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Market Perspectives for Products from Future Energy-Driven Biorefineries by 2020

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PREFACE

Produced within the framework of the JRC Biofuel Thematic Programme, this study aims to identify promising market opportunities and penetration strategies for products from future energy-oriented biorefineries in Europe by 2020. In view of the immature status of energy biorefinery technologies and concepts, the analysis mostly sketches qualitative perspectives, but it does not make detailed quantitative projections. Since currently considered energy biorefineries concentrate on bioethanol-side streams, the focus of the analysis is on ethanol-related technologies, pathways and products.

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Bibliographical references for literature or other sources where more information can be found on a given subject are given in square brackets []. For the sake of simplicity, these references are numbered, although the data and information sources themselves are listed in alphabetical order.

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EXECUTIVE SUMMARY

Unlike other industrial sectors, the transport sector is almost fully dependent on oil-derived fuels. Transport is also the only sector that did not reduce its greenhouse gas emissions since 1990. The security and diversity of energy supply for transport in an environmentally-friendly way is a key challenge for the EU policy-makers. Biofuels alleviate partially these problems, but current biofuel production is not as efficient as oil refining. The recently emerged bio-refinery approach that aims to optimise the energy, environmental and monetary cost of a portfolio of fuels and products (similar to oil refineries) is hoped to be able to overcome the drawbacks of current biofuels. The goal of this study is to identify promising market opportunities and penetration strategies for fuels for transport and other energy products from future energy-oriented biorefineries in the EU by 2020.

The fuel market in the EU and in the world is characterised with faster growth in diesel and middle distillates demand and lower (negative in the EU) growth in the demand for petrol and heavy fractions. Because of techno-economic constraints, oil refineries are not able to boost infinitely the diesel and middle distillates fraction at the expense of all other fractions. The sufficient supply of diesel and middle distillates with required qualities and consequently, the sustainability of fuel supply / demand balance both in the EU and worldwide is becoming a growing problem. The search for novel transport fuels should therefore focus on finding appropriate diesel and middle distillates additives or substitutes.

There are two main pathways to energy biorefineries – biochemical and thermo-chemical. The key fuel derivative of the biochemical route is ethanol. Ethanol can be blended with petrol, but this would not ease the EU's fuel balance, as it would increase petrol surplus, but it would not reduce gross crude oil imports. Ethanol blends with diesel would fit better the EU fuel mix, but they still face important technical and technological challenges. Other energy biochemical concepts include combined manufacturing of: acetone-butanol-ethanol, ethanol-furfural, as well as ethanol-solid biofuel (pellets). None of these concepts, however, offers great potential to lessen the pressure on EU's fuel balance by 2020.

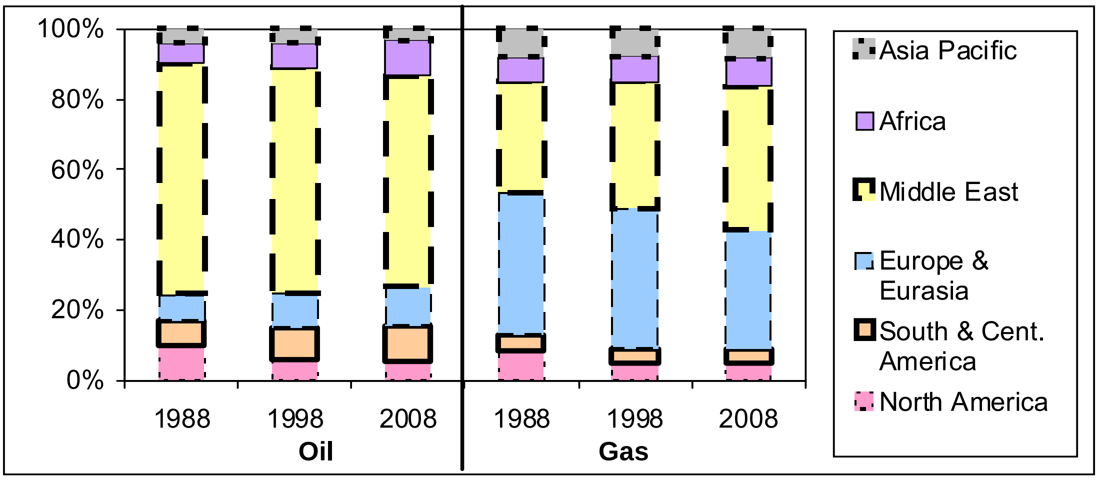
The thermochemical pathway could possibly provide a better response to market needs because its key derivatives – biomass-to-liquid (BTL) diesel and middle distillates – exhibit similar and even superior qualities than oil-based diesel. Other thermochemical products that may have fuel or energy application (though with much smaller potential) are methanol, di-methyl-ether and hydrogen. Nonetheless, similar to biochemical pathways, thermochemical pathways are still facing a number of techno-economic challenges, some of which have been researched for decades. To reach market-scale application, energy biorefinery technologies and products therefore need additional and continuous research efforts and funding.

In view of the immaturity of energy biorefinery technologies, a more conservative evolution-based approach for their development seems more appropriate rather than a more aggressive, revolution-based approach that aims at step changes within short time. Energy biorefineries should focus on a limited number of fuels and energy products. The aim to have a combined portfolio of fuels and chemicals might provoke tension with far more mature chemical bio-refineries and excessive market cost. The utilisation of biomass residues from primary fuel/s production for generation of power and/or heat in particular, should precede expansion towards other derivatives. The outlook for integration opportunities and synergy options between energy biorefineries and conventional oil refineries by 2020 is bleak.

1. BACKGROUND

The sharp increase in energy prices in 2008 and the temporary cutbacks in supplies of natural gas from Russia over the past few years have heightened EU concerns about the security, diversity, reliability and affordability of energy supply. The EU is particularly vulnerable to such developments, as it holds less than 1% and 2% of world oil and gas reserves respectively [2], while its share in world gross energy consumption is 17% for oil and 18% for gas [14]. In addition, the EU's indigenous production of oil and gas is stagnating and set to decline, while consumption is on the rise and will most likely keep growing in the next 10-20 years. The widening gap between production and consumption is covered by increasing imports from a small number of countries. To make matters worse, the geopolitical breakdown of world gas reserves is coming more and more to resemble that of oil reserves. Most new discoveries of economically exploitable natural gas over the past two decades have been in the Middle East – ***Figure 1***.

Figure 1: *Breakdown of world oil and gas reserves in 1988, 1998 and 2008[1] (%)*



Source: Adapted from [2]

Another challenge that Europe is facing today is Climate Change, caused by greenhouse gas (GHG) emissions, primarily those of carbon dioxide (CO_2). Under the Kyoto Protocol, the EU has committed to reduce its 1990 GHG emissions by 8% within 2008-2012. With current trends and applying all Kyoto Protocol tools, EU-15[2] is likely to meet its commitment [16]. In order to prevent the adverse impacts of Climate Change, the EU has set up a more ambitious goal for 20-30% cut of GHG emissions by 2020. The use of fuels with lower CO_2 footprint, such as renewables, is a way to further reduce net GHG releases to the atmosphere.

Amongst various sectors, the transport sector presents a particular challenge as it almost fully depends on oil-derived fuels. The transport energy consumption has been on a steady rise since 1990, despite various energy-saving measures taken at European and member states level. The transport sector has also been the only sector in the EU that did not show any improvement in its GHG performance since 1990.

Altogether, these facts and trends are exerting growing pressure on the EU – a pressure that extends well beyond the field of energy, transport and the

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[1] The Former Soviet Union, in particular Russia, holds the vast majority of oil and gas reserves in Europe / Eurasia.

[2] The commitments under Kyoto Protocol are binding only for the 15 EU member states before 01.05.2004.

environment. EU policy-makers are thus considering various alleviating measures, including the use of alternative (new and renewable) energy sources, in particular in the transport sector [20]. The production and use of biofuels for transport, as an alternative to oil-derived fuels, already takes place in almost all EU member states and the share of biofuels in EU's automotive fuel market reached 2.7% in 2007 [11]. The production of biofuels, however, is not yet as efficient as the production of conventional transport fuels in oil refineries. Biofuel manufacturers are therefore looking for options to increase the overall energy and environmental efficiency of the production process and hence, to improve the cost competitiveness of biofuels versus oil derivatives. As a result, the biorefinery approach (inspired by conventional oil refineries) that aims to optimise the overall product output has recently emerged. Although still at initial stage of development, the biorefinery concept *for the energy sector* (hereinafter called <u>energy biorefineries</u>) is gaining increasing interest and support worldwide.

While other research works look at various technical, technological and economic aspects of biorefineries, this study aims to identify promising market opportunities and penetration strategies for products from the upcoming energy biorefineries. The subsequent analysis is based on the following preliminary conditions and limitations:

- Sector / product scopes: The analysis focuses on biorefinery market strategies that are relevant to the energy sector. Market perspectives of bio-based products from the chemical industry (hereinafter called "chemical biorefineries") are not considered in the study. Unlike energy biorefineries that are still at the initial stage of development, biotechnologies in the chemical industry, e.g. for production of food additives, pharmaceuticals, pulp & paper, are mature and competitive to the fossil-derived alternatives. Detailed projections about market perspectives of chemical biorefinery products can be found in other national and European studies [3, 8, 44, 45, 46, 47, 48]. Some chemical products that could be obtained as side streams to the main energy product streams are, however, included in the analysis.
- Perspectives versus projections: Owing to the immature status of energy biorefineries, this study aims to sketch some *qualitative perspectives* for market realisation of energy biorefinery products, rather than to make concrete *quantitative projections*.
- Technical and technological aspects: The analysis is discharged as much as possible from technical and technological aspects of energy biorefinery products and manufacturing processes. A great deal of relevant technical data, information and analysis can be found in other studies with a clear technical focus.
- Geographical scope: Although the study aims to encompass potential trends and developments worldwide, the study has a clear European focus. The market perspectives are therefore estimated based on the European specifics and realities.
- Time horizon: The time horizon of the analysis is limited to 2020. Making longer-term estimates (beyond 2020) appears extremely challenging and could even be misleading, in view of the large number of techno-economic and regulatory uncertainties.

2. MAIN MARKET TRENDS OF REFINERY PRODUCTS IN EUROPE

In order to sketch prospective market niches for energy biorefineries, first it is necessary to identify the main trends in demand and supply of fuels from conventional oil refineries.

The key customer of refineries is the transport sector, which absorbs ≈60% of their output [4]. It is therefore of primary significance to track and analyse the developments in the transport fuel demand. The importance of the transport sector is further highlighted by the prevailing lack of competitive fuel alternatives or substitutes at a large scale. Conversely, most non-transport applications of refinery derivatives (e.g. naphtha, heating oil) do have competitive production trains or product equivalents based mostly on natural gas processing.

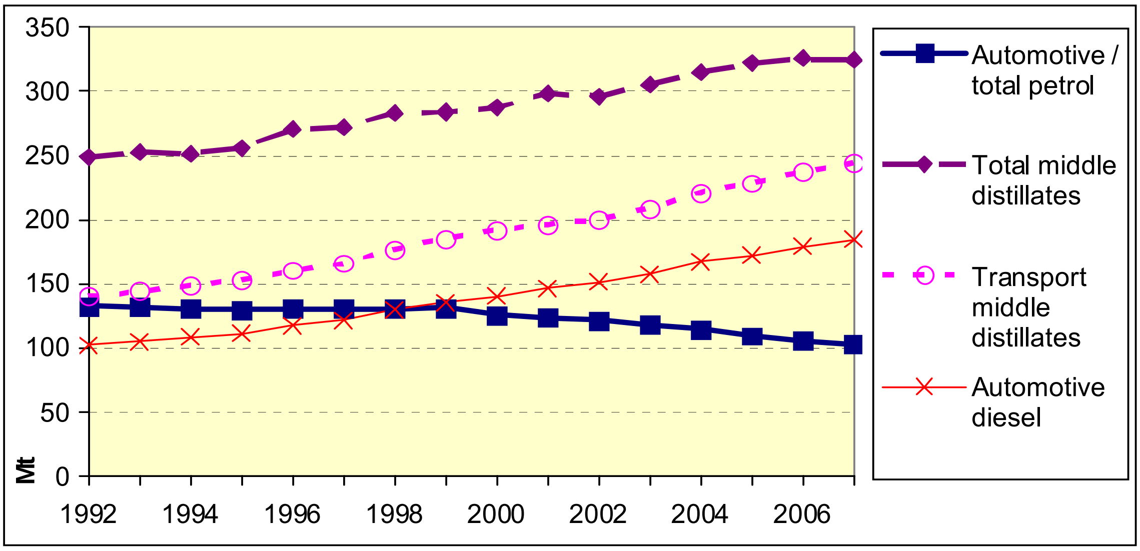
Road transport is by far the largest consumer of energy amongst transport modes, responsible for ≈82% of final energy demand in EU transport [14]. Road transport is also almost fully dependent upon oil derivatives, primarily petrol and diesel. The fuel consumption patterns in the automotive sector in reality define the supply profile of European refineries especially in view that road transport alone takes up more than half of the refinery output [4].

For various reasons – automotive CO_2 emission commitments / regulations [22] at EU level, technology progress and performance [33], etc. the number of diesel-powered motor vehicles has experienced a sustained growth since mid 1990's. This has been primarily due to the growth in passenger cars – the largest (≈80% of all vehicles [14]) automotive segment. The share of newly registered diesel passenger cars in all newly registered passenger cars in EU-15 gradually increased from less than a quarter in mid 1990s' to more than half in 2007 [10]. This shift in the balance between petrol and diesel cars has had a strong impact on the auto-motive fuel market. By the end of 1990's, the automotive consumption of diesel in the EU surpassed that of petrol. Since then, petrol demand (which is almost completely driven by the transport sector) has been in decline, while diesel demand has been on the rise – ***Figure 2***. Further pressure has been experienced by the booming air traffic, as modern planes use jet fuel that is a mixture of kerosenes – also a middle distillate oil fraction. Last, but not least, while petrol has basically just a single application as a fuel for road transport, middle distillates also have non-transport uses, e.g. light heating oil is employed as back-up fuel in gas-fired turbines in power generation facilities.

Altogether, the above factors put an enormous challenge on oil refineries in the EU to provide adequate supply of fuels. So far, they were trying to meet the growing diesel and middle distillates demand by expanding diesel & middle distillates fraction, at the expense of the petrol fraction, and optimising the utilisation rate of refining capacities. With an utilisation rate of more than 90%, the reserves from the latter component have been almost fully exploited. As regards the former element, the EU has been gradually expanding diesel & middle distillates yield at the expense of petrol yield. As a result, Europe currently has the largest diesel & middle distillates fraction in the world – ***Figure 3***.

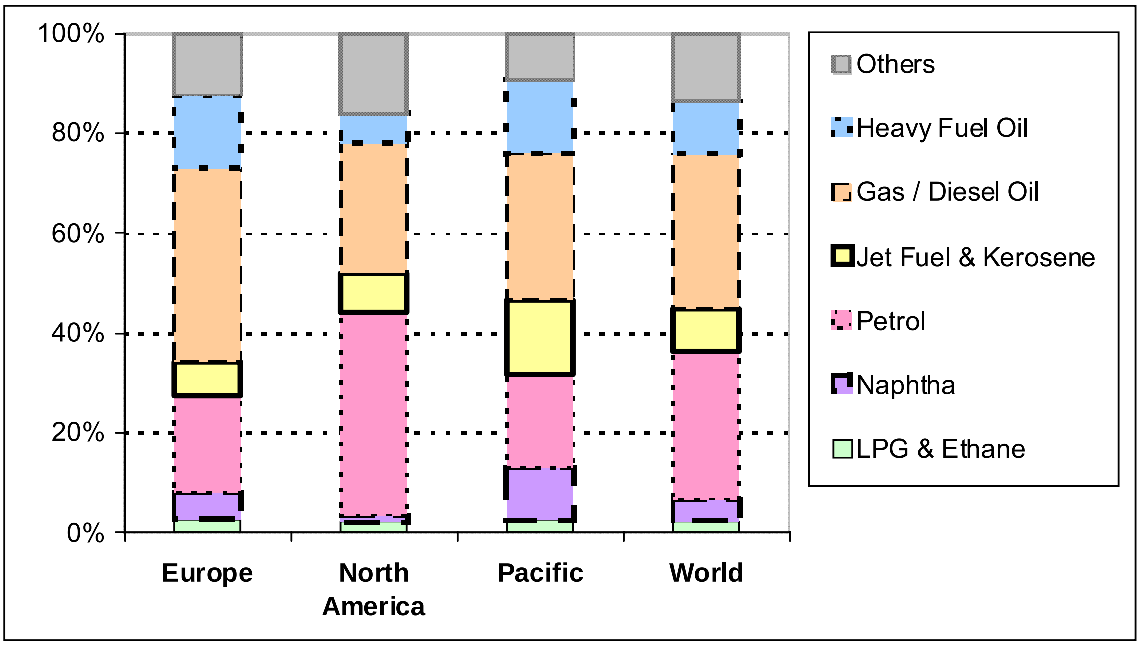
There is, however, an upper limit to the economically reasonable expansion of the diesel & middle distillates fraction. The optimal refinery output breakdown by fractions, achieved at minimum energy, environmental and monetary cost, is technologically determined to a large extent. It may vary within relatively narrow

Figure 2: *Total consumption of petrol and of middle distillates (jet fuel, diesel, light heating oil), middle distillates (jet fuel and diesel) consumption in transport and automotive diesel consumption in EU-27 within 1992-2007, (Mt)*



Source: Adapted from [7]

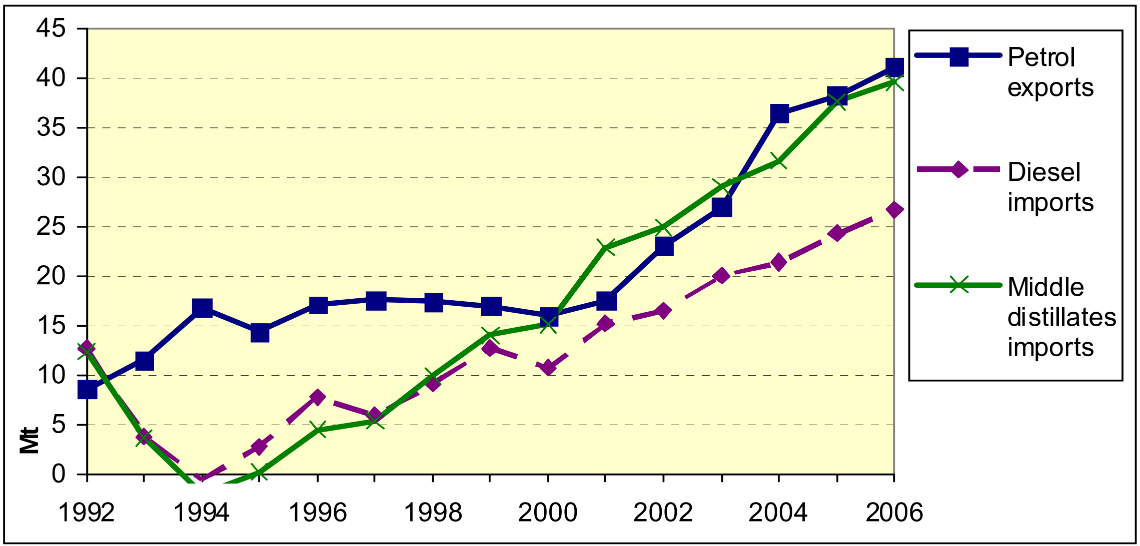
Figure 3: *Refinery gross output in OECD regions in 2008, (%)*



Source: Adapted from [29]

margins, depending on the specifications of oil feedstocks. The refinery output can be optimised towards enlarging a certain fraction, but only to a given extent. Beyond this extent, any further expansion of that fraction at the expense of another fraction (petrol-to-diesel conversion in Europe) results in prohibitively high energy, emissions and monetary costs. The recent data about energy, environmental and monetary cost of producing diesel and petrol in the EU suggest that the reasonable upper limit of this petrol-to-diesel conversion has either been already reached, or (in the best case) it is about to be achieved. The growing imbalance in fuel demand has to be covered with growing diesel / middle imports and growing petrol exports, as there is not enough demand within the EU for the obtained, actually as a by-product, petrol – ***Figure 4***.

Figure 4: *Net export of petrol and net import of diesel and jet fuel from/to EU-27 within 1992-2006, (Mt)*



Source: Adapted from [7]

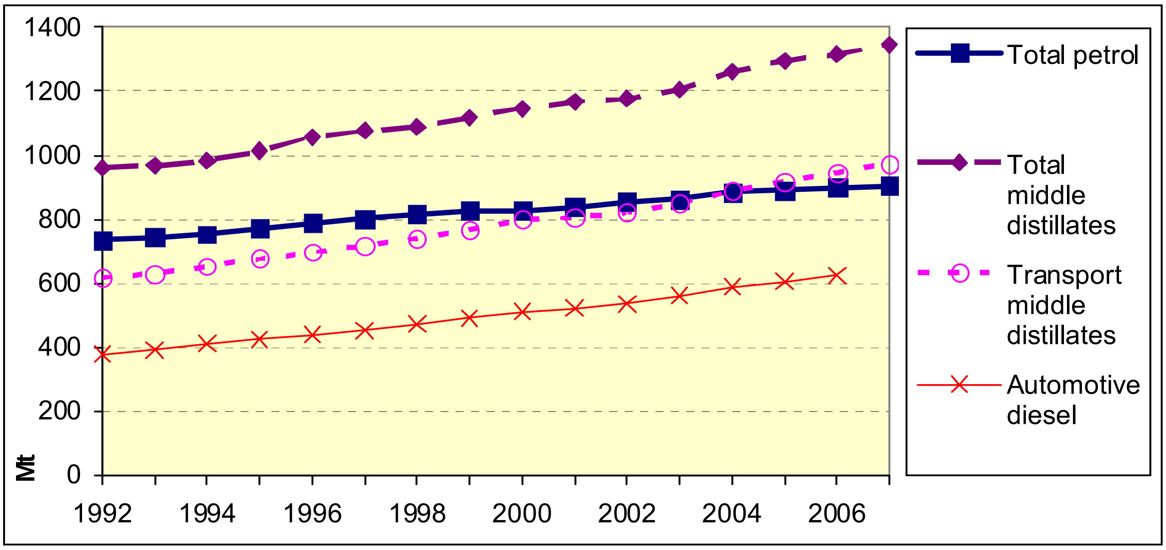
The EU foreign exchange in diesel / middle distillates and petrol is not balanced across the regions. The EU exports petrol mainly to the USA, while the imports of diesel come mostly from the FSU. This fuel exchange scheme does *not* reduce the overall import dependence of the EU on crude oil, as refineries still need to buy virtually the same amount of feedstock to produce diesel and middle distillates. Nonetheless, the fuel exchange scheme can still work if in the world fuel market there is enough demand for petrol and sufficient supply of diesel that meets EU's fuel quality standards. The prospects however look slightly gloomy at least for three reasons:

✓ Europe seems to be not the only region in the world that embarked on diesel. Over the past few years, diesel also started to penetrate the USA automotive market for light-duty vehicles and passenger cars. The fast-growing aviation sector is also contributing to increased demand for transport middle distillates worldwide. All in all, global demand for diesel / middle distillates in transport grows faster than global transport demand for petrol. The most obvious consequence of this trend was that in 2004 world middle distillates demand for transport exceeded that of petrol – ***Figure 5***.

✓ With fuel quality standards progressively tightening in the EU [12, 18, 19, 21] and most developed economies around the world (e.g. USA), the hunger for high-quality diesel and middle distillates is leading to a severe mismatch in supply and demand. Some traditional suppliers might not be able to meet the more stringent fuel quality standards any longer, because of outdated refinery facilities or technologies.

✓ The competition amongst suppliers of petrol to the USA is forecast to tighten owing to the new refining capacity expected to come on-stream by 2020 in the Middle East and India. Combined with the expected larger use of biofuels (bioethanol) as petrol blending component and the addition of some indigenous conversion capacity, by 2020 the US market may need smaller petrol imports than today [39].

Figure 5: *Total consumption of petrol and middle distillates, middle distillates consumption in transport, automotive diesel consumption in the world within 1992-2007, (Mt)*



Source: Adapted from [7]

Summing up the above facts and trends, the following market requirements emerge versus the substitutes or blending agents of oil refining derivates:

- One needs to find new / advanced fuels that complement and/or substitute diesel / middle distillate fuels in transport.
- These new / advanced fuels should meet the fuel quality regulations in the EU, or at least they should not deviate too much from the margins set up therein.
- To gain a market-relevant share in the automotive fuel market, these new / advanced fuels should be compatible with current and forthcoming vehicle powertrain systems. Fuels are typically produced to fit given engines but not the other way round.
- These new / advanced fuels should benefit as much as possible from the already available fuel logistics and distribution infrastructure. Building dedicated logistics and distribution infrastructure will always involve huge investment and time lag. The related cumulative cost will most likely make marketing of such novel fuels uncompetitive at least in the foreseeable future, but in any case – by the time horizon of the present study (2020).

3. ENERGY BIOREFINERIES – MAIN POINTS FOR CONSIDERATION AND CHALLENGES AHEAD

When considering energy biorefineries and their market perspectives, one has always to keep in mind that the whole biorefinery concept for the energy sector is still quite new, especially in Europe. A few years ago, the notion "biorefinery" with respect to energy was popular only in the USA. There, it was (and still it is) used to describe primarily advanced bioethanol facilities that employ ligno-cellulose biomass as feedstock along with some kind of co-generation of power and/or heat, i.e. process heat integration. Recently, the term (energy) "biorefinery" became popular in Europe and elsewhere, e.g. in the Far East, Brazil. However, a common understanding of what exactly is a (energy) biorefinery is still missing. One of the main goals of the currently on-going Task 42 of the Bioenergy Implementing Agreement of the International Energy Agency is to set up a common definition of biorefineries. Nonetheless, the forthcoming conclusions of Task 42 will be just recommendations, without any binding power, so there will still be plenty of room for interpretations. The lack of EU's broad legislative definition of energy biorefineries makes difficult the uniform understanding of the notion "biorefinery" even within the EU.

Another problem of biorefinery understanding from a *market* point of view today is that *all* energy biorefinery concepts are still at the research and development stage, not even at a demonstration stage. Although there is already some kind of *scientific* classification of energy biorefinery concepts, this categorisation is not sufficient to define credible biorefinery alternatives from a *market* point of view. The number and gravity of basic technological and techno-economic uncertainties at all stages of biorefinery processing (from biomass pre-treatment to end-products) is so great that at present nobody can actually claim which pathways and products will reach industrial maturity. Although over the past few years, significant research and technological breakthroughs have been achieved, there are still many challenges that are still awaiting solution. Some of those challenges have been researched for decades, but without substantial progress. The success or failure to resolve some or even all of those major and long-standing technological and techno-economic challenges in a *realistic* time perspective will play a critical role for the trends and development of energy biorefinery concepts in the future. Obviously, at present it is not possible to judge what bottlenecks will be eventually arise. Thus, it is extremely important to understand the difference between *scientific* and *market* understanding of biorefinery challenges and their solutions. Very often, some results or solutions may be well acceptable from the scientific point of view, but this does not necessarily mean that they would be acceptable also from the business point of view. In order to achieve satisfactory progress, both scientific and business views should go hand in hand, i.e. the improvement of technologies should be linked to what the market asks for and vice-versa. Anyhow, there is little business reason to project how much will be sold of a certain product if its manufacturing faces major and/or long-standing techno-economic challenges and/or there is negligible or simply no demand for that product at present or in the foreseeable future.

While energy biotechologies are immature, biotechnologies used in a number of other industries, e.g. food, pharmaceutical, pulp and paper, chemical, etc. have been developed over decades and are fully competitive with alternative production pathways that are based on fossil feedstocks. Some energy biorefinery concepts, quoted in purely scientific literature, assume a portfolio of products that includes a number of chemicals, along primary energy derivatives. Some concepts go even further by placing the emphasis on chemical products, moving away from the (presumably, primary) energy derivatives, replicating in one way or another chemical biorefineries. While such approaches could be interesting from a research point of view, their business realisation in practice will most likely prove to be difficult for several reasons:

- Trying to copy-paste the achievements of the chemical industry will most likely bring no benefits to the energy sector. In such a hypothetical situation, the energy / oil companies will be forced to enter new and largely unknown fields of competition with the chemical industry. Such aggressive strategies typically bring tension that sometimes may evolve into trade wars. The associated total entry cost for the invaders is high by definition. Finally, such incursions may be prevented by various market imperfections (e.g. exclusive patent rights), as well as by competition regulations at EU level.
- The energy / oil sector is much bigger in terms of business activity, turnover and market capitalisation than the chemical sector. The marginal benefits of entering and conquering such small (as per energy / oil sector's criteria) niche market/s might be quite poor, with rather unfavourable cost-to-benefit ratio.
- The markets for many chemical products are organised differently than traditional energy / oil-derivatives markets. While most energy / oil products are traded as commodities and the associated risks can be hedged by exchange tools and mechanisms, this is not the case for the large majority of chemicals. This fact would require developing a totally different sales culture and expertise inside energy / oil companies when moving to various chemical markets.
- The drivers to search for alternative resources are not really the same for the chemical and the energy / oil sectors. While the primary driver for the chemical sector is the reduction of feedstock cost and thus, production costs of chemicals, for the refining industry a high oil price is not a problem but rather an advantage.

With regard to the above analysis, a false belief about promising market perspectives for biorefinery products in the market segment of low-volume high-value specialised chemicals is sometimes encountered in purely scientific literature. In economic terms, the combination of "low-volume" and "high-value" products implies low market capacity and/or high production costs and/or market imperfections, such as naturally or intentionally imposed monopolies or oligopolies, including patent restrictions. In any case, in order to be profitable, such low-volume market segments are peculiar with high profit margins. They tend to be very specific, having particular behaviour, trends… and limited number of participants. The possibilities for new entrants are extremely restricted. The competition in such market segments is typically fierce and the competition advantages are not always confined to simple cost / price co-relations. If the future energy biorefineries decide to invade such markets for low-volume high-value products, they have to expect severe opposition from the existing market players. If the new entrants still manage to enter and boost supply, prices and profits are likely to fall, as this is not going to be a *low-volume* market any longer.

Although energy biorefineries are often perceived as conventional oil refineries but run on biomass, it may be challenging to achieve such a straight replication in reality because of scale restrictions. It is true that conventional oil refineries, although concentrating on transport fuels, have a very broad portfolio of products. This variety of products is, however, due to two reasons, which most likely will not be applicable to the future energy biorefineries:

- Crude oil is typically found in large single accumulations (fields). It can be therefore extracted with significant economies of scale. Crude oil can be also delivered at low cost and in huge quantities from remote locations by large see tankers. Conversely, biomass resource is dispersed by definition. Because of the much poorer energy density, bringing untreated biomass from remote locations is associated with excessive logistics costs. Converting biomass into semi-finished feedstock with higher energy density (biomass pre-treatment) can be an option, but then other incremental costs, linked to the pre-treatment, are incurred. For this reason, with the exception of some very specific cases, it is unlikely that energy biorefineries will ever approach the scale of conventional oil refineries. This fact implies lower potential for economies of scale for bio-facilities. They will have to find alternative ways to stay profitable and competitive. Thus, energy biorefineries will most likely have to focus on a smaller portfolio of derivatives than conventional oil refineries in order to achieve acceptable cost / benefit performance.
- Because of crude oil properties and specifics, the efficient oil refining process, i.e. the so-called natural refinery breakdown, results in a range of products. As already discussed, an oil refinery may in theory generate one or two products only by converting all the other fractions. Such a conversion, however, will always result in prohibitive manufacturing costs that make such a concept economically unfeasible. Conversely, currently considered technologies for energy biorefineries are capable of limiting the number of semi-finished and end-products to a much lower number.

The almost mandatory proximity of feedstock to the biorefinery site and the smaller scale of manufacturing suggest that the concept for de-centralised energy biorefineries may be viable. The product design of such energy biorefineries could be tuned on a case-by-case basis to the specifics of local and regional fuel demand. The de-centralised approach, along with the smaller scale, might also offer good opportunities for useful utilisation of the by-product heat. The incorporation of generation of electricity to be used on and/or nearby the site should not be ruled out either, because of the savings from building expensive transmission infrastructure to remote areas. Some secondary benefits that de-centralised energy biorefineries might bring about should also be taken into account – green image, self-energy sufficiency at local and regional level, boost to local employment, rural and regional development, optimised utilisation of biomass residues from other activities, etc.

The above analysis indicates that the right and safe market strategy for energy biorefineries seems to be finding its own niche market, building upon the already developed and available in-house expertise and experience. In this context, a conservative (evolutionary, lower risk) approach, rather than an aggressive (revolutionary, higher risk) approach, might prove to be more fruitful. The proposed approach is sketched in ***Figure 6***.

The starting point and mandatory pre-condition in the conservative approach is to have *high-quality* (at least with some degree of maturity) products to be offered. Initially, one can try to expand the use of those products in currently available markets (**Box 1** in ***Figure 6***), at the same time looking for new opportunities, such as new applications, other geographical areas, (**Box 2** in ***Figure 6***) etc. Upon improving (maturing) this starting marketing system, one can try to diversify by introducing new products that have been developed in the meantime, to the already developed and researched markets (**Box 3** in ***Figure 6***). As a last step in that strategy, one can try to find new applications for the so-developed new products (**Box 4** in ***Figure 6***). It is important to note that the so-described

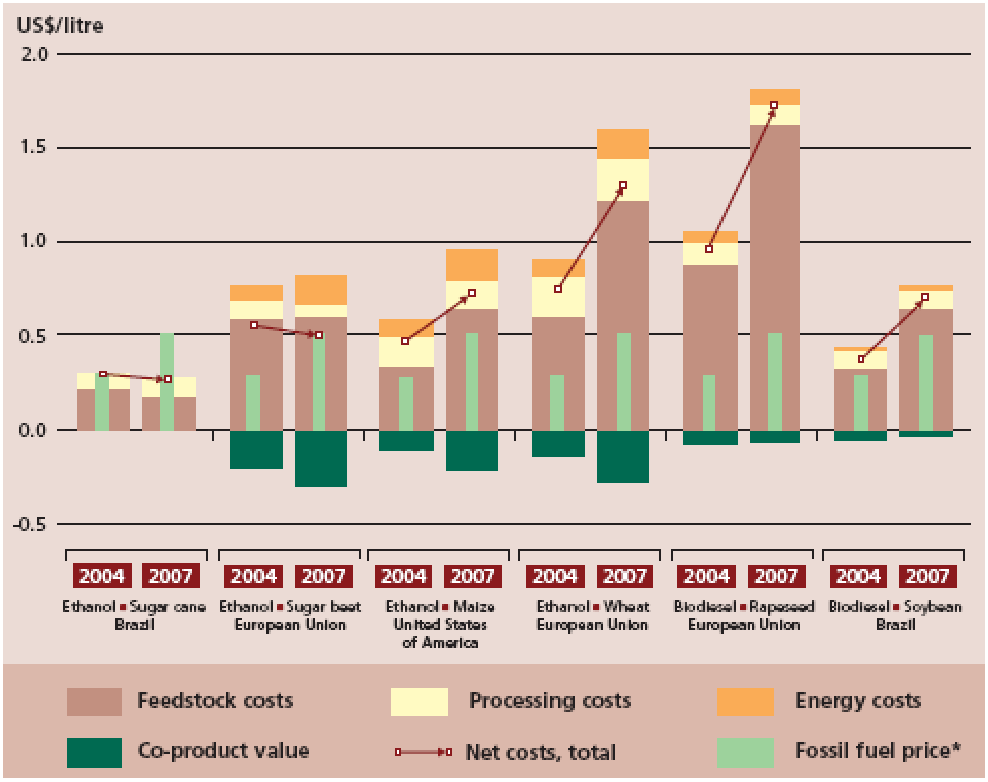
Figure 6: General market penetration strategies

MARKET STRATEGIES	Existing Markets	New Markets
Existing Products	1	2
New Products	3	4

market implementation strategy may not necessarily develop through all four stages in ***Figure 6***. It might reveal more appropriate to limit the development / expansion to e.g. **Box 2** or **Box 3**. Of course, the strategic market analysis of certain products may conclude that it is better not to diversify at all, i.e. not to go beyond **Box 1**, or even to completely skip the market (not to consider the alternatives from ***Figure 6*** at all). That means that although some pathways may look attractive from technical point of view, this may not be the case from an economic point of view.

As an illustration of the importance to strictly follow such a conservative, but pragmatic strategy, ***Figure 7*** shows that even the starting point of energy biorefineries – the production of biofuels that has already reached certain maturity – is generally not competitive on equal footing with conventional fossil fuels.

Figure 7: *Biofuel production costs in selected countries, 2004 and 2007*



Source: [24]

To summarise this Chapter, ***Figure 8*** recapitulates strengths, weaknesses, opportunities and threats of future energy biorefineries.

***Figure 8**: SWOT analysis of energy biorefineries*

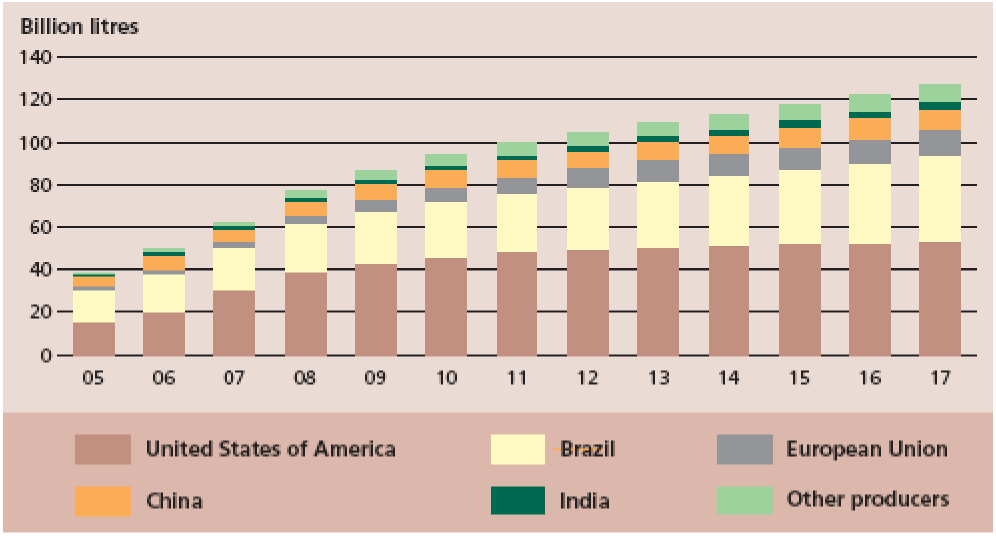
STRENGTHS	WEAKNESSES
✓ Political will and declared support at EU and global level ✓ A topical issue (security of supply) ✓ Building upon existing technologies and approaches, and on market necessities (cleaner fuels with superior engine performance characteristics)	✓ Currently almost non-existing – immature concepts, too may uncertainties of all kinds ✓ Not attractive at relatively low price of fossil fuel resources (oil, gas, coal) ✓ Generally not competitive to the principal fossil fuel analogues
OPPORTUNITIES	**THREATS**
✓ The "green" wave around the world ✓ Provide products with superior qualities than current / conventional analogues ✓ Concerns about security and diversity of supply of resources, and of climate change externalities ✓ Boost for national economies – local production (instead of out-flow of national treasure for fossil fuel imports), regional and rural development	✓ High level of uncertainty ✓ The needed and expected technological progress not to materialise in the desirable / foreseen timeframe ✓ Fierce competition for resources and markets with chemical biorefineries and other biomass and bioenergy applications ✓ Fierce competition for markets with traditional energy, fuel and chemical industries

4. INDICATIVE PRODUCTS FROM BIOCHEMICAL PROCESSING

When considering energy products obtained via biochemical processes, ethanol appears by far the main, if not the only derivative that is considered today. This is because ethanol seems to be the only biochemical derivative that has already gathered some market experience as a fuel component / additive to petrol. Often, especially in the USA, energy biorefineries are associated with advanced ethanol production from ligno-cellulosic feedstock. Already for quite a few years the USA has been adding ethanol to petrol. Novel production technologies for ethanol, earning larger yield at lower cost, have been thoroughly researched and developed in the USA. The product scope of energy biotechnologies was broadened only recently.

The largest producers and consumers of fuel ethanol worldwide are Brazil and the USA (***Figure 9***), which account for about 70% of both world supply and demand [7, 35].

Figure 9: *Major ethanol producers with projections to 2017*



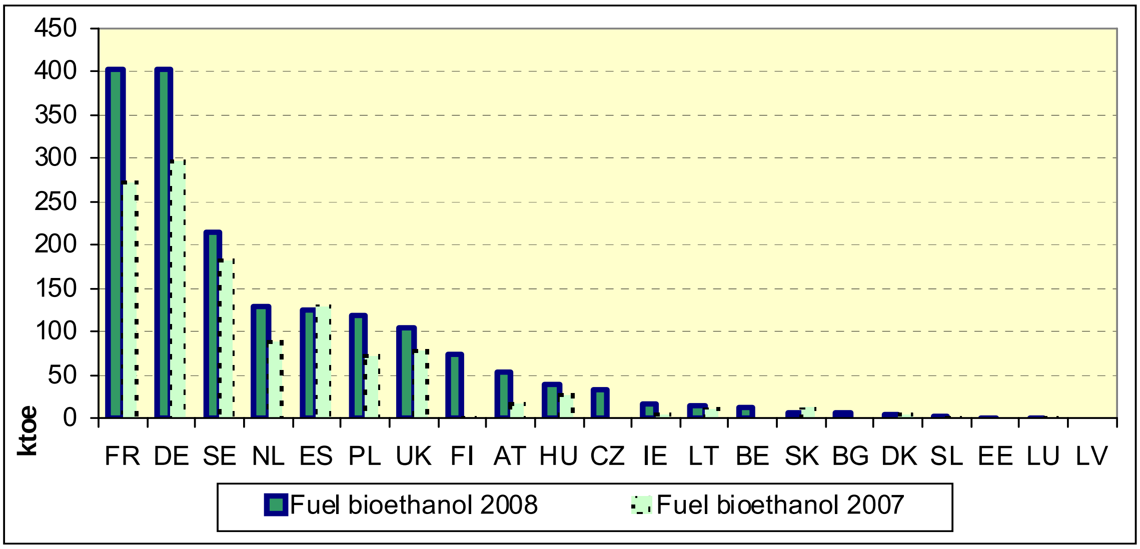
Source: [24]

The use of ethanol as an automotive fuel in Brazil has already gained quite a long experience. Years ago, ethanol has been picked up as a strategic fuel alternative because of security and diversity of supply concerns. At the time, Brazil was lacking significant reserves of oil. On the other hand, the country enjoyed favourable conditions for large-scale cultivation of sugar cane that could be subsequently processed to obtain sugar and ethyl alcohol (ethanol). Owing to these natural advantages, at present Brazilian bioethanol industry provides biofuel at the lowest cost worldwide – ***Figure 7***. Brazilian ethanol appears to be one of the very few, if not the only biofuel that is competitive to conventional oil-derived petrol and diesel today. The 2007-2008 rally of world oil prices provided strong impetus to indigenous ethanol industry and internal consumption exceeded 4.4 Mtoe in 2008 [7].

In the USA the choice of ethanol as a key fuel alternative for transport has been a result of a more lengthy process. The original push to look for alternative fuels came after the first oil shock in the beginning of 1970's and has been triggered by the second oil shock in the end of 1970's. Several options have been considered over the years but finally, ethanol became the primary choice. Amongst other factors, ethanol suits well the structure of USA fleet where petrol-driven vehicles traditionally prevail. The 10% ethanol blend with petrol (the so-called gasohol) gradually gained popularity and became widely used in many parts of the country. Internal demand is on the rise and reached almost 18.4 Mtoe in 2009, equal to almost 60% of world consumption [7]. The USA ethanol production based on corn is not as efficient as Brazilian sugar cane ethanol production. The USA therefore imports significant volumes of ethanol each year – about 840 ktoe in 2007 [30].

In Europe the use of ethanol as an automotive fuel is less popular, accounting for about 17% of total biofuel consumption [11], opposite to 95% in the USA [7]. While fuel ethanol is used in the large majority of EU member states – ***Figure 10***, just two countries (Germany and France) are responsible for almost half of EU's total consumption in 2007 and 2008. These two countries also account for the largest absolute growth in ethanol application in the EU. Furthermore, only seven EU member states used more than 100 ktoe of ethanol in 2008.

Figure 10: *Consumption of fuel bioethanol in EU-27 in 2007 and 2008 /estimated/, (ktoe)*



Source: Adapted from [11]

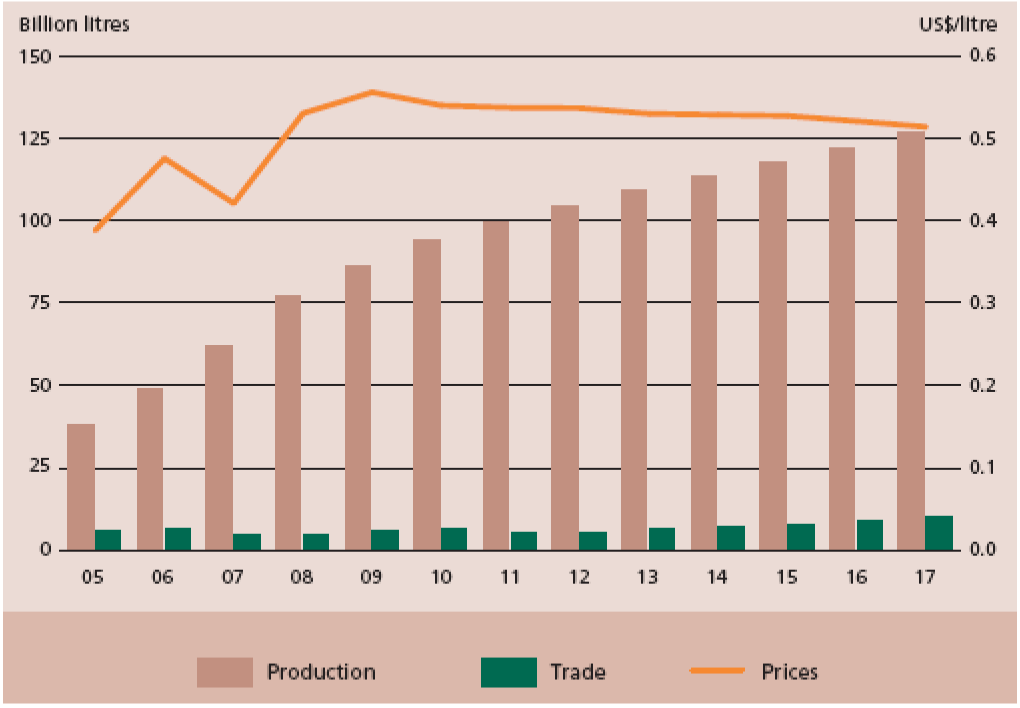
There are three main reasons for the limited penetration of fuel ethanol in the EU.

The first one is the old Fuel Quality Directive [17] that capped ethanol blending in petrol at 5% per volume. The entry into force of the new Fuel Quality Directive [21], which allows phasing in of 10% ethanol blend in petrol, will offer opportunities for larger penetration of fuel ethanol. With EU petrol demand projected to be around 100 Mtoe in 2020 [13], the fuel ethanol application may reach ≈6.5 Mtoe (≈10.5 Mt), i.e. three and a half times higher than the current level of about 1.8 Mtoe [11].

The second is the much lower demand for petrol as share of total transport fuel demand (***Figure 2***) and the petrol surplus in EU's overall fuel balance (***Figure 4***). Unlike the first reason, the second one appears to be more challenging to resolve. In fact, the direct result of blending ethanol with petrol for EU's fuel balance was the increase of petrol surplus for export, but not reduction of gross imports of crude oil. Since the trend for declining petrol demand is projected to continue at least until 2030 [13], the market perspectives of fuel ethanol as a blending agent for petrol in the EU will be continuously weakened.

The third unfortunate fact for the EU ethanol industry is the negligible size of the global ethanol market, as far as it exists. Apparently, only 6-7% of world ethanol production is traded internationally – ***Figure 11***. Brazil holds clear competitive advantages in world ethanol trade and the situation is not expected to change dramatically at least in the medium-term.

Figure 11: *Global ethanol production, trade and prices, with projections to 2017*



Source: [24]

Altogether, these facts imply that energy refineries that concentrate on biochemical / ethanol streams should look for alternatives. Today, there are four workable alternatives:

1) Ethanol as fuel for diesel engines or as blending component for diesel fuel;
2) Ethanol as chemical feedstock;
3) Optimised utilisation of by-products from primary ethanol manufacturing;
4) Portfolio of primary products that contain ethanol;

The four options are briefly analysed below.

1. Ethanol as fuel for diesel engines or as blending component for diesel fuel [35]

Theoretically, ethanol might be used to power diesel engines by blending it with conventional diesel fuel (e-diesel), typically up to 20%. Although this would bring important benefits such as improved EU fuel supply balance and reduced tailpipe emissions, currently the use of e-diesel faces major technological and techno-economic challenges. Some of these challenges are: poor miscibility of ethanol with conventional diesel; low water tolerance of e-diesel (lower than that of petrol-ethanol blends); extremely low cetane number of ethanol – 5-15 versus minimum 51 [21] for diesel; poor lubricating properties of ethanol, lower viscosity and higher vapour pressure (that can cause vapour lock inside the fuel system), etc. Although solutions for most, if not all of these drawbacks exist, they are not either cost-effective yet, or enough proven in tests. Furthermore, the different properties of e-diesel require some redesign of diesel fuel supply infrastructure, on-board systems and engine components, including some engine adjustments.

The key challenge of e-diesel, however, seems to be the extremely low flash point – below 20°C even for minor ethanol content, compared to 74°C for neat diesel. The low flash point requires special handling, storage and application measures, i.e. increases costs. Basically, e-diesel should be handled as petrol. For the time being, the low flash point issue appears to be missing a suitable solution, unlike other drawbacks.

Co-blending of biodiesel, ethanol and conventional diesel (co-blend diesel) was recently suggested as a promising option to overcome most of e-diesel drawbacks. The assumed advantages of co-blend diesel are improved: miscibility, lubricity, viscosity, cetane number, but chiefly – somewhat elevated flash point. Last, but not least, the overall renewable content of co-blend diesel might reach 30%, assuming 5-10% ethanol and 10-20% biodiesel blending shares. Nevertheless, more research and development work, including field tests, is needed for both e-diesel and co-blend diesel to become viable market alternatives.

Another option would be to run diesel vehicles on neat or almost neat ethanol. In that case, however, one needs to perform fundamental on-board re-design: special engine tuning, compatible fuel system materials, but chiefly – putting spark plugs, i.e. turning the engine from a compressed-ignited (CI, diesel) into a spark-ignited (SI, petrol). The other option would be to blend a special ignition improver, which is associated with incremental costs, too.

2. Ethanol as chemical feedstock

Like other bio-derivatives, ethanol contains carbon and hydrogen and in theory, it may replace or substitute other carbon and hydrogen containing compounds.

For instance, ethanol can substitute methanol in some applications. Methanol is a super-commodity, amongst the top-ten most used chemicals globally [41], with annual cumulative market of more than 40 million tonnes [38]. With regard to the energy / fuel sector, ethanol already replaces methanol in petrol oxygenates. The ethanol-derived ethyl tertiary-butyl ether (ETBE) gradually displaces methyl tertiary-butyl ether (MTBE). According to the EU fuel quality regulations, it is allowed to blend up to 15% on volumetric basis of either ETBE or MTBE in petrol [21]. Recently, ethanol also started to replace methanol in biodiesel manufacturing. The key advantage of ethanol over methanol is the non-toxicity of the former. Other substitute options, not confined to the energy or fuel sector only, might become available in the future, too.

Ethanol is also an important chemical semi-finished material that is used to produce other chemicals. Some of the products that can be synthesized from ethanol are:

- Ethane (for further processing into vinyl acetate and polymers);
- Acetaldehyde and then – acetic acid and acetic anhydride;
- Butadiene (with latter conversion into rubber);
- Ethyl lactate and ethyl levulinate;
- Diethyl ether [32];

3. Optimised utilisation of by-products from primary ethanol manufacturing

As already said, it is highly desirable that the residues left from ethanol production are used for generation of heat and eventually electricity for on-site consumption. On the other hand, ethanol processing, like almost all industrial processes, requires heat inputs. Due to its high transmission losses, heat has to be generated either on-site, or in close proximity to the biorefinery site. Generating heat from fossil energy sources to feed energy biorefineries does not make sense for a number of techno-economic and environmental reasons. Thus, the available biomass residues have to be used as much as possible to supply the heat that is needed for biorefinery processes, i.e. to aim at a closed resource cycle. If the biomass left after bioethanol production is just enough or even worse – not sufficient to generate the necessary process heat, the consideration of more sophisticated plant designs that earn a portfolio of ethanol *and* other primary products, becomes pointless. If there is excess process heat and there is an attractive nearby market for it, e.g. feeding other industrial sites or district heating / cooling, then same is also valid.

The case of combined heat and electricity generation from biomass residues is a bit more complicated and may not be as attractive as the heat-only concept. Adding electricity option would require additional capital costs that could be significant. Basically, that would mean to add another component to the plant, but not just to use a residual by-product (heat). The co-generation option would also absorb a lot more biomass, so the whole supply and logistics scheme of the plant would need an upgrade. Finally, electricity generation from neat biomass has relatively low efficiencies (typically, up to 30%) and some technological challenges. Conversely, power generation based on fossil fuels (coal, gas, nuclear) is more efficient (usually above 40%) and, unlike heat transmission, electricity can be transmitted at large distance with negligible losses.

Notwithstanding the above reflections, two interesting concepts to benefit from the residual heat were recently proposed [35]:

- Ethanol production by bio-chemical processes consists of relatively low temperature processes (up to 100°C). It may, therefore, benefit from residual heat from other energy and/or industrial facilities, such as power plants. The IBUS concept (Integrated Biomass Utilisation System, the Venzim vision) combines coal-fired power plant and advanced ethanol facility. Instead of being wasted, the residual heat from the power plant is used to feed the ethanol processes. On the other hand, the biomass residues from ethanol production are combusted at the power plant. The concept earns synergies and cost reductions. In particular, it saves on the heat generation unit for the ethanol facility.
- Another promising option seems to be the Maxifuel concept that combines production of ethanol, biogas and hydrogen, as well as solid biofuel (pellets) from the residual biomass. The goal of the concept is to re-use process streams and hence, optimise the energy and emission performance of the plant.

Finally, in the previous sub-paragraph, the co-blend of biodiesel, bioethanol and conventional diesel was described. An integration of biodiesel and bioethanol processing may be attractive, too. Ethanol could be produced from the biomass residues left after biodiesel manufacturing e.g. from rapeseed straw. Of course, burning the residual straw to generate heat (and electricity) for the biodiesel plant is always an, if not the primary option. Utilisation of bioethanol and/or biodiesel residues for biogas production is also an option that has been tried and successfully tested in a number of existing first generation biofuel installations

4. Portfolio of primary products that contain ethanol

In the first half of twentieth century, the co-fermentation of acetone, butanol and ethanol (ABE) from starch crops was quite popular. It was actually the key technology to obtain acetone. However, in 1950's and 1960's ABE fermentation gradually lost ground to the cheaper oil-based pathways. The recent high oil prices renewed the interest in ABE fermentation as a bio-refinery concept. Despite many years of research, the low yields from ABE fermentation remain a key challenge for the technology to become commercially viable once again.

The typical breakdown of fractions in conventional ABE fermentation is 3:6:1, i.e. for every three units of acetone, six units of butanol and only one unit of ethanol are obtained. With process re-design, it is possible to get rid of the acetone fraction and optimise yield towards 100% butanol or 100% ethanol. Such re-design might be appropriate in particular for Europe. Although the world acetone market is relatively large (estimated at 5.4 million tonnes in 2007), it tends to suffer from over-supply [28], and the consumers in Asia and the Middle East are likely to drive the market in the future [42].

Even though the key applications of butanol at present are chemical, recently the interest in butanol as an alternative fuel has grown thanks to the joint efforts and activities of BP and DuPont [15, 36]. Similarly to ethanol, butanol could be blended with petrol. Regardless of the early stage of assessment and development (the first field test with *oil*-derived butanol took place in 2005), butanol shows some properties superior to ethanol as a petrol blending component. These advantages include higher energy content (27MJ/l versus 21 MJ/l [20]), i.e. lower mileage penalty, less hygroscopic, lower corrosiveness and volatility, better miscibility and compatibility with petrol, etc. Owing in particular to the last advantage, isobutanol (a branched isomer of straight chain butanol) may be blended up to 15% on volumetric basis with petrol, versus 10% for ethanol [21]. On the other hand, butanol has an octane number that is similar to that of petrol and lower than that of ethanol. Thus, butanol cannot be employed as an octane enhancer. The key drawback of butanol, however, seems to be its toxicity [9]. Although butanol is less toxic than methanol, it is more dangerous than ethanol. Though butanol is less hygroscopic than ethanol, the risks and consequences of underground water contamination from accidental butanol spill must be considered. In this context, one has to recall that the key reason for phasing out the fuel use of methanol was actually its toxicity. Last, but not least, from the European fuel supply balance point of view, a wider fuel application of butanol would most likely boost petrol exports, rather than reduce gross imports of crude oil.

Another design that is sometimes investigated is the co-production of ethanol and furfural. Furfural is an industrial chemical with application mostly as a solvent and component to produce resins [5]. It is suggested that furfural derivatives could also be used as fuel additives [26]. Recent world demand is around 350,000 tonnes annually. Global production capacity is about 450,000 tonnes per year and the bulk of supply comes from China. Although from a technological point of view the co-production of ethanol and furfural seems attractive, the market perspectives for bio-furfural by 2020 are bleak. The key bottleneck for bio-furfural is the modest capacity of the market. Even biorefinery demonstration plants could generate some 20,000 tonnes of furfural per year, equal to ≈6% of world demand. In this context too, an ethanol-furfural facility with annual capacity of 323,000 tonnes of furfural (i.e. able to satisfy almost 100% of world demand!) was recently considered in the USA [31]. On top of that, any European bio-furfural production would compete with the low-cost Chinese production. Concerning potential fuel uses, in view of the total lack of any thorough research and investigations on the fuel performance of furfural derivatives and the long lead-times to implement any new fuel (for reference – the experience with bioethanol and biodiesel), it is not realistic to project market-scale fuel application of any furfural derivatives by 2020.

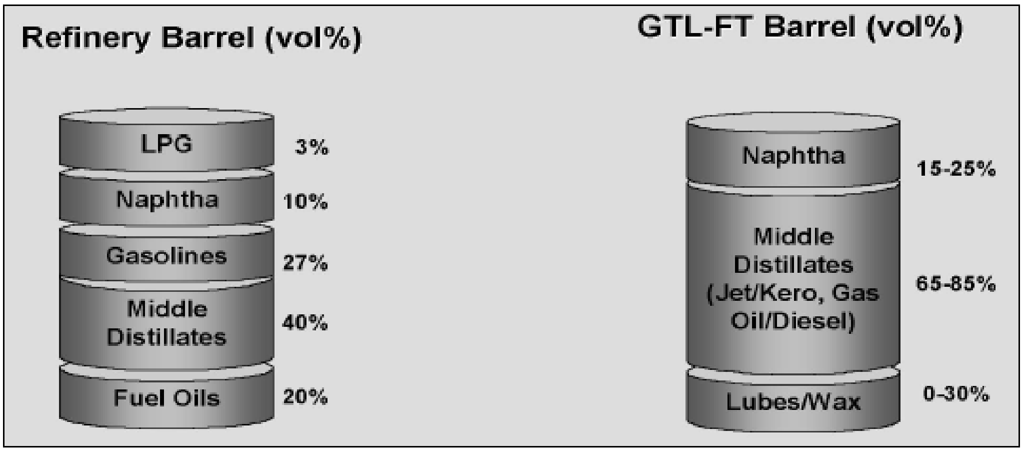
5. INDICATIVE PRODUCTS FROM THERMOCHEMICAL PROCESSING

The thermochemical pathway to fuels and chemicals from non-oil feedstocks has been known for almost a century. The process is also known as Gas-To-Liquid (GTL), Coal-To-Liquid (CTL), or commonly XTL (X-To-Liquid), as well as Fischer-Tropsch (F-T) synthesis, called after the names its founders – German scientists Franz Fischer and Hans Tropsch. While XTL technology is well known and developed for coal and gas, the F-T synthesis from biomass (Biomass-To-Liquid, BTL) is a novel concept that still faces a number of challenges, mainly at the first step – biomass gasification. The output in terms of both products and product properties, however, is the same as those of XTL, so the market perspectives of BTL products are somehow easier to predict.

XTL / BTL synthesis offers a few important advantages over the alternative biochemical pathway that make the former a more attractive option in the foreseeable future in particular for Europe.

- XTL generates fuels and products with very similar and even superior qualities than their oil-derived analogues: higher cetane number (73-81 [37] versus 51-53 for oil diesel); higher hydrogen-to-carbon ratio and almost total absence of sulphur (both resulting in cleaner combustion); easier transformation to other products (as XTL derivatives consist mainly of linear paraffins); etc. The drawbacks associated with ethanol handling and blending with petrol are not present – XTL fuels are almost fully compatible with today's engines, conventional fuels and fuel infrastructure. XTL fuels can be therefore blended easier and at higher ratios (e.g. 20-30%) with conventional fuels [34, 40, 41].

Figure 12: *Typical breakdown of fractions in oil refining and in F-T processing*[3]



Source: [23]

- The optimum (in terms of minimum energy losses, polluting emissions and production costs) oil refining breakdown by fractions is spread amongst a number of products. It is relatively constant and can vary within fairly narrow margins. Conversely, the optimum breakdown of fractions in XTL synthesis is more selective and flexible. It can be optimised to a larger extent versus the most desired (highest-value) products, i.e. middle distillates – ***Figure 12***.

[3] A small amount of light hydrocarbons (C1-C4) is also obtained from F-T processing [40].

- XTL synthesis could be optimised alternatively towards light fractions (petrol, olefins) or middle distillates (diesel, gasoil, kerosene). The optimisation depends on the synthesis conditions – temperature, pressure and catalysts. From a practical point of view, it seems cheaper to go for optimisation of middle distillate yields – ***Figure 12***, right hand side. This option appears attractive also in view of the trends in European and global fuel balances (***Figure 2*** and ***Figure 5***), where sufficient diesel / middle distillates supply is becoming a challenge.

All these advantages make XTL/BTL fuels extremely attractive from a market point of view. Considering the trends in EU's fuel consumption (***Figure 2***) and the 20-30% blending share without need for engine adjustments, the market potential only for XTL automotive diesel in Europe by 2020 amounts to some 40-60 million tonnes. Given the current modest volumes of XTL production (compared to total fuel demand worldwide) and the lack of any commercial scale BTL production, the market potential for XTL/BTL fuels in the foreseeable future is virtually unlimited. Because of that fact, various companies are working hard to develop and refine XTL /BTL technologies. In 2006 DaimlerChrysler, Renault, Royal Dutch Shell, Sasol Chevron and Volkswagen group launched an association – The Alliance for Synthetic Fuels in Europe (ASFE) – to promote XTL fuels in Europe and support research, demonstration projects and public-private cooperation [25].

Despite the strong interest in the technology, there are still major technical and technological challenges that are missing solutions. These drawbacks obstruct the market-scale evolution of thermo-chemical pathways. Unfortunately, the solutions of some bottlenecks are pending for several decades. Furthermore, XTL fuels and in particular – BTL fuels require high oil prices to be cost competitive to conventional oil derivatives. In the case of BTL, it is roughly estimated that the cost break-even point would be achieved in the range of 90-100 EUR per barrel of crude oil.

Besides BTL diesel and middle distillates, other thermo-chemical derivatives that could have fuel application, though with a far smaller market potential, are methanol, di-methyl-ether (DME) and hydrogen.

The fuel application of methanol has been mentioned in the previous chapter. Due to its high toxicity and associated grave health hazards, the fuel use of methanol and methanol derivatives as blending component of petrol is fading away in developed economies [34, 41]. The chemical applications of methanol have, however, enjoyed a sustained growth that has been linked mainly to growth in the construction industry. The methanol market is forecast to expand at an annual rate of 7.8% within 2008-2013 and the growth will be faster in the developing economies [43].

DME is a novel fuel whose concept emerged in the beginning of 2000's in several countries – Sweden, Japan, China, as well as in companies such as TotalFinaElf and Qatar Petroleum [6]. Similar to LPG, DME is gaseous at ambient conditions, but liquefies at moderate pressure (5-8 bar) and thus, DME could be mixed with LPG. DME can therefore exploit the existing LPG infrastructure, where available. It is suggested that low-concentration (10-20%) blends of DME with LPG require no or only minor system modifications. Furthermore, DME appears to be a suitable alternative fuel for diesel engines, since it has slightly higher cetane number than conventional diesel (55-60 versus 51-53) and cleaner combustion. Conversely, DME has only about half of the energy content of conventional diesel (19MJ/l versus 36 MJ/l), which brings about a considerable mileage penalty. Neat DME application also requires major engine modifications, the most important being the dedicated injection system. DME might potentially be used in non-transport energy appliances too, e.g. as a household fuel, moreover DME handling is somewhat safer than that of LPG. Nonetheless, because of its handling specificities and the need of dedicated refuelling infrastructure and onboard equipment, DME is likely to remain a niche fuel with limited penetration in the European fuel market [34].

Hydrogen is sometimes perceived as the fuel of the future that will be used in the next generation vehicles powered by fuel cells. From today’s perspective, however, the market-scale penetration of fuel cell vehicles by 2020 seems questionable. Nonetheless, at present hydrogen finds quite an important and large energy application in oil refineries. Oil refineries need increasing volumes of hydrogen to reform heavier fractions with low demand into lighter fractions (mostly middle distillates) with increasing demand – the so-called hydrocracking. Since the on-site production of hydrogen from oil residues is not sufficient, oil refineries are expected to seek growing quantities of hydrogen from the open market. As an indication for the size of that demand, at present oil refineries account for approximately a quarter of world syngas (a mixture of carbon monoxide and hydrogen) demand, while the XTL share is 2-3 times smaller [1].

6. INTEGRATION OPPORTUNITIES WITH OIL REFINERIES

At first glance, the straight integration of energy biorefinery technologies and products (co-processing and co-production) within conventional oil refineries appears challenging by 2020. First of all, biomass and crude oil have totally different physical and chemical properties. It is enough just to mention that originally biomass is solid, while oil is liquid. Crude oil and biomass processing are fundamentally different technologies, so it seems there is little room for direct synergies. As discussed in Chapter 3, the scale of biomass processing is and (most likely) will remain much smaller than that of oil processing. The cost-benefit ratio of adding biomass-processing modules to oil refining facilities would be quite unfavourable. The incremental administrative burden to get new and/or additional permits, environmental compliance, etc. could also be significant. Furthermore, most refineries in Europe have been built years ago and tend to be severely constrained in terms of space. For the large majority of them, adding new processing components or modules is simply not possible.

Since oil will be the leading component in such hypothetical co-processing systems in the coming decades, biomass must inevitably undergo some kind of pre-treatment, for instance liquefaction or gasification. The resulting biomass intermediates that could fit oil refining include hydro-treated or hydrogenated bio-oil, pyrolysis oil / slurry, as well as vegetable oils [27]. The suitability and compatibility even of these biomass derivatives seems, however, doubtful in the foreseeable future. Oil refining represents a highly complex and sophisticated system of processes and steps that are finely tuned to the quality and composition of specific crude oils. Drastically changing the composition and qualities of the feedstock inflow always implies enormous incremental costs to adjust processing facilities. Crude oil is almost entirely composed of carbon (≈85%) and hydrogen (10-14%). Conversely, biomass contains a large portion of oxygen (35-45%) besides carbon (45-50%) and hydrogen (≈6), as well as many other components that vary depending on biomass species and origin. Even upon pre-treatment, the oxygen content in biomass intermediates remains quite high – 16% in liquefaction oil and 35-40% in pyrolysis oil [27]. Efficient oil refining employs a wide range of catalysts. Oxygen has proven to be very harmful to the great majority of those catalysts. With present technologies, removing oxygen from biomass intermediates to be fed into the feedstock streams of conventional refineries can only be done at prohibitively high energy and monetary costs. Biomass intermediates do face also additional challenges that hinder co-processing with crude oil at industrial-scale. Provided these challenges are sorted out, crude oil processing may eventually enable low-blend tolerance of such biomass intermediates in the longer-term, but most likely beyond 2020.

Considering the properties of various semi-finished materials and products from biomass, the most feasible synergy option between energy biorefineries and conventional oil refineries seems to be BTL. It is because BTL products demonstrate the highest compatibility and even superior performance compared to conventional oil-based fuels. BTL derivatives could be either co-fed in oil processing or blended with final oil products. Because of various logistics limitations, however, the BTL manufacturing will most likely take place in standalone plants, but it will not be coupled with oil refineries.

In the shorter-term, conventional oil refineries might be increasingly interested in bio-derived products from chemical biorefineries, such as fuel components and additives. The driving forces would be the superior techno-economic properties of bio-derivatives and the imperative reduction of GHG emissions along fuel chains [21]. In the common case, however, oil refineries would just buy these components and additives from chemical biorefineries, rather than produce them on-site. This would therefore be an external (exogenous) integration with the chemical biorefining industry, which is outside the scope of this analysis.

7. CLOSING REMARKS AND RECOMMENDATIONS

The development of energy biorefinery technologies and products should not be confined to a laboratory environment that is isolated from the real world, but it should closely follow the trends and development of energy and fuel markets in Europe and worldwide.

In view of the immature status of energy biorefinery technologies, a more pragmatic and conservative, evolution-based approach in their development seems to be more appropriate than a more aggressive, revolution-based approach that aims at step changes within short time. That means concentration on a limited number of simpler concepts, technologies and products with possible later gradual shift to more sophisticated concepts that create a larger number of pathways and products. Spreading the efforts at the same time on too many fronts may result in poor results in all research directions. From a marketing point of view, it is always better to have a few really good products, rather than to have a large portfolio of products of average or even poor quality. In this context, the experience that has already been gathered by the chemical biorefining sector, in particular by the pulp and paper industry, might be extremely useful for the energy biorefineries.

When transferring energy biorefinery technologies and products from the demonstration scale to the real market, one should carefully investigate the primary and secondary impacts these technologies will exert. Special attention should be paid to potential externalities of energy biorefinery technologies and products. As an example, one should aim to avoid cases like the destruction of glycerine market, as a result of the expanded biodiesel production in the EU. A thorough SWOT analysis of market penetration of energy biorefinery technologies and products must be carried out before introducing them in the market by applying the systematic approach and taking into account as many as possible secondary effects and consequences.

One should acknowledge that there is no biomass feedstock that is pre-reserved for energy biorefineries. Energy biorefineries should gradually learn to compete for the limited biomass resource with other, more mature applications of biomass. These are generation of heat and electricity, solid biofuels and earlier generations of liquid biofuels, as well as chemical biorefineries and products. Beyond that, all bioenergy applications will be heavily competing in the land market with non-energy and in fact, primary biomass uses of higher value, such as food, feed and timber production. To sum up, biomass and bioenergy, in particular energy biorefineries, should be always considered within a broader framework of policy objectives and priorities.

The market introduction of technologies and products that are not fully developed yet, always involves some kind of regulatory support. In the EU we have a framework that ensures at least the initial penetration of most, if not all products out of energy biorefineries. Furthermore, significant funding is allocated to the development of energy biorefinery technologies. With the gradual evolution of energy biorefinery technologies and products, however, new and/or additional support schemes might be necessary at a later stage. In this context, one area that currently seems to be slightly overlooked is the free-flowing transfer and exchange of know-how. A great deal of the on-going research and development work is under the control of large companies via patent certificates. Sometimes patents may prevent or slow down the development of certain technologies and/or products. Public authorities may wish to think about ways of improving and facilitating the information flow on technology innovations and scientific achievements in the energy biorefinery field, in particular the research that is funded with public money.

Last, but not least – it has already been stressed several times that energy biorefinery technologies are still immature. If we want to have them on the market with contribution to the security and diversity of energy supply of the EU by 2020, additional significant research and development work is needed to improve concepts and design, energy, environmental and cost performance, reliability, etc. These substantial research and development efforts would need continuous institutional and financial support at both EU and member states level.

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