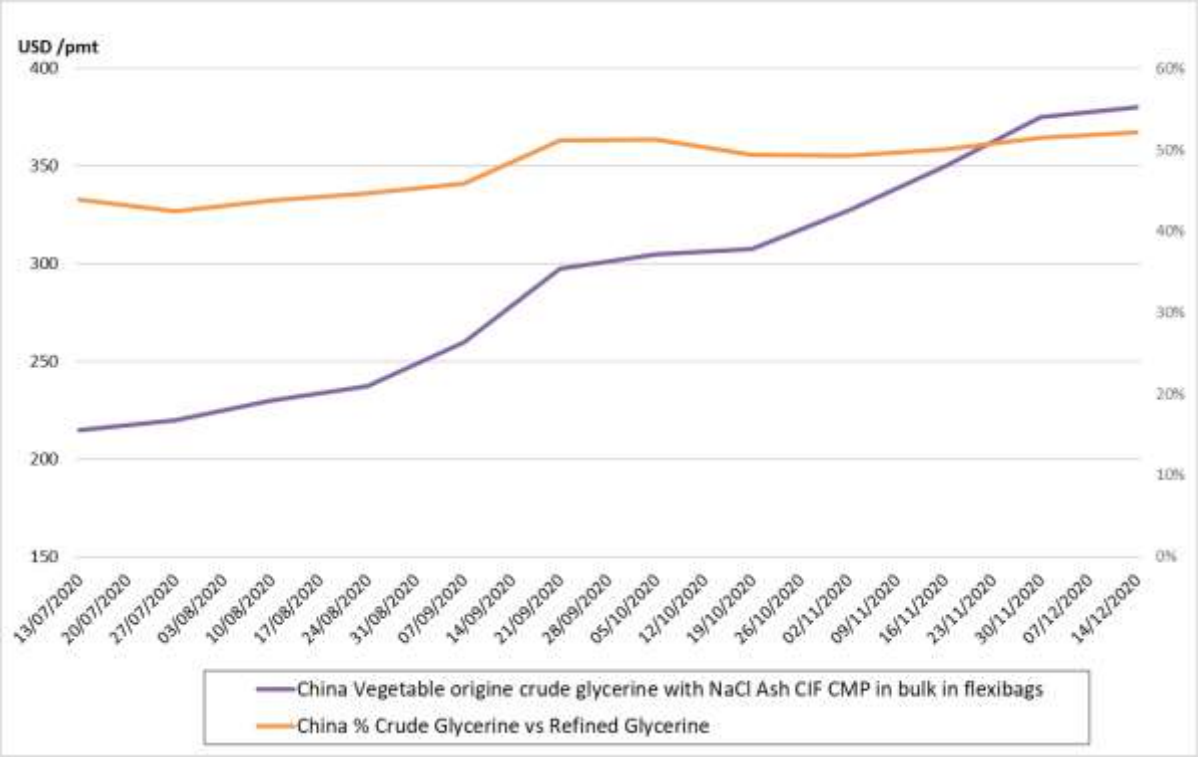

Figure 25: Crude glycerol spot import prices in USD per metric tonne and value compared to the domestic price of 95% min tech RG.

5.2.4 CONCLUSION FOR THE GLOBAL GLYCEROL MARKET

With no doubt 2020 has been an extraordinary year and had different effects and consequences for the glycerol market.

In December, the CG price soared up to 10 cents/lb for the North American market and it is expected that in Q1 2021 prices will rise sharply. This is due to the required imports Figure 10 which are needed to sustain US consumption which is mainly consisting of refined glycerol consumption. Currently, the North American market prices of various glycerol grades are lower compared to international prices which made them competitive even for technical applications.

Glycerol prices for the European market were balanced, marked by a poor demand and lower prices in Q1 and Q3 and the opposite in Q2 and Q4 where higher prices could be observed. It seems that the European market has demonstrated in 2020 that it is not dependent of exporting excess volumes to China because much of the crude glycerol produced can be used for domestic biogas production. Furthermore, it seems that the European glycerol market has found a sustainable price ceiling, along with a floor provided by good sales of crude glycerol into the biogas industry.

Concerning the international market, August 2020 marked the lowest import volumes of glycerol into China for the last two years. Especially as the reduced availability of glycerol in South East Asia and South America forced the Chinese market to work with less volumes and with higher prices than in 2019. Strong prices for epichlorohydrin have supported RG values. The flow of international business of glycerol to China is increasingly in the form of RG and long-term contracts while the demand will remain on the low side until the end of Q1 2021.

5.3 FUTURE DEVELOPMENTS

5.3.1 GLOBAL BIODIESEL MARKET (2018-2021)

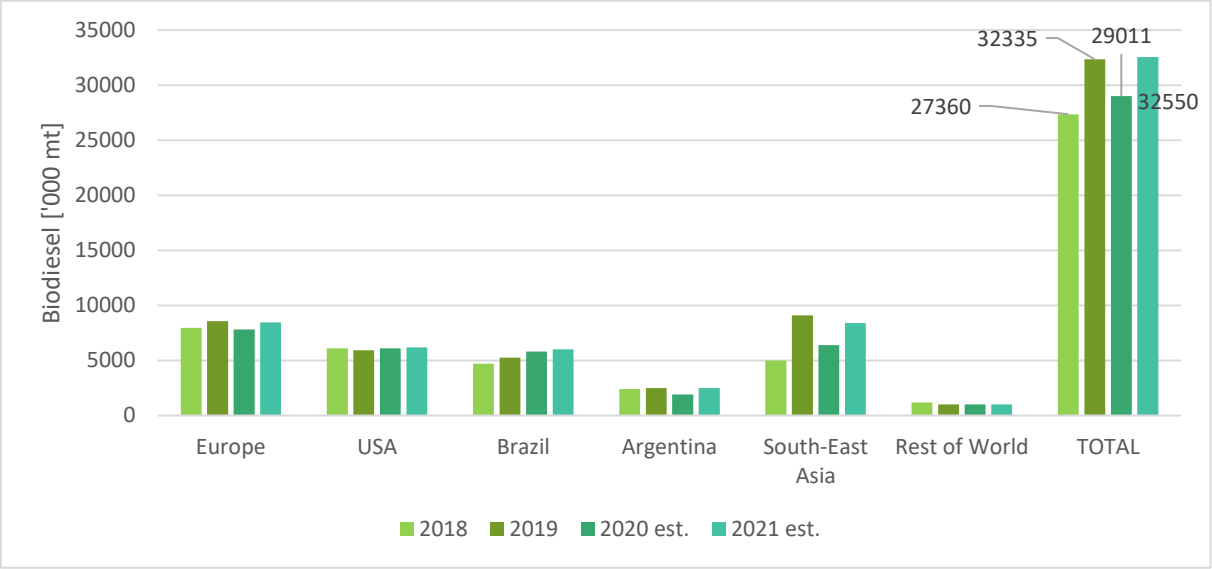

Figure 26: Biodiesel production, 2018 - 2021 est.

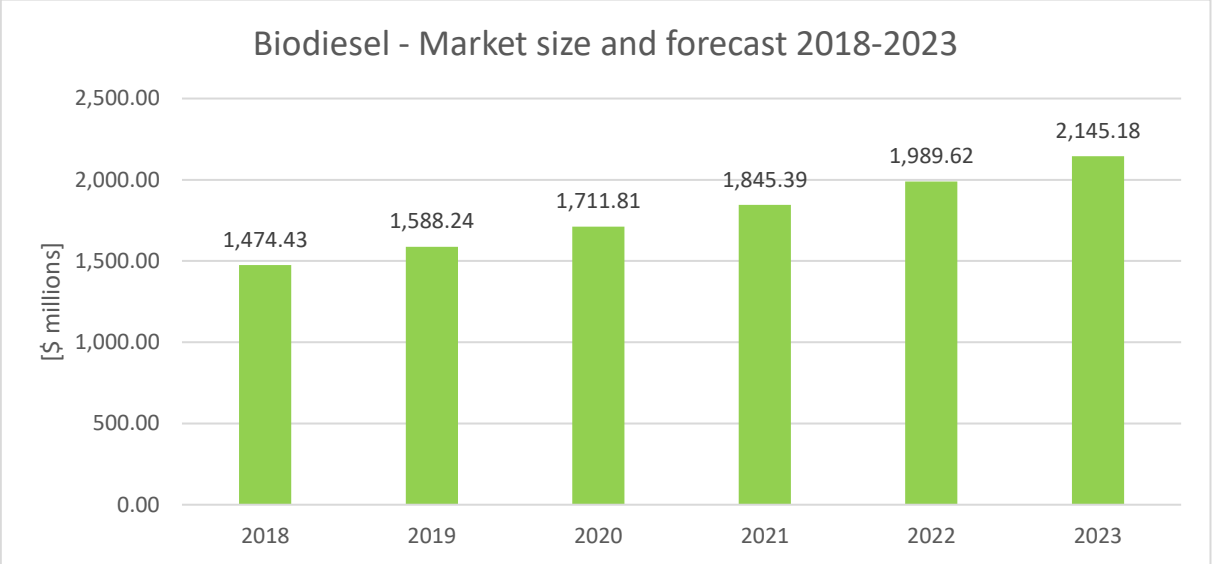

Figure 27: Forecast of the global biodiesel market size (2018-2023).

Since biodiesel is the most important factor for the availability and price of glycerol it is important to consider the forecasting volumes for the year 2021. As can be seen in Figure 26 the global biodiesel production had a significant decrease in the year 2020 due to the COVID-19 pandemic but will hopefully recover in 2021 due to immunology programs in many different countries.

This recovery will also supply additional volumes of glycerol and it is expected that global biodiesel production will reach a record amount of 32,550,000 tonnes offering an approximate amount of crude glycerol on the market of 3,550,000 tonnes with a share of 40% from Europe and the US.

5.3.2 GLOBAL GLYCEROL MARKET (2019-2023)

The effect the increase in biodiesel production has had on the global glycerol market can be seen in Figure 28. The global glycerol market size will have a value of 3,302.45 million USD by 2023 with an average CAGR of approximately 7.16%. It must be mentioned that this forecast has been conducted prior to the COVID-19 pandemic which does not take the adverse effects of the pandemic into account. Nevertheless, it is expected that the market progression will look similar once the pandemic situation has passed.

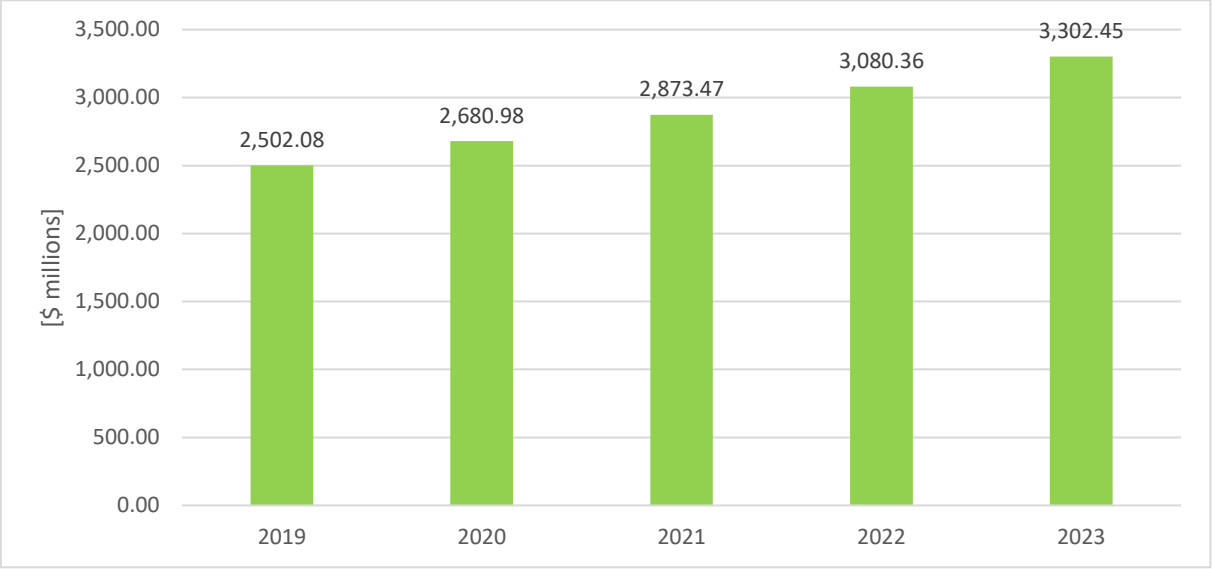

Figure 28: Forecast of the global glycerol market (2019-2023).

5.3.3 MARKET SHARE BY GEOGRAPHY (2018-2023)

The APAC (Asia-Pacific) area continued to dominate the market with a market share of 45.55% and it is estimated to have the highest growth compared to the EMEA (CAGR: 6.58%) and Americas (7.28%) markets with a CAGR of 7.52% in the period from 2018 – 2023. Within the APAC region China had the highest share with 22-24.5% followed by India with 6-7% while in the Americas region the US with 14-16% had the highest share and in the EMEA region Germany with 7-8%.

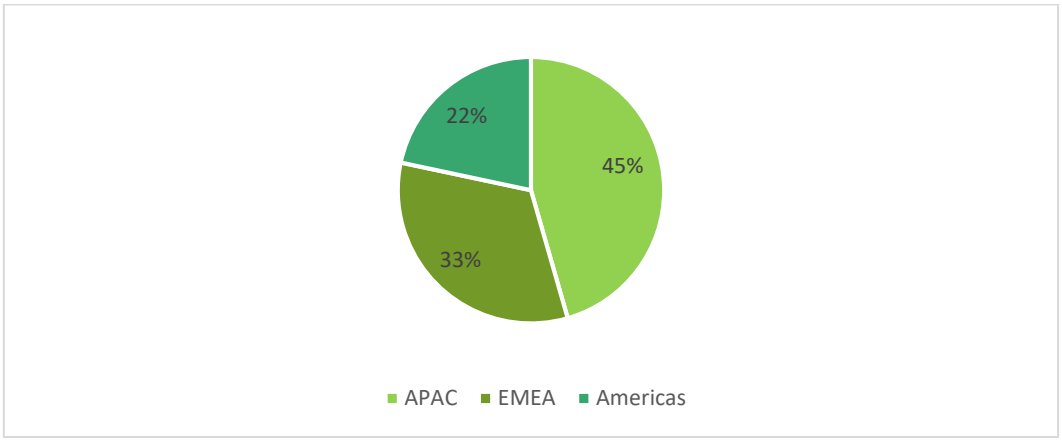

Figure 29: Market share by geography 2018.

Consequently, the APAC region will have the highest share for contribution to growth from 2018 – 2023 with a share of almost 50% compared to approximately 22% for Americas and approximately 30% for EMEA.

5.3.4 MARKET SHARE BY SOURCE (2018-2023)

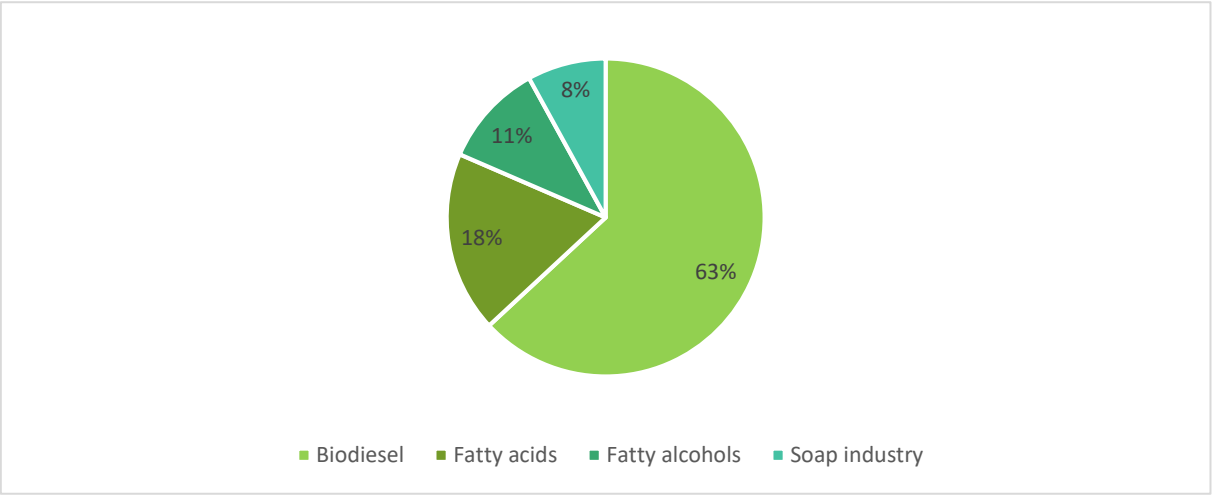

Figure 30: Market share by source 2018.

The majority of the glycerol was supplied by the biodiesel industry followed by the fatty acid industry, fatty alcohols industry and soap industry in 2018 as can be seen in Figure 30. It is estimated that this trend will continue, especially with mandates which dictate the increase of biodiesel share in diesel fuel. Indonesia had plans to increase the biodiesel share of transport fuel up to 30% but due to the situation mentioned in the previous chapter these plans have been suspended for now. biodiesel has also by far the highest CAGR with a value of 7.79%.

5.3.5 MARKET SEGMENTATION BY APPLICATION (2018-2023)

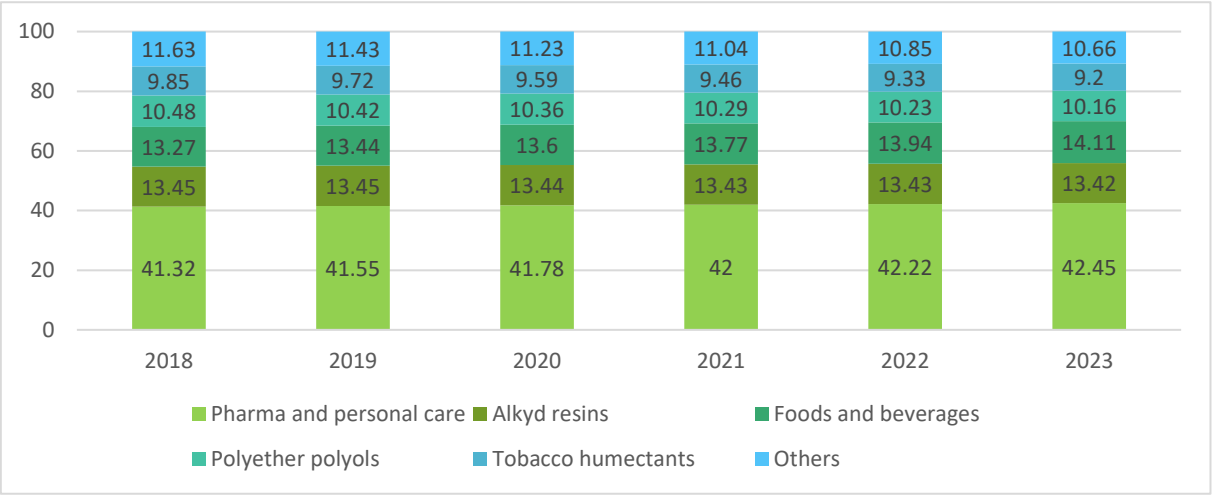

Figure 31: Application - Market share 2018-2023.

The market segmentation by application shows that the majority of glycerol is used for pharmaceutical and personal care uses. This trend will remain and even increase within the next few years, especially due to the COVID-19 crisis. It is estimated that this application area will increase by 1.13% by 2023. The only other application which will see a slight increase in share is the foods and beverages area with an increase of 0.84% until 2023. Every other area will see a decrease in the market share. Most likely, this is due to the shift to more price stable glycerol substitutes.

5.3.6 MARKET SEGMENTATION BY SOURCE (2018-2023)

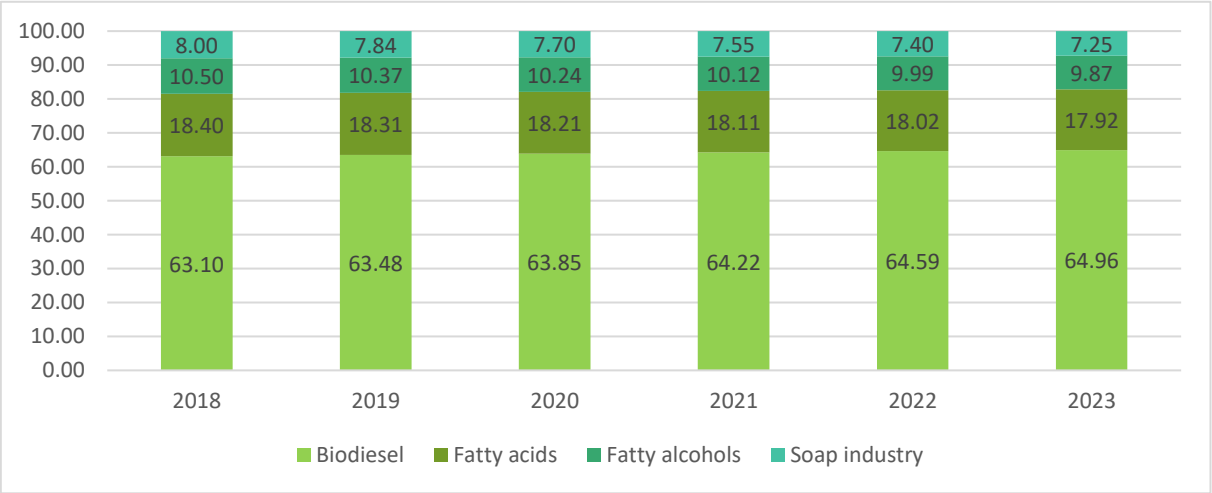

Figure 32: Market segmentation by source - 2018-2023.

It is estimated that the majority of glycerol is being produced by the biodiesel industry and this will continue. The share of glycerol coming from the biodiesel industry will even increase by the year 2023 by 1.86% while the shares from the fatty acid, fatty alcohol and soap industry will decrease albeit their industries will most likely increase due to the growing global population. About 810,000 tonnes of glycerol from vegetable- oils and around 150,000 tonnes of glycerol from UCOME and waste fatty acid biodiesel has been produced in Europe in 2015 while another 45,000 tonnes came from processing animal fats of category 1 and 2. Nevertheless, one must not neglect the fact that glycerol from the biodiesel industry is not as pure as from other industries. Crude glycerol obtained from waste-based biodiesel can only be used for technical purposes and cannot be refined to the stage of USP grade.

5.3 OTHER BIOGENIC FEEDSTOCKS

In terms of different biogenic feedstocks which could be used within the GLAMOUR process the most important factors are the availability and the price. Due to the low price of crude glycerol a competitive biogenic feedstock is considered interesting when a feedstock price of approximately below £300 per metric tonne is possible. In terms of availability there is a huge difference to glycerol. The supply of glycerol is mostly dependent on the biodiesel industry. Alternative biogenic feedstocks are coming from the food or waste or oleochemical industry which has a more steady and predictable availability.

The most interesting alternative feedstocks are Brown Grease (a mixture of oils, fats, solids and detergents from food wastes that are captured in grease traps), Tank bottoms (which are mainly residual waste fats from reactor bottoms in oleochemical processing) and FOGs (fats, oils and grease from the waste-water industry). In the following sections a closer look is taken to the prices and volumes of these feedstocks in historic terms and their suitability for the GLAMOUR process will be evaluated.

Brown grease consists mostly of fats, oils and grease (50-60 wt. %) from which approximately 80% is FFA, water (25-30 wt. %) and biosolids (15-20 wt. %) [7] while FOG and Tank Bottoms have a similar composition with less organics which makes them less valuable. Due to the fact that these feedstocks have no exchange, reliable market prices can't be determined. Nevertheless, as a company Argent Energy has the ability to purchase at specific prices which won't be disclosed due to confidentiality reasons.

Table 9: Price indices showing the volatility over the period of 2018-2021.

	Brown grease	FOG	Tank Bottoms
Year	**Index**	**Index**	**Index**
2018	100	-	-
2019	102	100	100
2020	112	153	-
2021	97	28	-

Hence, price indices are provided to show the volatility of the prices while the colour signals the costs compared to another. Red being the most expensive and green being less expensive. Brown grease is less volatile than FOG which can be seen at the index. The volumes purchased by Argent Energy seemed to be quite low in the past. Hence, it can't be concluded whether the prices will be the same if more is purchased. Comparing the prices with crude glycerol, the alternative biogenic feedstocks depict a viable source for the production of sustainable fuels. Especially, FOGs and Tank Bottoms are interesting due to their very low prices. Alone in the United States about 1,700,000 tons of brown grease is collected annually [7] while 2,2 billion litres of FOGs are produced solely in the United States making both reliable sources [8].

6. CONCLUSIONS AND OUTLOOK

Due to climate change and pressure from national governments, countries will increasingly implement measures to improve the sustainability and positive environmental impacts on society. Biofuels in general will play a major role in this transition from fossil-based industries to renewable industries.

As already mentioned above a strong increase in the production of biodiesel will most likely take place and the by-product glycerol production continues. Hence, the crude glycerol supply remains independent of the demand which has major impacts on the price consequently leading to a further decrease consequently.

A challenge the global glycerol market has, are the calls from the international community to stop using edible vegetable-based feedstock to produce biodiesel. Palm oil is an important feedstock for the production of biodiesel and its glycerol can be refined to kosher-grade glycerol. Palm oil producers have been criticised for destroying rainforests in order to create land for palm trees. Once international producers stop using vegetable oil for the production of biodiesel, they will need to shift to low priced waste-based feedstocks. These feedstocks are significantly more sustainable but the crude glycerol which is produced by these feedstocks differ and cannot be used for highly refined purposes but only for technical applications. This means that a future shift towards waste-based biodiesel will supply an excess of crude glycerol for technical applications and the amount of crude glycerol which can be used for USP grade will decrease significantly. Based on this fact it seems likely that the industry may shift again to synthetic glycerol for high end purposes. Hence, the number of synthetic glycerol processing plants can increase due to the increasing global population. The crude glycerol from waste-based feedstock will be a valuable and steadily increasingly available feedstock for technical applications. Currently, 2,000 possible applications are known and research is being undertaken to increase this number.

Another significant problem is the high price of edible vegetable oil feedstocks as well as of used cooking oil. In order to produce profitable biodiesel, producers will naturally shift towards more low-grade waste-based feedstocks. This will also add to the excess supply of crude glycerol making it a viable and reliable source for the GLAMOUR project in the future.

A different threat comes from HVO or renewable diesel which is being promoted by companies such as Neste [6. It has a higher energy density (44 MJ/kg) compared to FAME (37 MJ/kg) and less mass and volume is needed to fulfil a given biomandate when compared to FAME [7]. The problem with HVO is that no by-product-glycerol is being produced as a by-product in this process. If the biodiesel mandates are not increased in the future, it is possible that some market share will migrate to HVO which will cut some of the excess supply of crude glycerol. This can lead to a price increase of crude glycerol. Nevertheless, it remains questionable whether HVO will establish itself in the market and threaten the position of biodiesel and consequently lead to a diminished supply of crude glycerol.
If by-product glycerol volumes should decrease in the future alternative biogenic sources are available to be used in the process. Whether they can be used directly as feedstock remains questionable due to their high amount of FFAs. Most likely a pre-treatment step such as with crude glycerol must take place to make these feedstocks a viable alternative for the GLAMOUR process.

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