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High Octane Petrol Study

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High Octane Petrol Study

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ABSTRACT

The long-term goal of the EU is ambition of climate neutrality by 2050 (EU Energy Roadmap 2050). As introduction to reach this target, vehicle efficiency targets for passenger cars and light commercial vehicles have been defined in Regulation (EU) 2019/631 in the EU up to 2030. The expected benefit, from the CO_2 emission performance standards for cars and vans, is a 23% reduction of greenhouse gas emissions from road transport (total fleet) in 2030 compared to 2005[1].

In the current Regulation, vehicle efficiency targets are formulated in a technology neutral manner, but from a Tank-To-Wheel (TTW) perspective only. Manufacturers have the possibility to use the CO_2 reduction potential of internal combustion engines and electrification to be compliant. In this perspective, Concawe[2] investigated the CO_2 reduction potential of High Octane Petrol when used in an optimized engine with high compression ratio. This report investigates the feasibility of such High Octane Petrol production and its cost for EU refining.

This study was performed with the Linear Programming model developed by Concawe. It is used to simulate the performance, capabilities and behaviour of the European refineries. The model aggregates all the capacities from each individual refinery in European countries (EU27 + UK, Norway, Switzerland and Iceland).

As a first step, a series of cases have been developed with 10% of the demand switched to the High Octane Petrol grade. For the reference case of the HOP 102 RON, this evolution can easily be absorbed by the flexibility of refineries.

In a second step, a 2030 scenario is developed in which 50% of the gasoline demand switches to HOP 102 RON. A significant evolution is required in the refineries: the use of oxygenated components is increased significantly, which requires important imports of Oxygenates or investment in new Oxygenates plants, and the oxygen specification to be relaxed from 2.7 w.t% to 3.7 wt% in most of the regions. Exchanges between regions are also needed.

No simulation with demand post 2030 or with HOP percentage higher than 50% have been performed. We consider these scenarios as this long term ones, which will be very dependent on the evolution on the powertrain, the Demand for gasoline and the consequent evolution of the refinery system. The analysis of constraints of the 50% case shows that the European refining system is not able to produce much more than 50% HOP 102 RON without significant investments.

In the central case, 50% demand of RON 102, the CO_2 savings is more than 4Mt/y (5% vehicle efficiency gain from R95 to R102) per year and the cost of additional octane is assessed at 4.7$/t/point of RON. Even though it is significant, this octane value remains consistent with the market valorisation around 8.6 $/t/pt. RON (US market, historical figure).

[1] https://ec.europa.eu/clima/policies/transport/vehicles/regulation_fr
[2] Concawe report "Testing and modelling the effect of high octane petrols on an adapted vehicle" https://www.concawe.eu/wp-content/uploads/Rpt_20-8.pdf

KEYWORDS

High octane, petrol, HOP, efficiency, CO_2 emission, Internal Combustion Engine, ICE, Transport, passenger car.

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SUMMARY

The European Commission is proposing to take a worldwide leading role in tackling climate and environmental related challenges under the European Green Deal, aiming for very ambitious decarbonisation and energy efficiency targets up to 2050, in order become the first continent to reach climate neutrality by 2050.

Although the current 2030 target foresees already a 40% cut in greenhouse gas emissions (from 1990 levels), the Green Deal proposal is to increase this to 50 or even 55%.

Several regulatory instruments aiming at reducing GHG emissions in the Transport sector will be revised accordingly; among them, the Renewable Directive and its component on Transport, the Fuels Quality Directive, and the regulation on vehicles CO_2 emissions standards on. A 23% reduction of greenhouse gas emissions from road transport compared to 2005 must be achieved in 2030, thanks to the vehicle efficiency regulation alone. This intermediate step on the path to 2050 may face further tightening under the Green Deal.

Objective of the study

In this context the objective of this study is to assess the feasibility and impact of producing a "High Octane Petrol (HOP)" grade in the European (EU28+3) refining system, as a contribution to vehicle efficiency improvement up to 2030.

The gasoline research octane number (RON) is a measures of the fuel ability to withstand pre-ignition during compression in an engine cylinder and is a critical factor in engine design. Engine performance and efficiency increase with increasing compression ratio. However these engines require gasolines with higher octane ratings to realise the full benefit.

Hence this study evaluates the RON that can be produced by the EU refining, together with the impact on CO_2 emissions in the production process as well as by vehicle use (Tank-to-Wheel). An estimation of costs for the EU refining system producing HOP fuels is also made.

Assumptions and LP model

The Concawe European Refining system LP model was used as the main tool to assess the refinery impact of the variation of the HOP RON number from 98, to 100, to 102 and to 104. Thereby the HOP domestic demand share is varied from 10% by energy for short term to 50% by energy to provide a long-term evaluation in 2030. The remaining share (90% or 50%) is fulfilled with the current main gasoline RON 95 grade in the EU. To achieve 50% penetration of optimized ICE (capable of benefitting from 102RON) by 2030, this would require development programs to be started immediately.

It is assumed that, in an optimised engine, a RON 102 HOP would lead to a 5% efficiency increase compared to a RON 95 grade, based on testing carried out by Concawe[3] and confirmed by OEM's. For the intermediate HOP RON targets the efficiency gain was assumed linear between RON 102 and RON 95.

[3] Concawe report "Testing and modelling the effect of high octane petrols on an adapted vehicle", web: https://www.concawe.eu/wp-content/uploads/Rpt_20-8.pdf

The time frame for the development and the market penetration of these optimised engines has not been considered in this study. It is assumed that optimised engines will be available in the EU market to such extent that the benefit of HOP fuels is completely utilised.

The EU Refining systems energy efficiency are considered in the long-term set of cases to occur around 2030. To be in line with the expected refining energy efficiency improvement, it is assumed that between 2016 and 2030, the energy efficiency of the EU refineries would increase by ~10% (0.6%/y)[4].

Oxygenates are critical in this study, as their addition into the gasoline pool is an essential part of the targeted RON improvement. With regard of RED obligations, it is assumed that 100% bioethanol is used for direct blending and /or for the production of ETBE and TAEE. Instead MTBE is selected to account for all non-bio ethers that could be added to the gasoline grades. The bio energy content of domestic gasoline pools is fixed in all cases, and to simply the analysis, the only oxygenate that is varied is the MTBE. However, in case of restriction of MTBE in gasoline blending, it has been checked that replacing MTBE by “non-Bio ETBE” would lead to similar modelling results for all the cases.

Using the Concawe European Refining system LP model two different pathways have been defined to vary the Oxygenates content in the final gasoline pool. For the “Oxygenate pathway”, the MTBE price is set at 1.2 * RON 95 price, which corresponds to the historical average, and for the “Oxygenate light pathway”, the MTBE content is minimized by setting the value at 5.0 * RON 95 price in the model (these runs are only to determine capability of the EU refining system to produce HOP by itself, not to determine cost of production).

Results of the study

Even though the RON number 98, 100, 102 and 104 of the HOP fuels have been investigated the summary will focus on the HOP grade RON 102, which was shown as best compromise between vehicle benefit, and minimising refinery investment.

On the basis of the market demand of 2016, producing 10% of RON 102 gasoline (short-term case) would result in an increase of the overall gasoline RON requirement of 0.3 point (from 94.3 to 94.6). The reason for the limited increase is because the share of 98 RON grade was nearly 10% in 2016. . The volume of refining components would be reduced from 94.3% to 94.0% and the content of Oxygenates would increase from 1.1 wt% to 1.6 wt% to contribute to higher RON values. In the oxygenated light pathway, the Oxygenates content is minimized, the main change of HOP& R95 pool properties is that MTBE content reduces from 1.6 to 1.4% slightly increasing the volume of refining components.

Without investments at refineries, South East and Central Europe cannot produce, in the model, the required HOP 102 without importing material from other EU regions.

Although for the final HOP 102 grade all the parameters of EN 228 are met, for both the oxygenate and oxygenate light pathway, the aromatic content is maximised to 33 vol.% and vapour pressure limited to 58 kPa, which constrains any further changes to the fuel composition. With a bioenergy content of 3.4% and an oxygen content of 2.2

[4] Concawe report “CO_2 reduction technologies. Opportunities within the EU refining system (2030/2050).
https://www.concawe.eu/wp-content/uploads/Rpt_19-8.pdf

wt% the final RON of > 102 and MON of >91 are achieved. For the oxygenate light pathway the only visible change on HOP&R95 pool properties are the oxygenates, with a slight reduction from 2.2 to 2.0%, due to the minimization of Oxygenates content.

For the long-term case of 2030 the forecast[5] shows an overall 9% decrease in demand versus 2016, and more specifically a ~ 10% decrease for fossil gasoline.

The main results show that producing 50% of 102 RON gasoline in 2030 would result in an overall gasoline RON requirement increase of 2 points (from 94.4 to 96.4). Thereby the volume of refining components would reduce from 93.9% to 91.4%. In contrast the content of MTBE would increase from 1.1 wt% (0.8MTPY) to 5.3 wt% (4 MTPY) contributing to higher RON values. In the oxygenate light pathway, the MTBE content increases to 4.5 wt% (3.4 MTPY).

With a general content of MTBE > 4.0% the oxygen specification has to be relaxed from 2.7 wt% to 3.7 wt% in most of the regions, which is in line with the E10 specification of EN 228.

Considering the top of the barrel process units, utilisation rates have shown that there is limited margin for the system to further optimise the refining operations without requiring important investments, as the refining system is already constrained in the base case of HOP 98.

The modelling work is showing a feasible pathways for the refining industry in Europe (102RON and 50% Demand in the 2030 Demand scenario), which will require major refinery adaptation (process unit operation, increased trade flows within Europe and a more complex gasoline blending). The volume of gasoline export does not increase significantly. The increased of oxygenate blending is compensated by a lower crude T/P and minimisation of low octane gasoline blending components.

Though not developed in the report, the case for 100% HOP in 2030 has been investigated. Starting from the 2030 calibrated model (restricted unit capacities), more flexibility has to be given to the model to be feasible, mainly: reduce to 50% the minimum production for each region, allow investment in one region (South East) and full E10 in all EU regions (oxygen saturated at 3.7%). The cost of octane increases significantly (6.8 $/t/RON pt), the model is strongly constrained (translating significant efforts and adaptation from the refining sector), but a solution is found. The export of gasoline is increasing (to compensate for more oxygenates blending) from 36.4Mt to 45.8Mt in 2030 cases. A significant drop in export price does not reduce these volumes of gasoline export.

Sensitivity Study - Investments allowed

All the sensitivity cases were performed at a HOP RON target of 102, with a HOP demand at 50% of domestic market (long term 2030) and a MTBE price at 1.2 * RON95 price (oxygenate pathway). A sensitivity case was run allowing investments in CCR Reforming increasing capacity to +7%, Reformate splitters (+39%), Alkylation (+26%), Isomerisation (+2%) units and ETBE/MTBE units (+35%).

The main result of the investigation is that only the ether production contributes significantly to higher RON numbers. Aromatics are already at the limit of 33 wt% in

[5] WoodMackenzie 2019 database and forecast

HOP pool, isomerisation doesn't increase octane enough for HOP production and alkylates are limited in production due to C3/C4 olefin availability in refinery.

It has to be noted that the purpose of this case is not to promote one technology over another, but to show how the refining system can adapt to provide more RON to the gasoline pool, without necessarily maximizing the oxygenates imports. The individual refinery optimum however will depend on each refiner's strategy.

Hence the finished HOP 102 gasoline properties shows little change in comparison to the oxygenate pathway.

Sensitivity study - Increasing Bioenergy content

The purpose of allowing for a higher bioenergy content as a sensitivity case was to check the impact of considering an equivalent E10 (EU average) gasoline pool. In general Ethanol and ETBE, are the bioenergy options, but as ETBE has a higher RON/Oxygen ratio, it is considered as the free bio-component and ethanol is fixed at the 2030 forecasted value. As a result, a maximum of 14.1 wt% of ETBE can be added to the global HOP & RON 95 pool, limited by the oxygen content at 3.7 wt% corresponding to EN 228 specification for E10. The bio energy content reaches a level of 6.9% which is in line with the 1st generation biofuel cap of 7% according RED II regulation.

Fossil fuel displaced from local gasoline is sold as an export grade, consequently the overall refining system operation changes very little and the related CO_2 emissions are very similar (slight decrease of about 0.4%).

CO_2 emissions from the refining system and Tank-to-Wheel evaluation

HOP production has no major impact on direct CO_2 emissions from the refining system, as additional RON is mainly supplied by blending optimization and imported oxygenates, in both the oxygenate and light oxygenate pathways and both the HOP 10% (short term) and 50% (long term) of domestic demand.

For evaluating the overall CO_2 emission benefit of HOP grades, the refinery, the vehicle (Tank-to-Wheel) emissions and the Well to Tank emissions of the oxygenates also have to be considered. Emissions from cars are estimated from the gasoline pools carbon content, which is theoretical calculation, assuming that all carbon will end up into emitted CO_2.

The potential benefit in each case is shown in the next table compared to HOP 98 base case:

	Oxygenate pathway MTBE price @ 1.2 * RON 95		Oxygenate light pathway MTBE minimization	
CO_2 MTPY vs. 2016 Base (short-term) and vs. 2030 Base (long term)	**HOP 102 (short term)**	**HOP 102 (long term)**	**HOP 102 (Short term)**	**HOP 102 (long term)**
Direct emissions from refining	**- 0.3**	-0.3	**+ 0.0**	**+ 0.2**
Direct emissions from HOP & RON 95 cars	- 0.7	- 6.0	- 0.8	- 6.0
Oxygenates WTT impact	**+ 0.3**	**+ 2.0**	**+ 0.1**	**+ 1.6**
Total CO_2	**- 0.7**	**- 4.3**	**- 0.7**	**- 4.2**

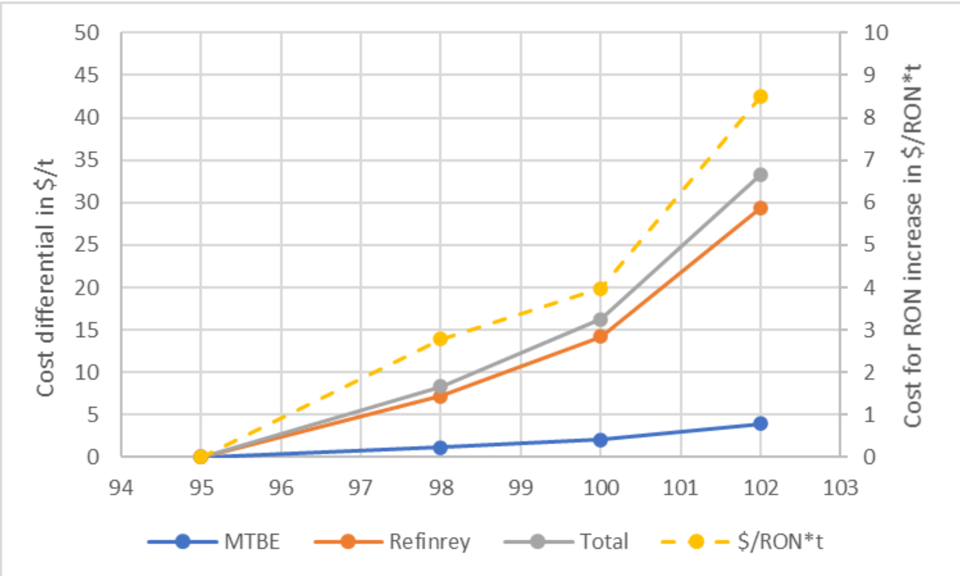
Economics

A cost sensitivity case was run to evaluate at which price differential it becomes profitable for the LP model to produce HOP. This cost study was performed on the long term (HOP at 50% of domestic demand), at several HOP RON levels (98 / 100 / 102 and at a price set based on 2016 yearly average. The cost sensitivity consists in running the LP model with step changes on HOP price differential versus RON 95 price.

To reach 50% of the domestic demand, HOP RON 102 differential versus RON 95 of 33 $/t were calculated. Considering a Brent price variation from 43 to 109 $/bbl, the HOP differential versus RON 95 differs only 7% to 8% of the RON 95 price.

If an unlimited price differential of HOP RON 102 compared to the base fuel was allowed, it does not lead to a significant increase in supply of HOP RON 102 over 50%. Hence the European refining system is not capable to produce much more RON 102 volume, without significant investments.

Breaking down the cost structure in details, the cost increase is caused by the higher Oxygenates demand and by the increased production costs of refinery components. The cost increase is not linear and increases in $ per RON and tons significantly from 2.8 $/t/pt. RON (from RON 95 to RON 98) to 8.5 $/t/pt. RON (from RON 100 to RON 102), which results in an average of 4.8$/t/pt. to produce RON 102.



It can be seen that the higher the RON the less attractive the production is from refinery economic perspective. Of course, it has to be noted that the consideration is based on a general European perspective and that this can differ significantly in terms of the local refinery structure.

1. BACKGROUND

The long-term goal of the EU is the decarbonisation of transport (EU Energy Roadmap 2050). In order to achieve this target, vehicle efficiency targets for passenger cars and light commercial vehicles are defined in Regulation (EU) 2019/631 in the EU for the period after 2020. Overall a 23% reduction of greenhouse gas emissions from road transport in 2030 compared to 2005 has to be achieved.

In order to keep liquid fuels a vital partner in the future of road transport, its carbon intensity will be reduced. Potential solutions include vehicle efficiency increases, also made possible by fuel quality improvements. In this context, High Octane Petrol (HOP) could play a role and has a high potential in the near future.

The gasoline research octane rating (RON) measures its ability to withstand pre-ignition during compression in an engine cylinder. Gasoline octane is a critical factor in engine design. Engine performance and efficiency increase with increasing compression ratio. Engines with higher compression ratios require gasolines with higher octane ratings.

Previous studies[1] have shown that an increase of octane (RON) from 95 to 102 leads to an improvement in engine efficiency, depending on drive cycles and in case the engine has been optimized for the use of high-octane fuel like RON 102, up to more than 15% for some specific point of operation (not on the full cycle). Hence adopted engines to be mass-market implemented by the OEMs (Original Equipment Manufacturer) (assuming same energy content of the fuel for RON 95 and 102) can lead to significant efficiency benefits in the future vehicle park.

1.1. OBJECTIVE

The objective of this study is to assess the feasibility and impact of a High Octane Petrol (HOP) grade in the European (EU28+3) refining system as contribution to vehicle efficiency improvement.

This study objective is to provide material to answer to the three following questions:

1. Which RON for HOP would be feasible for the EU refining system?
    - Feasibility is achieved if Concawe EU refining system Linear Programming (LP) model obtains a converged and optimal solution.
    - Such a solution implies that all refinery product demands are satisfied in quantity and quality, i.e. all refinery products meet current specifications.
    - Refinery products specifications implemented in Concawe LP model are provided in **Appendix 1**.
2. What would be the direct CO_2 emissions impact on EU refining system related to HOP production and what would be the Well-to-Wheel (WTW) CO_2 emissions impact related to HOP utilisation?
    - Direct CO_2 emissions for refining cover CO_2 emissions from fuel burning and CO_2 from chemical reactions (Hydrogen production processes mainly).
    - WTW CO_2 emissions are impacted by the direct CO_2 emissions from refining, but also by the level of non-fossil components added to the

[1] CO_2 Emission Reduction Synergies of Advanced Engine Design and Fuel Octane Number, SAE International, 2014

products (e.g. ethers) and by the carbon content of the fossil components.

3. What would be the estimated costs for EU refining system related to HOP production?
    - As each refiner would have its own strategy to cope with a new product available on the market, it would be sensitive to estimate global EU refining system investment costs to produce HOP grade. Such case is developed as a sensitivity only.
    - To represent the costs that would be borne by the EU refining industry, a tentative RON cost for HOP production is derived from the various cases during this study.
    - The introduction of a HOP grade will decrease the Demand as a direct result of efficiency gain, but it will trigger engine development enabling more cars to find a place in the market. This last effect is not valorised but should be considered by refiners in their strategic planning.

1.2. STUDY CASES

Three main parameters are evaluated in this study:

- HOP RON: four different RON values are tested 98 / 100 / 102 / 104.
    - RON 98 corresponds to the current situation, as in Europe there is currently approximately 10% of the produced gasoline for local market that has a RON value of 98.
    - RON 102 is the targeted value for this study. According to this study results, it would be a reasonable compromise between refining technical feasibility, refining costs and engine efficiency improvement.
    - RON 100 is an intermediate value, to analyse the steps and consistency of the model between the current 98 and the targeted 102.
    - RON 104 is an extreme case, leading to very high constraints on the refining system, considered mainly to assess the feasibility range for targeted 102.
    - All fuels modulated are compliant to current EN 228 standard with maximum oxygen content of 3.7 wt%.
- HOP domestic demand share: two values are tested, 10% and 50% (energy). The remaining share (90% and 50% respectively) is fulfilled with current EU RON 95 grade.
    - The 10% value represents the current (2016) situation, where approximately 10% of RON 98 grade is consumed in Europe. In the following report, the related cases are referred as to 'Short term' cases.
    - According to historical car replacement turnover, it has been estimated that HOP grade could represent 50% of the domestic share by 2030 (refer to next section for detailed calculation). 2030 is considered as a sensible horizon, beyond that there would be a higher uncertainty on the market forecasts and the EU refining system configuration. The related 50% cases are referred as to 'Long term' cases.
- HOP and RON 95 biofuels content: two values are tested 3.4% and 7.3% (energy).

- The 3.4% value is equivalent to an E5 grade (5% bioethanol energy equivalent). This value corresponds to the current (2016) average RON 95 and RON 98 EU domestic demand.
- The 7.3% value is equivalent to an E10 grade. It is an alternative case considering that the whole EU domestic demand would have to comply with E10 specifications, provided that sufficient bio components would be available. This scenario is referred as “high Bio” content.
- For the purpose of this study, bio energy content is achieved with pure bio ethanol or ETBE produced with bio ethanol (and fossil isobutene).

- Investment case: a case with investments in process units (2030 horizon) has been performed to evaluate the potential adaptation of refining system to the demand and RON constraint.

1.3. MAIN ASSUMPTIONS

This section presents the main assumptions that are most likely to affect the outcomes of the study. Additional information can be found in **Appendix 1**.

1.3.1. Engine efficiency impact on HOP demand due to higher RON

It is assumed that in an optimised engine, a RON 102 HOP would lead to a 5% efficiency increase compared to a RON 95 or RON 98 grade running in an optimized engine[2]. Consequently, for the same passenger-km or weight-km less energy is required for the transport system, which mechanically decreases the ‘domestic’ demand (potential impact on new fleet and market resistance are not taken into account). OEM’s confirm that based on an optimised engine, a 5% efficiency gain will be reached. It is assumed that for other HOP RON targets, efficiency gain would be linear versus the 5% assumption for RON 102 versus RON 95.

At the reference EU domestic demand (year 2016) the RON 98 / RON 95 grades distribution is 10 / 90 (in energy). Each of the case performed in this study is derived from this reference, based on the assumed efficiency gain / RON rule described above.

Examples

- HOP 104 / RON 95 distribution at 10 / 90: the expected engine efficiency increase is 6.4% (5.0%/7x9). Consequently, the HOP / RON 95 demand is respectively 9.4 (10x(1-6.4%)) / 90 in energy compared to an initial 10 / 90 distribution for a current engine.
- HOP 98 / RON 95 distribution at 50 / 50: the expected engine efficiency increase is 2.1% (5.0%/7x3). Consequently, the HOP / RON 95 demand is respectively 48.9 (50x(1-2.1%)) / 90 in energy compared to an initial 50 / 50 distribution for a current engine.

The table below shows the HOP / RON 95 domestic demand for cases evaluated in this study.

[2] Concawe report “Testing and modelling the effect of high octane petrols on an adapted vehicle” https://www.concawe.eu/wp-content/uploads/Rpt_20-8.pdf

Table 1 HOP and RON 95 grades domestic demand, all cases

	HOP RON 98 Ref.		HOP RON 100		HOP RON 102		HOP RON 104	
HOP / RON 95 ratio	10/90	50/50	10/90	50/50	10/90	50/50	10/90	50/50
HOP demand	9.8	48.9	9.6	48.2	9.5	47.5	9.4	46.8
RON 95 demand	90.0	50.0	90.0	50.0	90.0	50.0	90.0	50.0
Total demand	99.8	98.9	99.6	98.2	99.5	97.5	99.4	96.8

1.3.2. Constant fossil gasoline production

As assumed in the previous section, higher RON leads to a decrease of the corresponding HOP demand. Mechanically the fossil components demand decreases accordingly.

Because all other refinery products remain at the same level of demand (refer to **Appendix 1** for complete demand assumptions), the decrease of fossil gasoline demand adds pressure on the gasoline to distillate ratio production: to produce less gasoline but the same amount of other products, the EU refining system would have to change its supply structure and/or to rearrange the process units operations and utilisations.

To avoid this non-realistic over constraint on the EU refining system, it is assumed that the amount of fossil fuel not sent to domestic market could be exported to other regions. From the section above, it can be observed that this additional export represents less than 5% of the current gasoline domestic demand. In this study, no gasoline intermediates can be exported, these fossil components are exported as on specification products (gasoline export grades specifications are available in **Appendix 1**).

1.3.3. EU Refining system energy efficiency

The long term set of cases are considered to occur around 2030. To be in line with the expected refining energy efficiency improvement, it is assumed that between 2016 and 2030, the energy efficiency of the EU refineries would increase by 10% (see Concawe report 19-8[3], “CO_2 reduction technologies. Opportunities within the EU refining system (2030/2050)”).

1.3.4. Oxygenates

Oxygenates are critical in this study, as their addition to the gasoline pool is an essential part of the targeted RON improvement.

- Biofuels
  - When ethanol is added to the gasoline grades, it is 100% bioethanol
  - ETBE bio energy content is assumed to be 37%[4]. Although 100% bio ETBE could be available, it has been discarded from this study as a conservative approach.
  - ETBE and TAEE produced within EU refineries are included in Concawe LP model. It is considered that these ethers are produced from bioethanol.

[3] https://www.concawe.eu/wp-content/uploads/Rpt_19-8.pdf
[4] RED Renewable Energy Directive
https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028

- Non bio-oxygenates
  - To simplify the LP modelling, with no consequence on the results, MTBE is selected to account for all non-bio ethers that could be added to the gasoline grades.
  - Having more than one non-bio ether would not provide any added value to the study, as the optimisation between ethers would be driven almost only by the price differentials. This does not deliver any incentive about the feasibility of the HOP.

As the bio energy content of domestic gasoline pools is fixed in all cases, the only oxygenate that can really vary and bring more or less RON to the pools is the MTBE. However, the MTBE amount added to the pools depends not only on the RON requirements, but also on the economic incentive of blending oxygenates. In order to isolate the pure economic effect, two sensitivities are run for each case:

- “Oxygenate pathway”: Oxygenates (MTBE) price set at 1.2 * RON 95 price (average historical observation)
- “Oxygenate light pathway”: Oxygenates (MTBE) price set at 5.0 * RON 95 price. This 5.0 coefficient does not have any “market” or real justification; it is deemed to be sufficiently high to minimize the Oxygenates blending in the gasoline pools.

1.3.5. Crude Slate

For short-term scenario, 2016 crude slate is used (derived from Eurostat data). For long term scenario (2030), latest Wood Mackenzie forecasts are considered.

In Concawe LP model, there are 6 reference crudes and two intermediate residues that can be used to represent an actual crude slate. Two combinations of these bases are then calculated to match the actual 2016 and the forecasted 2030 EU crude slates.

Final LP model crude slates can be found in **Appendix 1**.

1.3.6. EU Refining finished products demand

Demand forecasts are mainly based on Wood Mackenzie data. For 2030 cases, 2020 IMO Marine Fuel specification change (from 3.5% to 0.5% Sulphur) is taken into account, considering the latest scrubber penetration assumption available.

Final EU product demands for 2016 and 2030 can be found in **Appendix 1**.

1.4. LP MODEL

1.4.1. Main features

Linear Programming (LP) is a mathematical tool that helps the decision-making process. LP consists in an optimization driven by an economic objective function (profit maximization or costs minimization), where variables involved are constrained by means of linear equations.

Concawe European Refining system LP model main features are:

- Approximately 90 000 columns (variables) and 20 000 rows (equations) – it is a very large model (~5 times more than a standard single refinery LP model)

- It is divided into 9 regions (1 period of 1 year) representing EU 27+4 (UK, Norway, Switzerland, Iceland)

Table 2 Regions and countries in Concawe LP model

Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU
Denmark Estonia Finland Iceland Latvia Lithuania Norway Sweden	Belgium Netherlands Luxembourg	Germany	Austria Czechia Hungary Poland Slovakia Switzerland	UK Ireland	France	Portugal Spain	Greece Cyprus Malta Slovenia Italia	Bulgaria Croatia Romania

- About 45 process unit types, 6 reference crudes, various intermediate product imports, natural gas, more than 30 finished products and some of the main petrochemical intermediates
- Mass, Carbon, Hydrogen and Sulphur balances ensured across the whole model
- New capacity investment structure (optional)

LP model main variables for optimization are:

- Crude throughput: fixed crudes ratio but free quantity (refer to **Appendix 1)**
- Oxygenates (ETBE, MTBE, and Ethanol): limited by gasoline pool specifications (mainly oxygen and bio contents)
- Other imports: limited by calibration runs
- Refining operations: routings, severities, utilizations
- Inter-regional transfers: finished products mainly and some distillate intermediates

For this study, it has been assumed that each region should individually produce at least 80% of HOP and RON 95 local demand (conservative approach). If a solution cannot be found, MTBE imports can be increased (till a maximum product oxygen content specification of 3.7 wt%) and if still infeasible, the minimum 80% is relaxed for the constrained region(s).

1.4.2. Calibration

The main potential drawback is that actual refineries may be subject to specific constraints that may not be properly represented on such a region-aggregated model. This type of models is subject to over-optimization, because all process unit capacities are available simultaneously for a given region, significantly increasing the degrees of freedom of the refining system. To mitigate this risk of over-optimization, a calibration run is performed prior to each Concawe study.

A reference year is selected (2016 for this study), for which all the data are available in Eurostat[5]. The main LP model settings for calibration are the following:

- Fixed demand per region
- Floating imports and exports, limited by actual values (as maximum values)

[5] Eurostat: https://ec.europa.eu/eurostat/, specifically nrg102, nrg103, nrg123, nrg133 series.

- Fixed crude recipe (crude ratios in %) for Europe, but the amount of crude slate processed is open and each region can process its own crude slate, as long as the overall EU crude slate is satisfied

Process units throughputs obtained in the calibration run are used as maximum capacities for the cases study (overall conservative approach).

This artificial way of reducing process unit's capacities allow to reduce the over-optimization. It could also be seen as conservative as it would be as if the refining assets would not adapt to the future constraints. Decades of experience in regional modelling showed us that it remains the best way to proceed to get results as realistic as possible. Furthermore, sensitivity cases allowing the model to invest in process units give an assessment of the adaption the refiners may choose to go to.

Refer to **Appendix 1** for further details on the calibration.

2. SHORT TERM: HOP AT 10% OF EU GASOLINE DOMESTIC DEMAND

2.1. MAIN RESULTS

Table 3 below summarizes the following results:

- At 10% of domestic demand (2016 Demand data), overall gasoline RON requirement increases from 0.2 to 0.4 (export included)
- At RON 100 and RON 102, South East Europe and Central Europe regions show slight difficulty to produce HOP grade: MTBE content consequently increased (other oxygenates fixed by definition)
- At RON 104, additional MTBE is required in all regions

As mentioned in section 1.4.2, it has to be noted that potential refinery adaptation (investments, modifications) are not considered in these cases.

Table 3 Overall pool results: average of HOP, RON 95 and export grades – HOP 10% of domestic demand

	Oxygenate pathway MTBE price @ 1.2 * RON 95				Oxygenate light pathway MTBE minimization (***)		
Overall gasoline RON 95 + HOP + Export average	HOP 98 Base	HOP 100	HOP 102	HOP 104	HOP 100	HOP 102	HOP 104
Overall pool RON	94.3	94.5	**94.6**	94.7	94.5	**94.5**	94.6
Average RON of refining components (*)	92.8	92.9	**93.0**	93.0	92.9	**93.0**	93.0
Average RON of oxygenates (**)	119.7	119.7	**119.5**	119.4	119.7	**119.6**	119.5
Volume % of refining components (*)	94.3%	94.3%	**94.0%**	93.8%	94.3%	**94.2%**	94.0%
MTBE content, wt% (in HOP & R95)	1.1%	1.1%	**1.6%**	2.0%	1.1%	**1.4%**	1.7%

(*) Excludes oxygenates produced by the refining system
(**) Oxygenates imported and produced by the refining system
*(***) MTBE price @ 5 * RON 95, for modelling purpose only*

2.2. FINISHED GRADES COMPOSITION

The finished grades composition is shown in the next tables, for both oxygenate pathways.

2.2.1. Oxygenate pathway

Average HOP & RON95 composition does not vary a lot between cases. There is a constant increase in MTBE requirements. HOP 98 and HOP 100 compositions are very similar, but when RON reaches 102, HOP composition changes noticeably, reflecting the adaptation for the system to achieve this level of RON. However, for the overall gasoline pool (HOP & 95R), the evolution remain minor.

Table 4 HOP composition and HOP & R95 weighted average composition – Oxygenate pathway – HOP 10% of domestic demand

	HOP Composition				HOP & R95 weighted average composition			
HOP Composition, wt%	HOP 98 Base	HOP 100	HOP 102	HOP 104	HOP 98 Base	HOP 100	HOP 102	HOP 104
C4s	1.5%	1.0%	1.5%	1.8%	0.6%	0.6%	0.7%	0.6%
Naphtha	3.8%	0.0%	0.0%	0.0%	4.4%	4.7%	4.5%	4.1%
Isomerate	6.2%	2.7%	0.7%	0.5%	9.2%	9.3%	8.7%	9.3%
Alkylate	18.7%	21.0%	28.5%	28.6%	9.2%	9.2%	9.3%	9.4%
Reformate	49.5%	43.8%	36.1%	30.1%	52.3%	51.8%	51.5%	50.8%
FCC Cracked Naphtha	1.9%	5.3%	6.0%	0.4%	9.3%	9.1%	9.2%	9.2%
BTX / SC Gasoline	9.3%	15.8%	16.7%	24.2%	6.0%	6.3%	6.6%	6.8%
TAEE	1.1%	2.6%	1.5%	2.2%	1.0%	1.0%	1.0%	1.0%
ETBE	3.3%	2.9%	3.2%	2.9%	3.3%	3.3%	3.3%	3.3%
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%
MTBE	1.1%	1.4%	2.2%	5.6%	1.1%	1.1%	1.6%	2.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
MTPY	8.1	8.0	7.9	7.8	82.4	82.2	82.3	82.2
MM3PY	10.7	10.5	10.4	10.2	109.6	109.5	109.3	109.3

2.2.2. Oxygenate light pathway

In the oxygenate light pathway, at high HOP RON values, the pool requires a lower MTBE content than in the oxygenate pathway. At HOP 98 / 100 / 102 there is no real minimisation of MTBE, the blended amount is the minimum required to meet the RON specifications (increasing from 1.1% to 1.4% in HOP&95R pool).

Table 5 HOP composition and HOP & R95 weighted average composition – Oxygenate light pathway – HOP 10% of domestic demand

	HOP Composition				HOP & R95 weighted average composition			
HOP Composition, wt%	HOP 98 Base	HOP 100	HOP 102	HOP 104	HOP 98 Base	HOP 100	HOP 102	HOP 104
C4s	1.5%	1.0%	1.1%	1.7%	0.6%	0.6%	0.6%	0.5%
Naphtha	3.8%	0.0%	0.0%	0.0%	4.4%	4.6%	4.2%	4.4%
Isomerate	6.2%	2.7%	3.4%	1.1%	9.2%	9.4%	9.9%	10.1%
Alkylate	18.7%	20.9%	25.7%	28.9%	9.2%	9.3%	9.2%	9.3%
Reformate	49.5%	44.3%	34.8%	28.6%	52.3%	51.8%	51.4%	50.5%
FCC Cracked Naphtha	1.9%	4.0%	5.3%	0.0%	9.3%	8.9%	9.0%	9.0%
BTX / SC Gasoline	9.3%	16.8%	19.4%	27.2%	6.0%	6.4%	6.3%	6.6%
TAEE	1.1%	2.4%	1.2%	1.0%	1.0%	1.0%	1.0%	1.0%
ETBE	3.3%	2.9%	3.2%	3.2%	3.3%	3.3%	3.3%	3.3%
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%
MTBE	1.1%	1.4%	2.2%	4.7%	1.1%	1.1%	1.4%	1.7%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
MTPY	8.1	8.0	7.9	7.8	82.4	82.2	82.2	82.1
MM3PY	10.7	10.5	10.4	10.2	109.6	109.5	109.4	109.3

2.3. FINISHED GRADES PROPERTIES

By definition, LP optimisation provides the best solution to the problem submitted by the user. This optimisation is then achieved through a cost minimisation. Consequently, the giveaways on specification constraints are also minimised as they represent a cost for the refiner.

In the pools properties presented in the sections below, main European gasoline constraints are saturated: RON (main constraint in this study), Aromatics and Benzene (mainly because of Reformate, which is a major RON contributor) and RVP (mainly because a summer stringent specification was chosen for this study).

It can be noted that no specification was applied on MON in HOP grades as it is uncertain how MON specification would evolve with the HOP. In addition, from a technical point of view, the engine would be tuned on RON only, hence the MON specification would have a minor impact.

2.3.1. Oxygenate pathway

Table 6 HOP properties and HOP & R95 weighted average properties - Oxygenate pathway – HOP 10% of domestic demand

	HOP Properties				HOP & R95 weighted average properties			
HOP Properties	HOP 98 Base	HOP 100	HOP 102	HOP 104	HOP 98 Base	HOP 100	HOP 102	HOP 104
Specific gravity	0.758	0.758	0.757	0.762	0.752	0.751	0.752	0.752
RON	**98.3**	**100.3**	**102.3**	**104.3**	**95.6**	**95.8**	**96.0**	**96.1**
MON	88.3	89.4	91.5	92.8	85.7	85.9	86.0	86.1
Olefins, vol%	3.9	6.9	6.5	7.0	4.4	4.3	4.4	4.3
Aromatics, vol%	**33.0**	**33.0**	**33.0**	**33.0**	**33.0**	32.9	**33.0**	**33.0**
Benzene, vol%	**0.9**	**0.9**	0.8	0.4	**0.9**	**0.9**	**0.9**	**0.9**
Oxygen, wt%	2.0	2.0	2.2	2.8	2.0	2.0	2.1	2.2
RVP, kPa	**58**	**58**	**58**	**58**	**58**	**58**	**58**	**58**
Evap. @70°C, vol%	29	32	29	34	32	33	32	33
Evap. @100°C, vol%	49	49	47	47	53	53	53	53
Evap. @150°C, vol%	86	83	84	85	85	85	85	84
LHV, GJ/T	42.4	42.4	42.3	42.0	42.4	42.4	42.3	42.3
Bio energy e%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%

Properties on constraint highlighted in **bold orange**

2.3.2. Oxygenate light pathway

Minimizing the MTBE content, the only visible change on HOP&95R pool properties is the oxygenates (going down from 2.1 to 2.0%).

Table 7 HOP properties and HOP & R95 weighted average properties - Oxygenate light pathway – HOP 10% of domestic demand

	HOP Properties				HOP & R95 weighted average properties			
HOP Properties	HOP 98 Base	HOP 100	HOP 102	HOP 104	HOP 98 Base	HOP 100	HOP 102	HOP 104
Specific gravity	0.758	0.758	0.756	0.762	0.752	0.751	0.751	0.751
RON	**98.3**	**100.3**	**102.3**	**104.3**	**95.6**	**95.8**	**96.0**	**96.1**
MON	88.3	89.3	91.3	92.7	85.7	85.9	86.0	86.1
Olefins, vol%	3.9	6.9	6.9	6.9	4.4	4.3	4.4	4.4
Aromatics, vol%	**33.0**	**33.0**	**33.0**	**33.0**	**33.0**	32.9	**33.0**	32.9
Benzene, vol%	**0.9**	**0.9**	0.7	0.3	**0.9**	**0.9**	**0.9**	0.8
Oxygen, wt%	2.0	2.0	2.2	2.6	2.0	2.0	2.0	2.1
RVP, kPa	**58**	**58**	**58**	**58**	**58**	**58**	**58**	**58**
Evap. @70°C, vol%	29	32	33	34	32	33	33	34
Evap. @100°C, vol%	49	49	49	46	53	53	53	53
Evap. @150°C, vol%	86	83	85	84	85	85	85	84
LHV, GJ/T	42.4	42.4	42.3	42.1	42.4	42.4	42.3	42.3
Bio energy e%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%

Properties on constraint highlighted in **bold orange**

2.4. CALIBRATED CAPACITIES UTILIZATION

In the table below are presented the "top of the barrel" process units (the one linked to the gasoline's components production) utilisation rates. The percentages reported are per 'calibrated' capacities, as obtained in calibration (refer to section 1.4.2). Calibrated capacities being lower than installed capacities, a 100% do not necessarily mean that the utilisation is at full installed capacity.

Most of the process units being saturated in the base case, there is no much margin to provide more RON in HOP cases. However, when MTBE is minimised and when HOP RON is at high level, it can be seen that Isomerisation (with recycle) utilisation rate increases.

Table 8 Calibrated capacities utilisation

	Oxygenate pathway				Oxygenate light pathway			
Process units utilization % *	HOP 98 Base	HOP 100	HOP 102	HOP 104	HOP 98 Base	HOP 100	HOP 102	HOP 104
CDU	100%	100%	100%	100%	100%	100%	100%	100%
FCC	100%	99%	100%	100%	99%	100%	100%	100%
NHT	87%	88%	86%	87%	88%	87%	88%	87%
CN HDT	99%	100%	100%	100%	100%	100%	100%	99%
SR REF	100%	100%	100%	100%	100%	100%	100%	100%
CCR REF	93%	96%	93%	93%	96%	94%	95%	93%
ALK	100%	100%	100%	100%	100%	100%	100%	100%
ISOM OT	76%	78%	78%	81%	78%	83%	84%	76%
ISOM REC	72%	71%	62%	79%	71%	72%	87%	72%

Process units utilization % *	Oxygenate pathway HOP 98 Base	Oxygenate pathway HOP 100	Oxygenate pathway HOP 102	Oxygenate pathway HOP 104	Oxygenate light pathway HOP 98 Base	Oxygenate light pathway HOP 100	Oxygenate light pathway HOP 102	Oxygenate light pathway HOP 104
ETBE **	100%	98%	100%	100%	98%	100%	99%	100%
TAEE **	100%	100%	100%	100%	100%	100%	100%	100%
SRU	100%	99%	100%	100%	99%	100%	100%	100%
H2 Plant	99%	100%	98%	98%	100%	98%	98%	99%

** As percentage of 'calibrated' capacity, e.g. 100% of FCC calibrated capacity corresponds to 87% of installed capacity. Calibration methodology developed to reduce LP over-optimisation.*
*** To simplify, it has been considered that MTBE/ETBE and TAME/TAEE would run only on ETBE and TAEE modes.*

2.5. REGIONAL PRODUCTIONS AND HOP BALANCES

The refinery products in each region for both pathways are shown below. There are no significant variations between both.

The vision shown per region, as defined in the Concawe LP model, is not to identify or determine the actual and future evolution of the production in these individual 9 regions. The model was not built for this purpose, the accuracy of the trade flows between regions (for intermediate and finished products) is not good enough.

The vision as shown for each region is there to check that, for different refinery configuration (each region having different process units' capacities), the refining system was able to produce significant quantity of the HOP demand (the minimum being fixed at 80% of the regional HOP demand). It helps to understand that the evolution is not valid for one average refinery configuration but applies for a multiple variety of different refinery schemes.

2.5.1. Oxygenate pathway

As can be seen on the tables and figures below, for this short term case at low HOP demand, the refining system can always produce 80% of the HOP requested in each region, even at RON 102.

Table 9 Regional productions, MTPY – Oxygenate pathway - HOP 10% of domestic demand

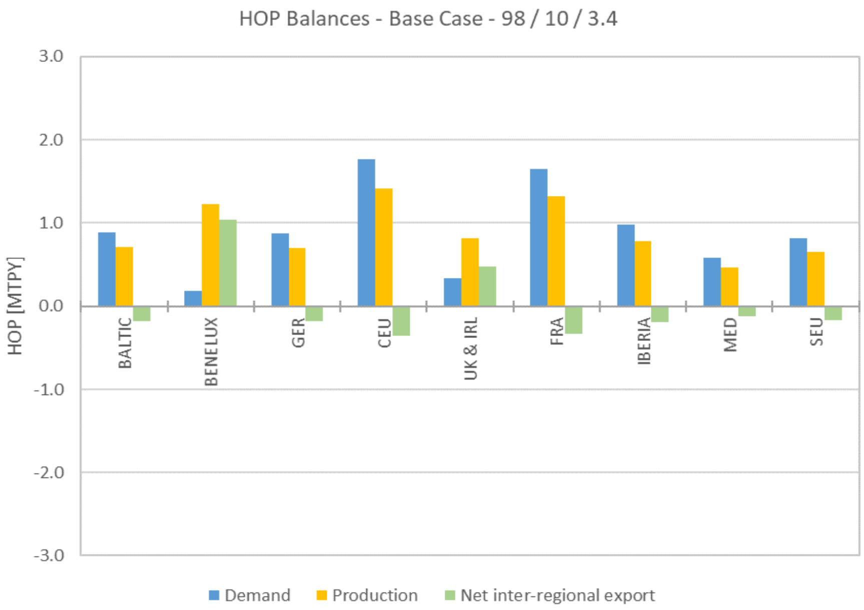
Base Case Productions, MTPY *	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	Total
LPG	1.6	1.1	1.6	2.8	1.3	1.7	2.1	3.9	1.1	**17.1**
Gasoline Premium 95	5.2	5.1	13.8	8.0	10.5	6.4	10.6	13.3	1.4	**74.3**
Gasoline 98	0.7	1.2	0.7	1.4	0.8	1.3	0.8	0.5	0.7	**8.1**
Gasoline Export	7.5	7.4	3.1	1.5	6.1	4.0	3.2	10.2	2.6	**45.7**
Jet	4.2	5.9	10.2	3.8	16.4	5.9	7.2	6.1	0.6	**60.2**
Middle - Distillate	28.1	44.3	37.1	35.7	26.6	26.3	35.7	44.0	8.5	**286.4**
Heavy Fuels	4.9	14.1	4.1	1.9	2.9	2.9	9.5	10.3	0.6	**51.3**
Other	4.3	16.9	20.6	9.8	6.6	8.4	10.4	10.6	3.3	**90.9**
Total	**56.5**	**95.9**	**91.3**	**64.8**	**71.2**	**56.9**	**79.5**	**99.0**	**18.8**	**634.0**

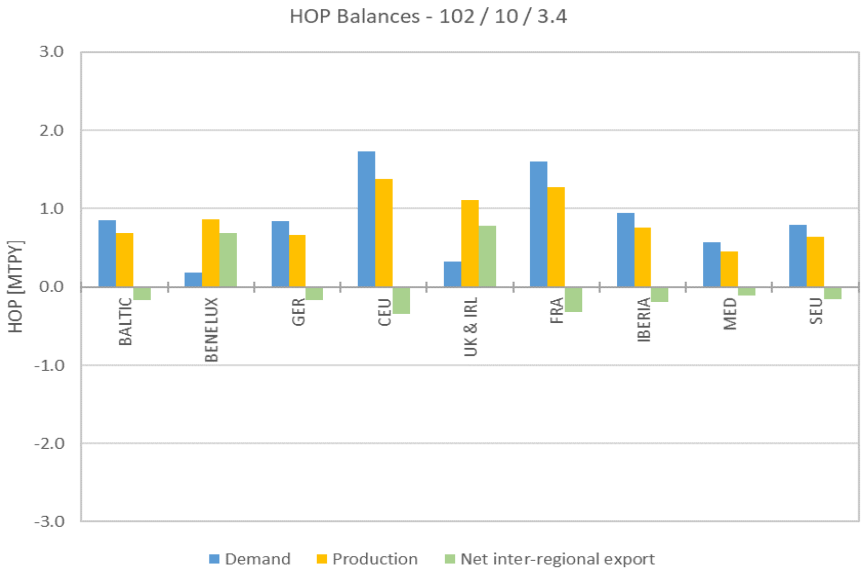
HOP 102 (10%) Productions, MTPY *	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	Total
LPG	1.7	1.1	1.6	2.7	1.3	1.7	2.1	3.9	1.1	**17.1**
Gasoline Premium 95	5.4	5.3	13.8	8.0	10.5	5.6	10.5	13.8	1.4	**74.4**
Gasoline HOP (102)	0.7	0.9	0.7	1.4	1.1	1.3	0.8	0.5	0.6	**7.9**
Gasoline Export	7.4	7.2	3.4	1.9	5.7	4.6	3.3	9.7	3.0	**46.3**
Jet	4.2	6.2	10.1	3.8	16.1	6.0	7.2	6.1	0.6	**60.2**
Middle - Distillate	28.0	44.6	37.2	34.9	26.5	26.8	35.6	44.2	8.5	**286.4**
Heavy Fuels	4.9	14.1	4.2	1.9	2.9	2.9	9.5	10.4	0.6	**51.4**
Other	4.2	16.9	20.6	9.8	6.6	8.4	10.5	10.6	3.3	**90.9**
Total	**56.5**	**96.2**	**91.6**	**64.5**	**70.7**	**57.3**	**79.4**	**99.1**	**19.2**	**634.6**

** Productions include intermediate components imported from other regions.*

It can be observed that Benelux and UK & Ireland regions 'export' part of their production to satisfy other regions demand. Though there may be some logistics constraints not taken into account in the modelling, this is explained by the higher Reformer / Alkylation / Isomerisation capacities (relative to crude capacity) in these regions compared to the rest of Europe.

Figure 1 HOP balances - RON 98 Base case vs RON 102 - Oxygenate pathway - HOP 10% of domestic demand





2.5.2. Oxygenate light pathway

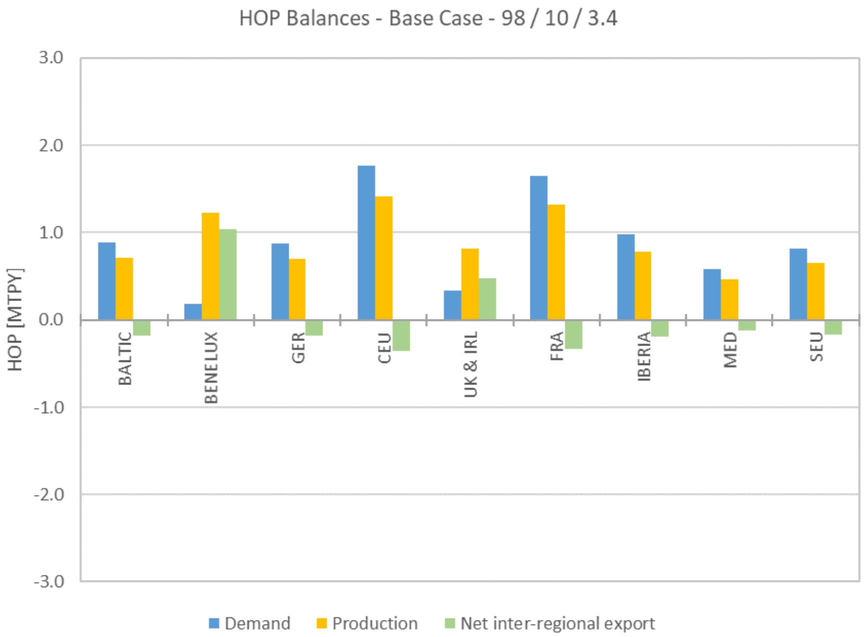
At this low level of HOP demand, there is almost no difference between oxygenate and oxygenate light pathways.

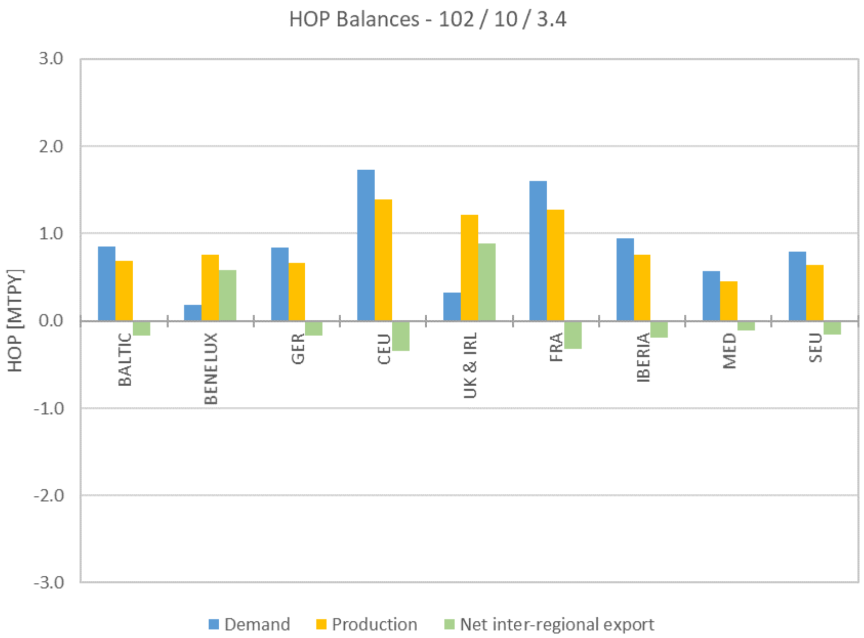
Table 10 Regional productions - Oxygenate light pathway – HOP 10% of domestic demand

Base Case Productions, MTPY *	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	Total
LPG	1.6	1.1	1.6	2.8	1.3	1.7	2.1	3.9	1.1	**17.1**
Gasoline Premium 95	5.2	5.1	13.8	8.0	10.5	6.4	10.6	13.3	1.4	**74.3**
Gasoline 98	0.7	1.2	0.7	1.4	0.8	1.3	0.8	0.5	0.7	8.1
Gasoline Export	7.5	7.4	3.1	1.5	6.1	4.0	3.2	10.2	2.6	**45.7**
Jet	4.2	5.9	10.2	3.8	16.4	5.9	7.2	6.1	0.6	**60.2**
Middle - Distillate	28.1	44.3	37.1	35.7	26.6	26.3	35.7	44.0	8.5	**286.4**
Heavy Fuels	4.9	14.1	4.1	1.9	2.9	2.9	9.5	10.3	0.6	**51.3**
Other	4.3	16.9	20.6	9.8	6.6	8.4	10.4	10.6	3.3	**90.9**
Total	**56.5**	**95.9**	**91.3**	**64.8**	**71.2**	**56.9**	**79.5**	**99.0**	**18.8**	**634.0**

HOP 102 Productions, MTPY *	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	Total
LPG	1.7	1.1	1.5	2.7	1.3	1.7	2.1	3.9	1.1	**17.1**
Gasoline Premium 95	5.7	4.8	14.0	8.0	10.5	5.7	9.8	14.4	1.4	**74.3**
Gasoline HOP (102)	0.7	0.8	0.7	1.4	1.2	1.3	0.8	0.5	0.6	7.9
Gasoline Export	7.4	7.7	3.1	1.7	5.6	4.6	3.9	9.2	2.7	**46.1**
Jet	4.1	6.2	10.0	3.8	16.4	5.8	7.2	6.1	0.6	**60.2**
Middle - Distillate	28.2	45.0	37.2	34.2	26.7	26.9	35.6	44.1	8.5	**286.4**
Heavy Fuels	4.8	14.1	4.2	1.9	2.9	2.9	9.5	10.3	0.6	**51.4**
Other	4.3	16.9	20.6	9.8	6.6	8.4	10.5	10.6	3.3	**90.9**
Total	**57.0**	**96.6**	**91.4**	**63.4**	**71.3**	**57.2**	**79.3**	**99.2**	**18.9**	**634.3**

Figure 2 HOP balances – RON 98 Base case vs RON 102 - Oxygenate light pathway – HOP 10% of domestic demand





2.6. REGIONAL COMPOSITIONS

2.6.1. Oxygenate pathway

Depending on the refining configuration of each region, there are some discrepancies in pool compositions. This confirms that there is not a single refining configuration that allows to reach a HOP at high RON (102).

Table 11 Regional composition, RON 98 Base case– Oxygenate pathway – RON 98 10% of domestic demand

RON 98 Base case Composition, wt%	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	EU average
C4s	1.5%	2.2%	2.4%	0.0%	1.6%	1.6%	1.7%	1.7%	1.3%	**1.5%**
Naphtha	0.0%	5.1%	4.7%	1.1%	0.0%	8.7%	9.8%	0.0%	0.9%	**3.8%**
Isomerate	7.7%	0.0%	1.3%	18.3%	0.0%	5.3%	0.0%	8.1%	11.0%	**6.2%**
Alkylate	20.7%	22.1%	22.9%	10.8%	21.6%	17.3%	19.4%	21.0%	19.9%	**18.7%**
Reformate	54.6%	54.6%	58.2%	42.8%	57.1%	43.1%	42.7%	47.0%	53.1%	**49.5%**
FCC Cracked Naphtha	2.2%	0.0%	0.0%	0.0%	7.4%	2.2%	1.9%	7.2%	0.0%	**1.9%**
BTX / SC Gasoline	5.0%	7.8%	2.2%	14.3%	4.1%	13.5%	16.3%	6.7%	5.4%	**9.3%**
TAEE	0.0%	0.0%	0.0%	6.1%	0.0%	0.0%	0.0%	0.0%	0.0%	**1.1%**
ETBE	3.6%	3.5%	3.5%	1.9%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.3%**
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.6%**
MTBE	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	**1.1%**
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**100.0%**
MTPY	0.7	1.2	0.7	1.4	0.8	1.3	0.8	0.5	0.7	**8.1**
MM3PY	0.9	1.6	0.9	1.9	1.1	1.7	1.0	0.6	0.9	**10.7**

Table 12 Regional composition, HOP 102 – Oxygenate pathway – HOP 10% of domestic demand

HOP 102 Composition, wt%	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	EU average
C4s	1.8%	1.3%	1.4%	2.4%	1.3%	1.2%	0.0%	1.4%	2.5%	**1.5%**
Naphtha	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
Isomerate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.9%	**0.7%**
Alkylate	30.0%	28.4%	31.1%	28.7%	29.2%	30.7%	19.4%	27.7%	29.8%	**28.5%**
Reformate	41.8%	25.6%	24.7%	42.8%	37.1%	36.9%	37.2%	30.4%	41.2%	**36.1%**
FCC Cracked Naphtha	1.3%	8.1%	18.0%	0.0%	3.8%	18.1%	0.0%	0.0%	0.0%	**6.0%**
BTX / SC Gasoline	16.8%	28.3%	16.5%	7.4%	20.2%	4.8%	35.1%	32.3%	5.5%	**16.7%**
TAEE	0.0%	0.0%	0.0%	8.3%	0.0%	0.0%	0.0%	0.0%	0.0%	**1.5%**
ETBE	3.6%	3.6%	3.6%	1.2%	3.6%	3.6%	3.6%	3.6%	3.5%	**3.2%**
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.6%**
MTBE	1.1%	1.1%	1.1%	5.6%	1.1%	1.1%	1.1%	1.1%	5.0%	**2.2%**
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**100.0%**
MTPY	0.7	0.9	0.7	1.4	1.1	1.3	0.8	0.5	0.6	**7.9**
MM3PY	0.9	1.1	0.9	1.8	1.5	1.7	1.0	0.6	0.8	**10.4**

2.6.2. Oxygenate light pathway

There is no major difference in pool composition between both pathways, as these compositions depend on the refining configuration rather than on the MTBE/Gasoline price differential.

Table 13 Regional composition, RON 98 Base case – Oxygenate light pathway – RON 98 10% of domestic demand

RON 98 Base case Composition, wt%	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	EU average
C4s	1.5%	2.2%	2.4%	0.0%	1.6%	1.6%	1.7%	1.7%	1.3%	**1.5%**
Naphtha	0.0%	5.1%	4.7%	1.1%	0.0%	8.7%	9.8%	0.0%	0.9%	**3.8%**
Isomerate	7.7%	0.0%	1.3%	18.3%	0.0%	5.3%	0.0%	8.1%	11.0%	**6.2%**
Alkylate	20.7%	22.1%	22.9%	10.8%	21.6%	17.3%	19.4%	21.0%	19.9%	**18.7%**
Reformate	54.6%	54.6%	58.2%	42.8%	57.1%	43.1%	42.7%	47.0%	53.1%	**49.5%**
FCC Cracked Naphtha	2.2%	0.0%	0.0%	0.0%	7.4%	2.2%	1.9%	7.2%	0.0%	**1.9%**
BTX / SC Gasoline	5.0%	7.8%	2.2%	14.3%	4.1%	13.5%	16.3%	6.7%	5.4%	**9.3%**
TAEE	0.0%	0.0%	0.0%	6.1%	0.0%	0.0%	0.0%	0.0%	0.0%	**1.1%**
ETBE	3.6%	3.5%	3.5%	1.9%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.3%**
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.6%**
MTBE	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	**1.1%**
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**100.0%**
MTPY	0.7	1.2	0.7	1.4	0.8	1.3	0.8	0.5	0.7	**8.1**
MM3PY	0.9	1.6	0.9	1.9	1.1	1.7	1.0	0.6	0.9	**10.7**

Table 14 Regional composition, HOP 102 - Oxygenate light pathway – HOP 10% of domestic demand

HOP 102 Composition, wt%	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	EU average
C4s	2.0%	1.4%	1.4%	0.2%	1.3%	1.2%	0.0%	1.4%	1.8%	**1.1%**
Naphtha	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
Isomerate	0.0%	0.0%	0.0%	11.2%	0.0%	0.0%	0.0%	0.0%	18.1%	**3.4%**
Alkylate	30.3%	27.2%	31.1%	15.1%	29.3%	30.4%	19.3%	27.7%	26.3%	**25.7%**
Reformate	41.9%	27.2%	24.7%	36.2%	37.3%	37.0%	35.6%	30.4%	36.2%	**34.8%**
FCC Cracked Naphtha	0.0%	0.0%	18.0%	0.0%	5.1%	18.4%	0.0%	0.0%	0.0%	**5.3%**
BTX / SC Gasoline	17.6%	36.0%	16.5%	19.6%	18.7%	4.8%	36.8%	32.3%	5.5%	**19.4%**
TAEE	0.0%	0.0%	0.0%	7.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**1.2%**
ETBE	3.6%	3.6%	3.6%	1.6%	3.6%	3.6%	3.6%	3.6%	3.5%	**3.2%**
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.6%**
MTBE	1.1%	1.1%	1.1%	5.5%	1.1%	1.1%	1.1%	1.1%	4.9%	**2.2%**
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**100.0%**
MTPY	0.7	0.8	0.7	1.4	1.2	1.3	0.8	0.5	0.6	**7.9**
MM3PY	0.9	1.0	0.9	1.8	1.6	1.7	1.0	0.6	0.8	**10.4**

3. LONG TERM – 2030: HOP AT 50% OF EU GASOLINE DOMESTIC DEMAND

3.1. SPECIFIC ASSUMPTIONS

Main assumptions are similar as for short term cases (refer to section 1.3).

A '2030 calibration' is performed to generate a set of process unit's capacities in line with 2030 demand (similar to 2016 calibration described in section 1.4.2):

- Crude slate (ratio, not amount) and products demand are fixed based on latest Wood Mackenzie forecasts
- Imports / Exports can vary from 0 to values forecasted by Wood Mackenzie (set as 'maximum' type of constraint)
- Optimisation can adjust the total amount of crude processed, the routings of intermediate products, the exchanges between EU regions, the amount of imports / exports
- The Demand decreasing significantly between 2016 and 2030 (**see Appendix 1**), the resulting process unit's utilizations are set as maximum capacities for the 2030 HOP. It is a conservative approach, but on purpose to avoid modelling over-optimization.

2030 Base case is set up considering 10% of RON 98 production. The assumption is that if the HOP RON is not higher than today, it is unlikely that the demand for this grade would increase between 2016 and 2030. At RON 100 and higher, it is considered that HOP would represent 50% of the gasoline domestic demand.

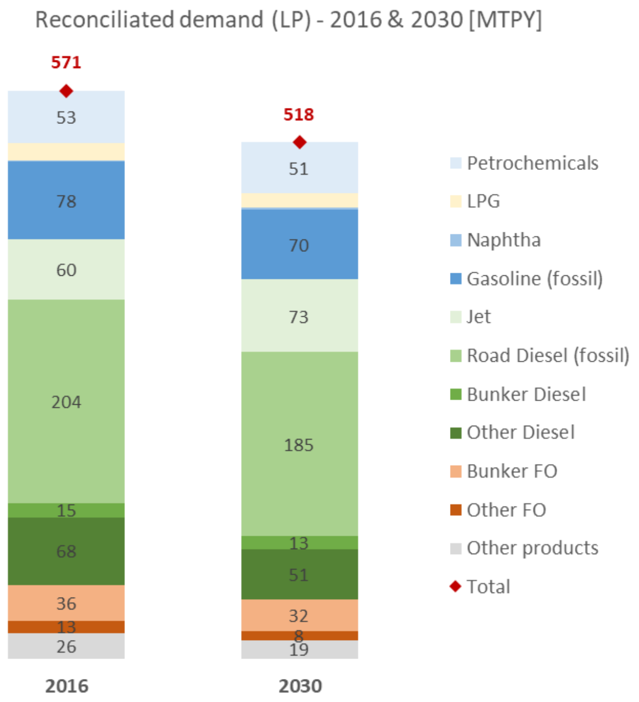
3.2. DEMAND COMPARISON, 2016-2030

Demand is mainly based on Eurostat (2016) and Wood Mackenzie (2030 forecasts) data and is reconciled to cope with study basis definitions (EU regions, product categories, imports/exports).

By 2030, the forecast shows an overall 9% decrease in demand versus 2016, with the following distribution:

- ~ 10% decrease for fossil gasoline
- ~ 10% decrease for fossil road diesel
- ~ 7% decrease for total middle distillates

Figure 3 Reconciled demand (2016 and 2030), Bio excluded



3.3. MAIN RESULTS

Table 15 below - Overall pool results: average of HOP, RON 95 and export grades - summarizes the following results:

- At 50% of domestic demand, overall gasoline RON requirement increases from 1.2 (HOP at RON 100) to 2.4 (HOP at RON 104). The overall gasoline RON includes the domestic grades (RON 95 and HOP) and the export grades (US and 'Other').
- Finished grade transferred between regions is increasing
- Additional MTBE is required for all targeted RON: > 4% vs. a 2016 value around 1.1%, oxygen specification has to be relaxed from 2.7 wt% (E5 specification) to 3.7 wt% (E10 specification) in most of the regions.
    - In case of MTBE restriction in the gasoline pool, it has been checked that replacing MTBE by "non-Bio ETBE" would lead to similar modelling results.
- As expected, RON 104 is difficult to achieve as we do not allow investment or optimization of the refinery assets. The minimum amount of MTBE required to achieve RON 104 is not linear with RON: +0.6% from RON 100 to 102, +3.8% from RON 102 to 104.

Table 15 Overall pool results: average of HOP, RON 95 and export grades – HOP 50% of domestic demand

	Oxygenate pathway MTBE price @ 1.2 * RON 95				Oxygenate light pathway MTBE minimization (***)		
Overall gasoline RON 95 + HOP + Export average	**HOP 98 Base 10%**	**HOP 100**	**HOP 102**	**HOP 104**	**HOP 100**	**HOP 102**	**HOP 104**
HOP ratio on domestic demand, wt%	10	50	**50**	50	50	**50**	50
Overall pool RON	94.4	95.6	**96.4**	96.8	95.6	**96.4**	96.9
Average RON of refining components (*)	92.7	93.5	**94.2**	93.9	93.7	**94.4**	94.4
Average RON of oxygenates (**)	120.2	119.1	**119.0**	118.2	119.3	**119.5**	118.5
Volume % of refining components (*)	93.9%	91.9%	**91.4%**	88.2%	92.4%	**92.4%**	91.9%
MTBE content, wt% (in HOP & R95)	1.1%	4.6%	**5.3%**	10.6%	3.9%	**4.5%**	8.3%

(*) Excludes oxygenates produced by the refining system
(**) Oxygenates imported and produced by the refining system
*(***) MTBE price @ 5 * RON 95, for modelling purpose only*

3.4. FINISHED GRADES COMPOSITION

At this high level of HOP demand, impacts on the gasoline pool are clearer. The optimisation tends to maximise the MTBE 'solution' as it is leading to the model optimal solution for the system. However, when MTBE is minimised the overall gasoline pool structure changes marginally as the MTBE minimum value is still high, at 83% of the optimised value (for RON 102 case).

3.4.1. Oxygenate pathway

Table 16 HOP composition and HOP & R95 weighted average composition - Oxygenate pathway - HOP 50% of domestic demand

	HOP Composition				HOP & R95 weighted average composition			
HOP Composition, wt%	HOP 98 Base 10%	HOP 100	HOP 102	HOP 104	HOP 98 Base 10%	HOP 100	HOP 102	HOP 104
C4s	1.2%	0.8%	0.8%	1.6%	0.6%	0.4%	0.4%	0.8%
Naphtha	2.5%	0.5%	0.0%	0.0%	4.0%	1.9%	1.3%	2.0%
Isomerate	5.6%	6.2%	5.2%	1.2%	10.2%	10.7%	12.3%	8.8%
Alkylate	18.6%	16.1%	19.7%	25.0%	9.9%	11.3%	12.0%	12.4%
Reformate	49.1%	47.5%	41.0%	38.8%	53.4%	50.5%	47.3%	46.1%
FCC Cracked Naphtha	4.9%	7.2%	9.7%	6.2%	7.4%	6.9%	7.8%	4.6%
BTX / SC Gasoline	9.7%	7.7%	8.4%	8.2%	5.6%	5.9%	6.0%	7.1%
TAEE	0.3%	1.2%	1.7%	1.8%	0.8%	0.8%	0.9%	0.8%
ETBE	3.5%	3.1%	3.0%	2.9%	3.4%	3.3%	3.3%	3.1%
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%
MTBE	1.1%	6.0%	6.9%	10.7%	1.1%	4.6%	5.3%	10.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
MTPY	8.2	37.6	37.0	36.8	77.1	76.3	75.8	76.2
MM3PY	10.8	49.7	49.0	48.4	102.9	101.7	101.0	100.9

3.4.2. Oxygenate light pathway

Table 17 HOP composition and HOP & R95 weighted average composition - Oxygenate light pathway - HOP 50% of domestic demand

	HOP Composition				HOP & R95 weighted average composition			
HOP Composition, wt%	HOP 98 Base 10%	HOP 100	HOP 102	HOP 104	HOP 98 Base 10%	HOP 100	HOP 102	HOP 104
C4s	1.2%	0.8%	0.8%	1.6%	0.6%	0.4%	0.4%	0.8%
Naphtha	2.5%	0.4%	0.0%	0.0%	4.0%	2.2%	1.0%	1.7%
Isomerate	5.6%	7.1%	5.2%	1.3%	10.2%	11.3%	12.6%	9.9%
Alkylate	18.6%	17.0%	20.8%	25.0%	9.9%	11.1%	12.5%	12.4%
Reformate	49.1%	46.4%	40.9%	38.8%	53.4%	49.4%	47.3%	45.5%
FCC Cracked Naphtha	4.9%	8.3%	10.3%	6.0%	7.4%	7.7%	8.7%	7.6%
BTX / SC Gasoline	9.7%	7.1%	8.1%	8.4%	5.6%	6.3%	5.6%	6.1%
TAEE	0.3%	1.2%	0.5%	1.8%	0.8%	0.8%	0.6%	0.9%
ETBE	3.5%	3.2%	3.3%	2.9%	3.4%	3.3%	3.3%	3.2%

Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%
MTBE	1.1%	5.0%	6.5%	10.7%	1.1%	3.9%	4.5%	8.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
MTPY	8.2	37.5	37.0	36.8	77.1	76.2	75.7	75.8
MM3PY	10.8	49.7	49.0	48.4	102.9	101.5	100.9	100.5

3.5. FINISHED GRADES PROPERTIES

Saturated specifications are consistent with the short term cases.

3.5.1. Oxygenate pathway

Table 18 HOP properties and HOP & R95 weighted average properties - Oxygenate pathway - HOP 50% of domestic demand

	HOP Properties				*HOP & R95 weighted average properties*			
HOP Properties	HOP 98 Base 10%	HOP 100	HOP 102	HOP 104	HOP 98 Base 10%	HOP 100	HOP 102	HOP 104
Specific gravity	0.755	0.755	0.756	0.760	0.750	0.751	0.751	0.755
RON	**98.3**	**100.3**	**102.3**	**104.3**	**95.6**	**97.7**	**98.7**	**99.7**
MON	88.4	89.6	91.7	93.8	85.9	87.5	88.5	89.4
Olefins, vol%	4.8	5.5	6.8	5.9	4.1	4.1	4.4	3.7
Aromatics, vol%	**33.0**	**33.0**	**33.0**	**33.0**	32.8	32.6	32.5	31.9
Benzene, vol%	**0.9**	**0.9**	0.8	0.7	**0.9**	**0.9**	0.8	0.8
Oxygen, wt%	2.0	2.9	3.0	**3.7**	2.0	2.6	2.7	**3.7**
RVP, kPa	**58**	**58**	**58**	**58**	**58**	**58**	**58**	**58**
Evap. @70°C, vol%	29	35	35	33	32	36	37	39
Evap. @100°C, vol%	49	54	54	50	53	56	57	57
Evap. @150°C, vol%	86	87	88	87	87	88	88	88
LHV, GJ/T	42.4	42.0	42.0	41.6	42.4	42.1	42.1	41.6
Bio energy e%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%

Properties on constraint highlighted in **bold orange**

3.5.2. Oxygenate light pathway

Table 19 HOP properties and HOP & R95 weighted average properties - Oxygenate light pathway - HOP 50% of domestic demand

	HOP Properties				HOP & R95 weighted average properties			
HOP Properties	HOP 98 Base 10%	HOP 100	HOP 102	HOP 104	HOP 98 Base 10%	HOP 100	HOP 102	HOP 104
Specific gravity	0.755	0.754	0.755	0.760	0.750	0.751	0.750	0.754
RON	**98.3**	**100.3**	**102.3**	**104.3**	**95.6**	**97.7**	**98.7**	**99.7**
MON	88.4	89.8	91.8	93.8	85.9	87.6	88.6	89.4
Olefins, vol%	4.8	5.6	6.4	5.9	4.1	4.2	4.6	4.2
Aromatics, vol%	**33.0**	**33.0**	**33.0**	**33.0**	32.8	**33.0**	32.6	32.6
Benzene, vol%	**0.9**	**0.9**	0.8	0.7	**0.9**	**0.9**	**0.9**	0.8
Oxygen, wt%	2.0	2.7	3.0	**3.7**	2.0	2.5	2.6	3.3
RVP, kPa	**58**	**58**	**58**	**58**	**58**	**58**	**58**	**58**

Evap. @70°C, vol%	29	34	34	33	32	36	37	37
Evap. @100°C, vol%	49	53	53	50	53	56	56	55
Evap. @150°C, vol%	86	86	87	87	87	87	87	87
LHV, GJ/T	42.4	42.1	42.0	41.6	42.4	42.2	42.1	41.8
Bio energy e%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%

Properties on constraint highlighted in **bold orange**

3.6. CALIBRATED CAPACITIES UTILIZATION

In the table below are presented the top of the barrel process unit utilisation rates. The percentages reported are per 'calibrated' capacities, as obtained in calibration (refer to section 1.4.2).

Refining system being already constraint in the base case, there is not much margin for the system to further optimise the refining operations. However, where there is some margin, Isomerisation mainly, utilisation increases with the RON requirements.

The assessment of a possible scenario with the evolution of the refinery process units is shown in the Investment sensitivity case (see 3.9.1).

Table 20 Calibrated capacities utilisation

	Oxygenate pathway				Oxygenate light pathway			
Process units utilization % *	**HOP 98 Base 10%**	**HOP 100**	**HOP 102**	**HOP 104**	**HOP 98 Base 10%**	**HOP 100**	**HOP 102**	**HOP 104**
CDU	100%	100%	100%	100%	100%	100%	100%	100%
FCC	97%	97%	98%	99%	97%	96%	98%	100%
NHT	80%	80%	83%	95%	80%	83%	84%	97%
CN HDT	77%	81%	92%	73%	77%	89%	100%	90%
SR REF	100%	100%	98%	99%	100%	100%	98%	100%
CCR REF	92%	97%	100%	100%	92%	99%	100%	100%
ALK	100%	100%	100%	100%	100%	100%	100%	100%
ISOM OT	71%	80%	82%	80%	71%	83%	83%	74%
ISOM REC	69%	74%	94%	93%	69%	82%	97%	100%
ETBE **	100%	100%	100%	100%	100%	96%	100%	100%
TAEE **	100%	100%	100%	100%	100%	100%	76%	100%
SRU	96%	96%	95%	94%	96%	97%	96%	94%
H2 Plant	98%	97%	98%	98%	98%	98%	98%	98%

** As percentage of 'calibrated' capacity, e.g. 100% of FCC calibrated capacity corresponds to 87% of installed capacity. Calibration methodology developed to reduce LP over-optimisation.*
*** To simplify, it has been considered that MTBE/ETBE and TAME/TAEE would run only on ETBE and TAEE modes.*

3.7. REGIONAL PRODUCTIONS AND HOP BALANCES

As mentioned in section 2.5, the vision shown for each region is there to check that, for different refinery configuration (each region having different process units' capacities), the model was able to produce significant quantity of the HOP demand.

At this high level of HOP demand, difficulties for region to supply 80% of the HOP requested are emphasised. According to the Concawe modelling, at least three regions cannot supply 80% of the HOP demand, even with high MTBE imports allowed. There is no real MTBE minimisation in the oxygenate light pathway, as the optimisation is driven by the feasibility rather than by the economics (LP optimisation needs to satisfy all the system constraints at any cost, it cannot 'prioritise' or 'skip' some constraints to increase the profitability).

It is to be noted that in the refinery Investment case, the regional issues disappear. It is seen by some obverse as a more realistic adaptation of the refinery system.

3.7.1. Oxygenate pathway

The pressure on gasoline export is increasing slightly (from 36.5Mt to 36.6Mt), but it is not significant. The oxygenate blending is increasing (MTBE from 1.1 to 5.3% (+3MTPY) in gasoline HOP+95), but it is compensated by lower crude T/P and optimization of the gasoline blending (minimisation of low octane gasoline components).

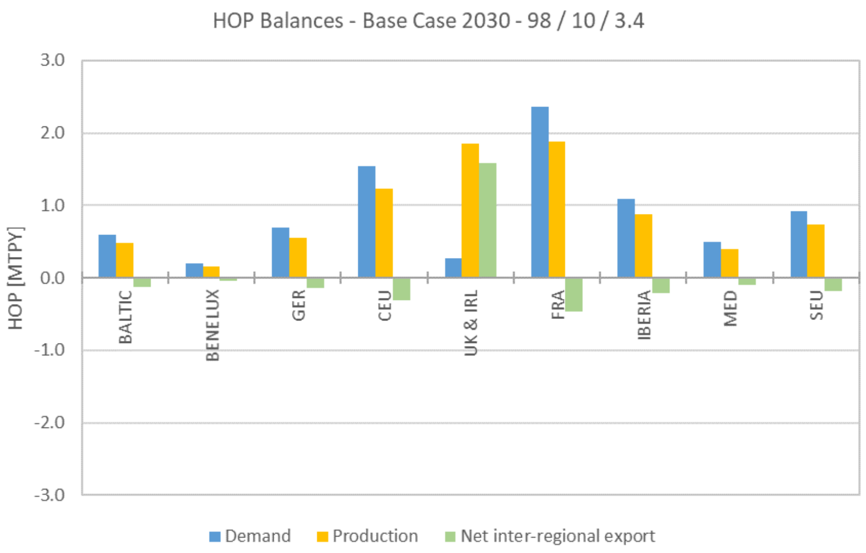
Table 21 Regional productions, MTPY - Oxygenate pathway - HOP 50% of domestic demand

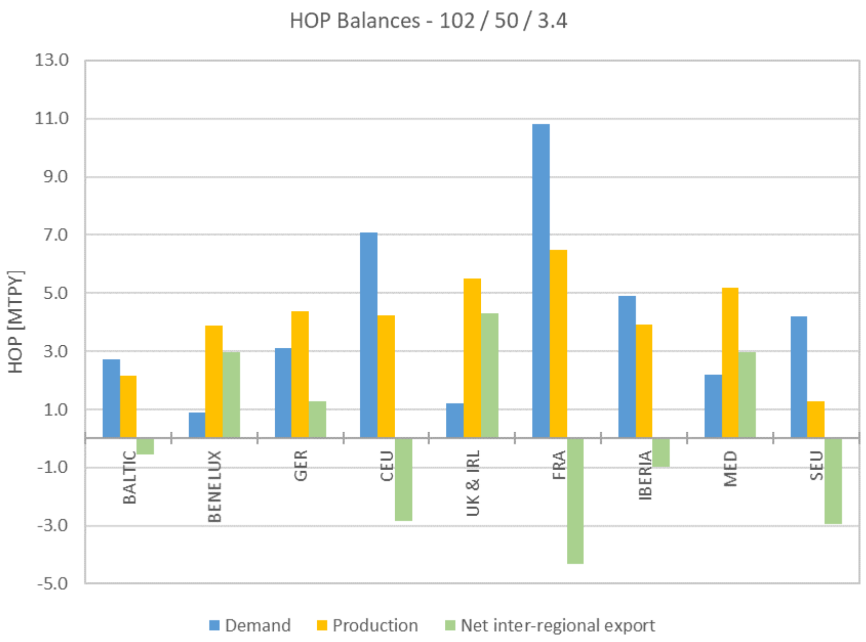
HOP 98 Base 10% Productions, MTPY *	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	Total
LPG	1.6	2.2	2.1	1.4	1.6	1.3	1.9	2.1	1.0	**15.2**
Gasoline Premium 95	4.4	6.3	12.2	7.2	8.5	6.7	9.7	12.4	1.6	**69.0**
Gasoline 98	0.5	0.2	0.6	1.2	1.9	1.9	0.9	0.4	0.7	8.2
Gasoline Export	8.2	6.3	2.3	1.6	4.8	2.6	2.7	6.0	2.0	**36.5**
Jet	5.0	7.1	11.0	5.0	18.0	8.0	10.3	7.6	1.1	**72.9**
Middle - Distillate	27.3	35.7	34.2	27.6	23.5	23.8	34.8	42.0	9.8	**258.6**
Heavy Fuels	6.2	1.9	3.1	1.8	3.0	2.0	3.8	7.6	0.9	**30.1**
Other	3.8	16.4	16.8	7.9	6.0	7.7	11.2	9.5	3.6	**83.0**
Total	**56.9**	**76.1**	**82.1**	**53.7**	**67.2**	**54.1**	**75.1**	**87.6**	**20.7**	**573.5**

HOP 102 (50%) Productions, MTPY *	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	Total
LPG	2.1	1.4	0.7	1.4	1.3	0.5	3.4	3.0	1.4	**15.2**
Gasoline Premium 95	3.4	2.8	6.4	4.9	4.8	3.8	3.3	7.4	2.0	**38.8**
Gasoline HOP (102)	2.2	3.9	4.4	4.3	5.5	6.5	3.9	5.2	1.3	37.0
Gasoline Export	8.9	4.8	3.1	1.1	4.7	1.5	5.6	6.0	0.9	**36.6**
Jet	5.8	7.1	11.0	4.1	18.0	8.0	10.3	7.8	0.9	**72.9**
Middle - Distillate	27.8	34.0	33.9	30.6	24.2	23.5	33.4	39.3	10.2	**257.0**
Heavy Fuels	5.1	2.5	3.5	2.3	3.4	2.2	3.9	7.7	1.0	**31.5**
Other	4.0	16.5	16.6	7.8	6.1	7.7	11.1	9.7	3.4	**83.0**
Total	**59.3**	**72.9**	**79.6**	**56.5**	**68.0**	**53.8**	**75.0**	**86.1**	**20.9**	**572.2**

** Productions include intermediate components imported from other regions.*

Figure 4 HOP balances – RON 98 Base case vs RON 102 - Oxygenate pathway - HOP 50% of domestic demand





3.7.2. Oxygenate light pathway

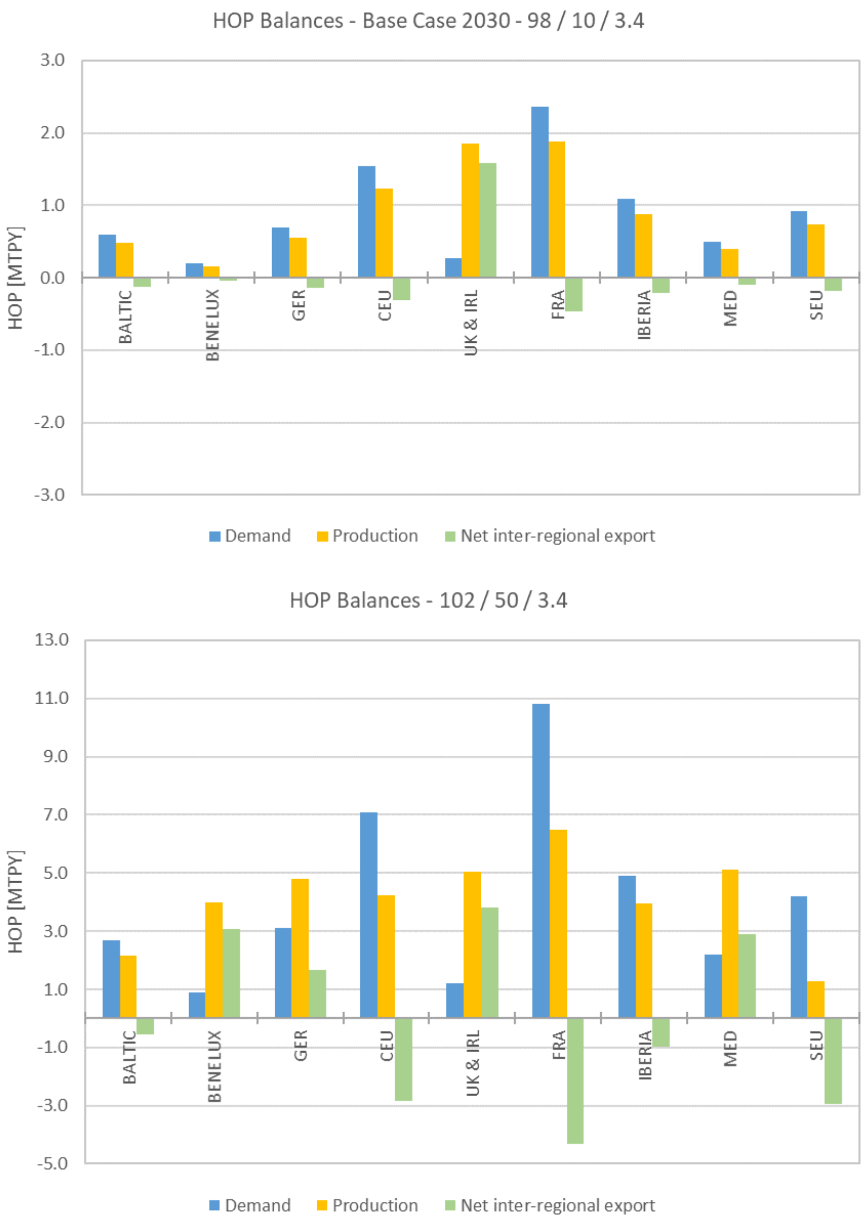
Table 22 Regional productions - Oxygenate light pathway - HOP 50% of domestic demand

HOP 98 Base 10% Productions, MTPY *	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	Total
LPG	1.6	2.2	2.1	1.4	1.6	1.3	1.9	2.1	1.0	**15.2**
Gasoline Premium 95	4.4	6.3	12.2	7.2	8.5	6.7	9.7	12.4	1.6	**69.0**
Gasoline 98	0.5	0.2	0.6	1.2	1.9	1.9	0.9	0.4	0.7	8.2
Gasoline Export	8.2	6.3	2.3	1.6	4.8	2.6	2.7	6.0	2.0	**36.5**
Jet	5.0	7.1	11.0	5.0	18.0	8.0	10.3	7.6	1.1	**72.9**
Middle - Distillate	27.3	35.7	34.2	27.6	23.5	23.8	34.8	42.0	9.8	**258.6**
Heavy Fuels	6.2	1.9	3.1	1.8	3.0	2.0	3.8	7.6	0.9	**30.1**
Other	3.8	16.4	16.8	7.9	6.0	7.7	11.2	9.5	3.6	**83.0**
Total	**56.9**	**76.1**	**82.1**	**53.7**	**67.2**	**54.1**	**75.1**	**87.6**	**20.7**	**573.5**

HOP 102 (50%) Productions, MTPY *	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	Total
LPG	2.2	0.9	0.7	1.0	1.1	1.3	3.5	3.1	1.5	**15.2**
Gasoline Premium 95	3.7	2.7	6.4	4.1	5.6	3.8	3.9	7.6	0.9	**38.7**
Gasoline HOP (102)	2.2	4.0	4.8	4.3	5.0	6.5	3.9	5.1	1.3	37.0
Gasoline Export	8.7	4.1	3.1	1.4	3.7	1.4	5.2	6.0	2.0	**35.6**
Jet	5.1	7.1	11.0	4.8	18.0	8.0	10.3	7.8	0.8	**72.9**
Middle - Distillate	25.0	34.0	33.8	30.0	24.0	23.0	34.6	38.5	10.2	**253.2**
Heavy Fuels	6.5	2.8	3.2	2.3	3.5	2.2	4.1	8.4	1.5	**34.5**
Other	4.1	16.6	16.5	7.8	6.1	7.7	11.2	9.7	3.4	**83.1**
Total	**57.5**	**72.2**	**79.6**	**55.6**	**67.1**	**53.8**	**76.6**	**86.3**	**21.6**	**570.3**

** Productions include intermediate components imported from other regions.*

Figure 5 HOP balances – RON 98 Base case vs RON 102 - Oxygenate light pathway - HOP 50% of domestic demand



3.8. REGIONAL COMPOSITIONS

At this high HOP demand, the blending composition discrepancies between regions are emphasised, especially at HOP RON 102.

The regions with the highest blending of MTBE (CEU, FRA, SEU) have a combination of high HOP demand (relative to their refining capacity) and relatively low process units' capacities delivering high RON components.

Feasibility high RON / high demand being limiting, there is no room for an important MTBE reduction. Consequently, oxygenate and light oxygenate pathways show very similar results.

3.8.1. Oxygenate pathway

Table 23 Regional composition – RON 98 Base case - Oxygenate pathway

RON 98 Base 10% Composition, wt%	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	EU average
C4s	2.5%	2.4%	0.0%	0.5%	1.5%	1.5%	1.8%	1.6%	0.2%	**1.2%**
Naphtha	2.4%	0.0%	0.0%	6.0%	0.0%	0.0%	12.6%	1.3%	0.0%	**2.5%**
Isomerate	12.7%	2.2%	14.4%	4.6%	0.0%	3.7%	0.0%	3.9%	23.2%	**5.6%**
Alkylate	18.9%	24.9%	13.7%	13.6%	22.4%	20.6%	18.1%	21.8%	13.1%	**18.6%**
Reformate	39.7%	59.5%	47.3%	42.1%	54.0%	52.1%	46.5%	47.6%	49.3%	**49.1%**
FCC Cracked Naphtha	15.1%	0.0%	8.2%	0.0%	11.4%	3.7%	0.0%	0.0%	0.0%	**4.9%**
BTX / SC Gasoline	0.3%	2.8%	8.2%	23.4%	2.4%	10.0%	12.6%	15.6%	6.0%	**9.7%**
TAEE	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.3%**
ETBE	3.6%	3.5%	3.6%	3.1%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.5%**
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.6%**
MTBE	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	**1.1%**
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**100.0%**
MTPY	0.5	0.2	0.6	1.2	1.9	1.9	0.9	0.4	0.7	**8.2**
MM3PY	0.6	0.2	0.7	1.6	2.5	2.5	1.1	0.5	1.0	**10.8**

Table *24* Regional composition – HOP 102 - Oxygenate pathway - HOP 50% of domestic demand

HOP 102 Composition, wt%	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	EU average
C4s	1.9%	2.3%	0.0%	0.2%	0.8%	0.6%	0.0%	1.0%	0.7%	**0.8%**
Naphtha	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
Isomerate	7.9%	0.0%	0.0%	22.8%	0.0%	6.8%	0.0%	0.0%	27.0%	**5.2%**
Alkylate	25.8%	29.4%	16.9%	11.7%	24.0%	15.5%	17.9%	22.0%	15.1%	**19.7%**
Reformate	41.9%	42.6%	37.4%	40.0%	41.6%	45.7%	37.3%	41.0%	36.2%	**41.0%**
FCC Cracked Naphtha	0.0%	0.0%	13.9%	0.0%	17.2%	8.2%	23.2%	11.2%	0.0%	**9.7%**
BTX / SC Gasoline	5.9%	13.6%	19.7%	6.5%	4.3%	5.7%	9.5%	5.7%	3.5%	**8.4%**
TAEE	5.7%	0.0%	0.0%	1.7%	0.0%	0.0%	0.0%	8.8%	0.0%	**1.7%**
ETBE	2.0%	3.5%	3.5%	2.9%	3.5%	3.4%	3.5%	1.1%	3.4%	**3.0%**
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.6%**
MTBE	5.4%	5.0%	4.9%	10.7%	4.9%	10.6%	4.9%	5.6%	10.6%	**6.9%**
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**100.0%**
MTPY	2.2	3.9	4.4	4.3	5.5	6.5	3.9	5.2	1.3	**37.0**
MM3PY	2.9	5.1	5.8	5.7	7.3	8.6	5.2	6.8	1.7	**49.0**

3.8.2. Oxygenate light pathway

Table 25 Regional composition – RON 98 Base case - Oxygenate light pathway

RON 98 Base 10% Composition, wt%	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	EU average
C4s	2.5%	2.4%	0.0%	0.5%	1.5%	1.5%	1.8%	1.6%	0.2%	**1.2%**
Naphtha	2.4%	0.0%	0.0%	6.0%	0.0%	0.0%	12.6%	1.3%	0.0%	**2.5%**
Isomerate	12.7%	2.2%	14.4%	4.6%	0.0%	3.7%	0.0%	3.9%	23.2%	**5.6%**
Alkylate	18.9%	24.9%	13.7%	13.6%	22.4%	20.6%	18.1%	21.8%	13.1%	**18.6%**
Reformate	39.7%	59.5%	47.3%	42.1%	54.0%	52.1%	46.5%	47.6%	49.3%	**49.1%**
FCC Cracked Naphtha	15.1%	0.0%	8.2%	0.0%	11.4%	3.7%	0.0%	0.0%	0.0%	**4.9%**
BTX / SC Gasoline	0.3%	2.8%	8.2%	23.4%	2.4%	10.0%	12.6%	15.6%	6.0%	**9.7%**
TAEE	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.3%**
ETBE	3.6%	3.5%	3.6%	3.1%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.5%**
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.6%**
MTBE	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	**1.1%**
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**100.0%**
MTPY	0.5	0.2	0.6	1.2	1.9	1.9	0.9	0.4	0.7	**8.2**
MM3PY	0.6	0.2	0.7	1.6	2.5	2.5	1.1	0.5	1.0	**10.8**

Table 26 Regional composition – HOP 102 - Oxygenate light pathway - HOP 50% of domestic demand

HOP 102 Composition, wt%	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Med.	South East EU	EU average
C4s	1.7%	2.3%	0.0%	0.2%	1.4%	0.6%	0.0%	0.4%	0.7%	**0.8%**
Naphtha	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.0%**
Isomerate	8.5%	0.0%	0.0%	22.4%	0.0%	6.6%	0.0%	0.0%	27.0%	**5.2%**
Alkylate	25.3%	30.2%	18.6%	11.7%	29.5%	15.5%	17.9%	23.3%	15.1%	**20.8%**
Reformate	41.0%	42.1%	39.9%	40.4%	40.6%	45.8%	36.1%	40.2%	36.2%	**40.9%**
FCC Cracked Naphtha	0.8%	0.0%	14.2%	0.0%	13.6%	7.9%	24.4%	18.8%	0.0%	**10.3%**
BTX / SC Gasoline	6.1%	13.3%	15.3%	6.5%	4.7%	6.0%	9.6%	5.7%	3.5%	**8.1%**
TAEE	5.7%	0.0%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	**0.5%**
ETBE	2.0%	3.5%	3.5%	2.9%	3.6%	3.4%	3.5%	3.5%	3.4%	**3.3%**
Ethanol	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	**3.6%**
MTBE	5.3%	5.0%	4.9%	10.7%	3.0%	10.6%	4.9%	4.4%	10.6%	**6.5%**
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	**100.0%**
MTPY	2.2	4.0	4.8	4.3	5.0	6.5	3.9	5.1	1.3	**37.0**
MM3PY	2.9	5.2	6.3	5.7	6.7	8.6	5.2	6.8	1.7	**49.0**

3.9. SENSITIVITY CASES – HOP RON 102 – OXYGENATE PATHWAY – LONG TERM

All the sensitivity cases were performed at a HOP RON target of 102, with a HOP demand at 50% of domestic market (long term 2030) and a MTBE price at 1.2 * RON95 price (oxygenate pathway).

Though not developed in the report, the case for 100% HOP in 2030 has been investigated. Starting from the 2030 calibrated model (restricted unit capacities), more flexibility has to be given to the model to be feasible, mainly: reduce to 50% the minimum production for each region, allow investment in one region (South East) and full E10 in all EU regions (oxygen saturated at 3.7%). The cost of octane increases significantly (6.8 $/t/RON pt), the model is strongly constrained (translating significant efforts and adaptation from the refining sector), but a solution is found.

The export of gasoline is increasing (to compensate for more oxygenates blending) from 36.4Mt to 45.8Mt in 2030 cases. The rise is significant but deemed feasible as it is similar to the 2016 base case (45.7MTPY). A significant drop in export price (-20 $/t) does not reduce these volumes of gasoline export, as the model is more driven by Demand and feasibility rather than prices. The impact would be seen on the cost of octane increasing to 7.2 $/t/RON pt.

3.9.1. Investments

A sensitivity case was run allowing investments (on top of the installed capacity, no limit applied) in CCR Reforming, Reformate splitters, Alkylation, Isomerisation (recycle) units and ETBE/MTBE units. Only these investments were allowed as these process units provide higher RON upgrade of gasoline components.

The main outcomes are (refer to the table below):

- Increase in CCR Reforming capacity is limited as the gasoline pools are already saturated in Aromatics. However, investments in splitters allow for more flexibility on the reformates routings.
- On the overall, there is no real increase in Isomerisation utilisation rate. Despite the RON improvement that occurs in Light Naphtha Isomerisation, the Isomerate RON level (around 83-87) remains too low for HOP production.
- Alkylates has a high RON, no Aromatics and a low RVP, and is therefore an excellent candidate to increase the pool RON. However, C3/C4 olefins (Alkylation feed) are limited in the refinery, so Alkylate can have a limited contribution to satisfy the RON increase.
- Main cases described in the sections above show that ethers can bring the missing RON. Thus it is expected to see investments in ethers production (limited by iso-butene availability in the refinery, as no iso-butene import is allowed)

Table 27 Sensitivity case – Investments allowed - Additional capacity

Additional capacity	Wt%
CCR Reforming	+ 7%
Reformate splitters	+ 39%
Isomerisation (recycle)	+ 2%
Alkylation	+ 26%
ETBE / MTBE	+ 35%

It has to be noted that the purpose of this case is not to promote a technology rather than another, but to show that refining system can adapt to provide more RON to the gasoline pool, without necessarily maximizing the oxygenates imports. The individual refinery optimum would depend on each refiner strategy.

Pool compositions summarized in the table below confirm the observations above: oxygenates decrease though remain high (produced in the refining system rather than imported) and are compensated by Reformate and Alkylate. The investments allow for a fossil contribution increase at the expense of oxygenates.

Table 28 Sensitivity case – Investments allowed - HOP composition and HOP & R95 weighted average composition

	HOP Composition		HOP & R95 weighted average composition	
HOP Composition, wt%	HOP 102 Oxy.	HOP 102 Invest.	HOP 102 Oxy.	HOP 102 Invest.
C4s	0.8%	1.0%	0.4%	0.5%
Naphtha	0.0%	0.0%	1.3%	0.5%
Isomerate	5.2%	6.1%	12.3%	12.0%
Alkylate	19.7%	22.4%	12.0%	14.8%
Reformate	41.0%	40.8%	47.3%	49.2%
FCC Cracked Naphtha	9.7%	8.2%	7.8%	6.8%
BTX / SC Gasoline	8.4%	7.9%	6.0%	4.8%
TAEE	1.7%	0.5%	0.9%	0.9%
ETBE	3.0%	3.4%	3.3%	3.3%
Ethanol	3.6%	3.6%	3.6%	3.6%
MTBE	6.9%	6.2%	5.3%	3.6%
Total	100.0%	100.0%	100.0%	100.0%
MTPY	37.0	37.0	75.8	75.6
MM3PY	49.0	48.9	101.0	100.7

As shown in the table below, finished gasoline properties do not vary a lot, RON, RVP and Aromatics remaining the major constraints.

Table 29 Sensitivity case – Investments allowed - HOP properties and HOP & R95 weighted average properties

	HOP Properties		HOP & R95 weighted average properties	
HOP Properties	HOP 102 Oxy.	HOP 102 Invest.	HOP 102 Oxy.	HOP 102 Invest.
Specific gravity	0.756	0.755	0.751	0.751
RON	**102.3**	**102.3**	**98.7**	**98.7**
MON	91.7	92.1	88.5	88.7
Olefins, vol%	6.8	5.6	4.4	3.9
Aromatics, vol%	**33.0**	**33.0**	32.5	**33.0**
Benzene, vol%	0.8	0.8	0.8	0.8
Oxygen, wt%	3.0	2.9	2.7	2.4
RVP, kPa	**58**	**58**	**58**	**58**
Evap. @70°C, vol%	35	33	37	35
Evap. @100°C, vol%	54	52	57	55
Evap. @150°C, vol%	88	86	88	87
LHV, GJ/T	42.0	42.0	42.1	42.2
Bio energy e%	3.4%	3.4%	3.4%	3.4%

Properties on constraint highlighted in **bold orange**

3.9.2. High Bio energy content

Another sensitivity case run, allowing for higher bio energy content. The purpose of this case is to check what would be the impact of considering an equivalent E10 (EU average) gasoline pool, rather than an *equivalent E5* as in the main cases.

The high bio content is allowed only as a sensitivity in the HOP study as both events are not linked to each other (even though high bio facilitates the HOP production from the refinery perspective).

There are two bio-oxygenate components considered in this study, Ethanol and ETBE (refer to 1.3.4 Oxygenates). As ETBE has a higher RON/Oxygen ratio, it was considered as the free bio-component for this case. Ethanol was fixed at the 2030 forecasted value (as in the main cases). MTBE is not a bio-component in this study, so it is also fixed (at 1.1 wt% of domestic grades, RON 95 and HOP).

As can be seen on the tables below, a maximum of 14.1 wt% of ETBE can be added to the global HOP & RON 95 pool, limited by the oxygen content saturated at 3.7 wt% (E10 specification). The bio energy content achieved is 6.9%.

Fossil fuel displaced from local gasoline is sold as export grade, consequently the overall refining system operation do not vary a lot and the related CO_2 emissions are very similar (slight decrease of about 0.4%).

Table 30 Sensitivity case -High bio energy content - HOP composition and HOP & R95 weighted average composition

	HOP Composition		HOP & R95 weighted average composition	
HOP Composition, wt%	HOP 102 Oxy.	HOP 102 High bio	HOP 102 Oxy.	HOP 102 High bio
C4s	0.8%	1.1%	0.4%	0.9%
Naphtha	0.0%	0.5%	1.3%	3.4%
Isomerate	5.2%	3.0%	12.3%	7.8%
Alkylate	19.7%	14.4%	12.0%	7.3%
Reformate	41.0%	46.2%	47.3%	50.0%
FCC Cracked Naphtha	9.7%	9.9%	7.8%	5.9%
BTX / SC Gasoline	8.4%	4.7%	6.0%	5.0%
TAEE	1.7%	1.5%	0.9%	0.8%
ETBE	3.0%	13.8%	3.3%	14.1%
Ethanol	3.6%	3.6%	3.6%	3.6%
MTBE	6.9%	1.1%	5.3%	1.1%
Total	100.0%	100.0%	100.0%	100.0%
MTPY	37.0	37.4	75.8	76.8
MM3PY	49.0	49.4	101.0	101.9

Table 31 Sensitivity case - High bio energy content - HOP properties and HOP & R95 weighted average properties

	HOP Properties		HOP & R95 weighted average properties	
HOP Properties	HOP 102 Oxy.	HOP 102 High bio	HOP 102 Oxy.	HOP 102 High bio
Specific gravity	0.756	0.758	0.751	0.754
RON	**102.3**	**102.3**	**98.7**	**98.7**
MON	91.7	91.0	88.5	88.1
Olefins, vol%	6.8	5.8	4.4	3.7
Aromatics, vol%	**33.0**	32.9	32.5	31.5
Benzene, vol%	0.8	0.8	0.8	**0.9**
Oxygen, wt%	3.0	**3.7**	2.7	**3.7**
RVP, kPa	**58**	**58**	**58**	**58**
Evap. @70°C, vol%	35	29	37	33
Evap. @100°C, vol%	54	55	57	58
Evap. @150°C, vol%	88	87	88	88
LHV, GJ/T	42.0	41.5	42.1	41.6
Bio energy e%	3.4%	**6.9%**	3.4%	**6.9%**

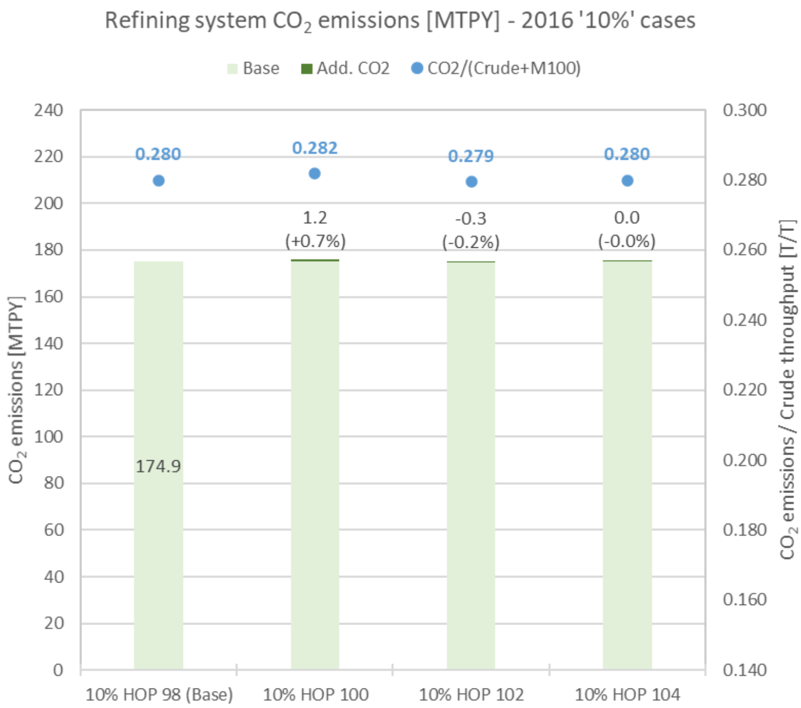
Properties on constraint highlighted in **bold orange**

4. DIRECT CO_2 IMPACTS

4.1. DIRECT CO_2 EMISSIONS FROM THE REFINING SYSTEM

No major impact on direct CO_2 emissions from the refining system is expected, as additional RON is mainly supplied by blending optimization and imported oxygenates, in both oxygenate and light oxygenate pathways and both HOP 10% (short term) and 50% (long term) of domestic demand.

Figure 6 Refining system CO_2 emissions – Oxygenate pathway - HOP 10% of domestic demand



[the figures above the bars are showing the variation versus the reference ("10% HOP 98 (base)")]

Figure 7 Refining system CO_2 emissions - Oxygenate pathway - HOP 50% of domestic demand

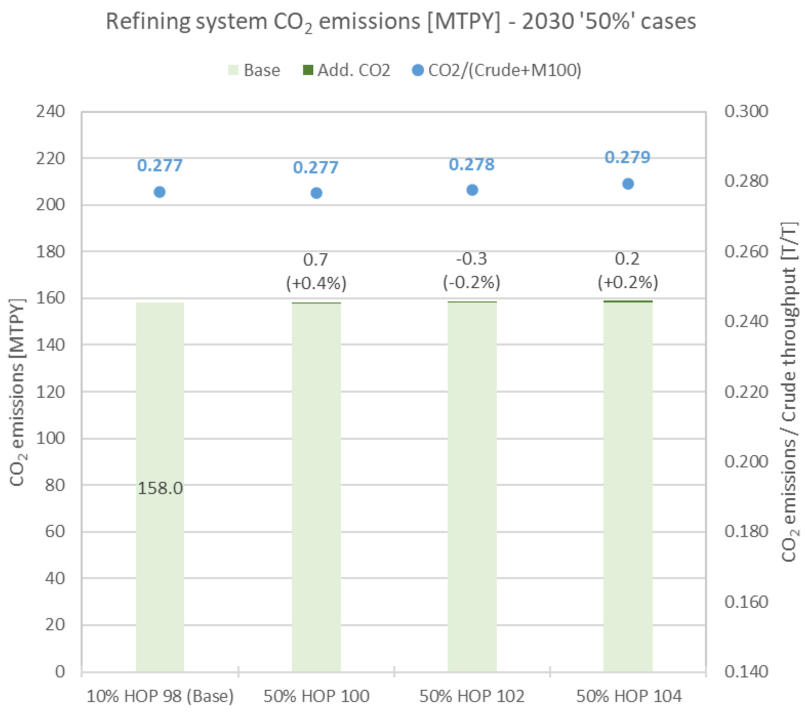


Figure 8 Refining system CO_2 emissions - Oxygenate light pathway - HOP 10% of domestic demand

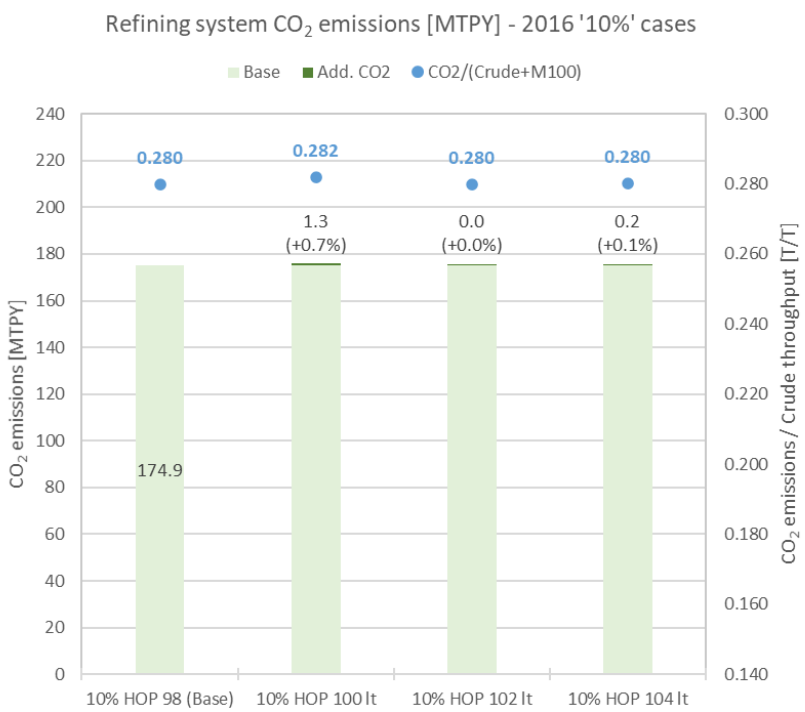
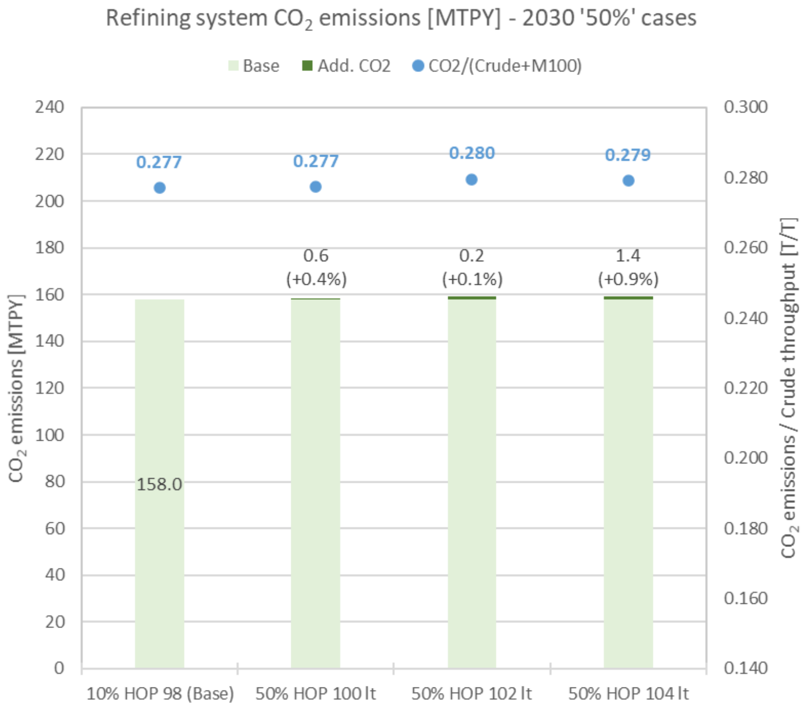


Figure 9 Refining system CO_2 emissions – Oxygenate light pathway - HOP 50% of domestic demand



4.2. ESTIMATED IMPACT ON GLOBAL CO_2 EMISSIONS

Emissions from cars are estimated from gasoline pools carbon content (Concawe LP model is carbon balanced, as mentioned in section 1.4.1 Main features). It allows a theoretical calculation, considering that all carbon will end up into emitted CO_2.

The potential benefit in each case is shown in the next table.

Table 32 Direct CO_2 emissions balance

		Oxygenate pathway MTBE price @ 1.2 * RON 95			Oxygenate light pathway MTBE minimization		
CO_2 MTPY vs. 2016 Base (short-term)	HOP 98 Base	HOP 100	HOP 102	HOP 104	HOP 100	HOP 102	HOP 104
Direct emissions from refining	Base	+ 1.2	**- 0.3**	**- 0.0**	+ 1.3	**+ 0.0**	**+ 0.2**
Direct emissions from HOP & RON 95 cars	Base	- 0.8	**- 0.7**	- 1.2	- 0.8	**- 0.8**	- 1.2
Oxygenates WTT impact	Base	+ 0.0	**+ 0.3**	+ 0.5	+ 0.0	**+ 0.1**	+ 0.3
Total CO_2	Base	+ 0.5	**- 0.7**	- 0.7	+ 0.5	**- 0.7**	- 0.7

		Oxygenate pathway MTBE price @ 1.2 * RON 95			Oxygenate light pathway MTBE minimization		
CO_2 MTPY vs. 2030 Base (long-term)	HOP 98 Base	HOP 100	HOP 102	HOP 104	HOP 100	HOP 102	HOP 104
Direct emissions from refining	Base	+ 0.7	- 0.3	+ 0.2	+ 0.6	+ 0.2	+ 1.4
Direct emissions from HOP & RON 95 cars	Base	- 4.1	**- 6.0**	- 7.6	- 4.2	**- 6.0**	- 7.6
Oxygenates WTT impact	Base	+ 1.7	**+ 2.0**	+ 4.7	+ 1.3	**+ 1.6**	+ 3.5
Total CO_2	Base	- 1.7 (-1.1%)*	**- 4.3 (-2.7%)***	- 2.7 (-1.7%)*	- 2.3 (-1.5%)*	**- 4.2 (-2.7%)***	- 2.7 (-1.7%)*

** Percentage of the direct emission from refining*

The potential benefit in direct CO_2 emissions reduction is higher in long-term cases, where 50% of gasoline demand is HOP. The major benefit is coming from the lower direct emissions from cars, that offset the increase in direct CO_2 emissions from oxygenates (WTT values).

Sensitivities

From the two main sensitivity cases performed, the following can be observed:

- Investments in refining system to produce high RON components (fossil and/or oxygenates) are compensated by savings on the cars direct emissions. It has to be noted, the CO_2 value being low in the economical function optimization (40 $/t CO_2), the model does not optimize (minimize) the refinery CO_2 production. Hence the higher emission from the refinery system (not totally compensated by a reduction of the Oxygenate WTT impact).
- At high-bio content, due to the additional oxygenates brought to the pool, more CO_2 is emitted compared to the low bio reference case (RON 98, 10% of 2030 domestic demand)

Table 33 Direct CO_2 emissions balance - Sensitivity cases - Oxygenate pathway - HOP 50% of domestic demand

CO_2 MTPY vs. 2030 Base (long-term)	HOP 98 Base	HOP 102 Invest.	HOP 102 High Bio
Direct emissions from refining	Base	+ 2.0	- 0.4
Direct emissions from HOP & RON 95 cars	Base	- 6.0	- 5.8
Oxygenates WTT impact	Base	+ 1.1	+ 9.6
Total CO_2	Base	- 2.9	+ 3.5

5. ECONOMICS

5.1. ASSUMPTIONS

The main price set used is historical data from 2016 and sensitivities have been performed with yearly data from 2013 to 2017. The set of prices is the same (real 2016) for both short term (10% HOP) and long term (50% HOP, 2030). The price set will influence the economics (cost of octane) and to a very limited extend the mass balance as the model is primarily driven by product Demand.

For the gasoline export, a unique price (FOB) is used for every EU region.

The different price sets considered in the economic study are shown in the table below.

Table 34 Price sets6 - 2016 yearly average as reference

	Price, $ / t					Spread, $ / bbl				
Main Products	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
Brent FOB	827	752	395	328	410	109.4	99.4	52.2	43.4	54.2
MTBE (1.2 x RON95)	1171	1091	674	554	662	+ 28.4	+ 29.0	+ 27.1	+ 21.8	+ 23.7
LPG	816	697	356	305	439	- 39.6	- 39.8	- 21.8	- 17.3	- 16.7
Gasoline RON 95	976	909	562	462	552	+ 6.8	+ 8.8	+ 14.6	+ 11.5	+ 11.5
Gasoline RON 98	993	920	573	472	561	+ 8.8	+ 10.1	+ 15.9	+ 12.7	+ 12.5
Export Gasoline US	959	898	552	452	543	+ 4.7	+ 7.5	+ 13.4	+ 10.4	+ 10.4
Jet	978	898	515	417	521	+ 14.8	+ 14.6	+ 13.1	+ 9.5	+ 11.9
Road Diesel	936	855	500	397	494	+ 16.5	+ 15.6	+ 15.0	+ 9.9	+ 12.2
LSFO 1.0%S	609	559	263	216	308	- 13.4	- 11.3	- 10.8	- 9.4	- 5.7
Bunker 3.5%S	581	520	250	202	294	- 17.9	- 17.5	- 12.9	- 11.6	- 7.9

5.2. HOP COST SENSITIVITY

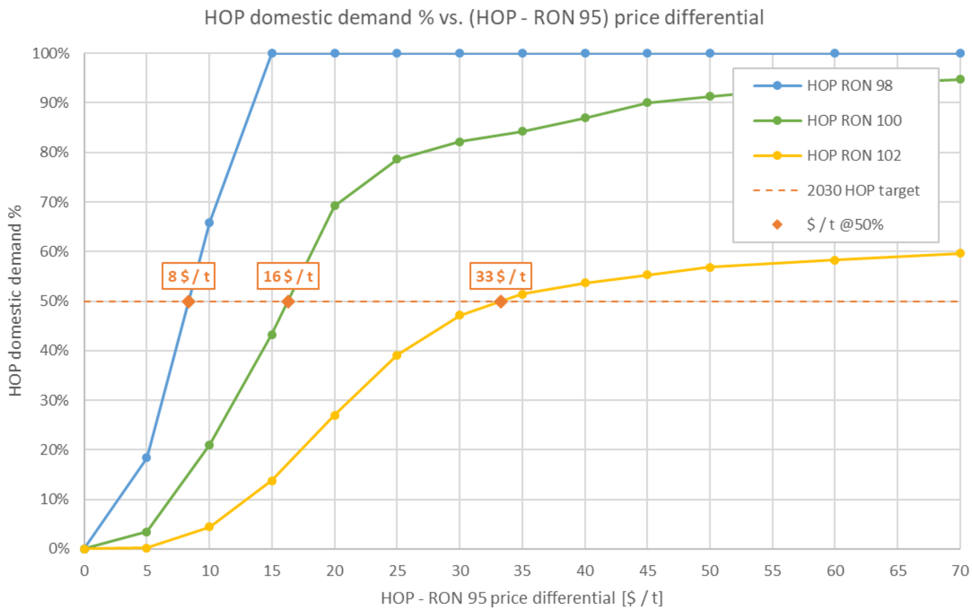
A cost sensitivity was run to evaluate at what price differential it becomes profitable for the LP model to produce HOP grade. This cost study is performed on the long term (HOP at 50% of domestic demand), at several HOP RON levels (98 / 100 / 102), at a price set based on 2016 yearly average. The cost sensitivity consists in running the LP model with step changes on HOP price differential versus RON 95 price.

To reach 50% of the domestic demand, HOP differential versus RON 95 ranges from 8 to 33 $/t, i.e. from +2% to +7% of RON 95 price (refer to figure below). As expected, the higher the RON, the higher the HOP – RON 95 price differential to reach 50% of the domestic demand. From the figure below, it can also be observed that even at high differential price, HOP at RON 102 do not get close to 100% of the domestic demand. This emphasises that the refining system is over-constrained when high RON / high volume are requested (the system then needs a strong incentive to produce the additional HOP at high RON). This statement is valid without any investments, i.e. without considering that refiners can adapt their refineries to fit with the market,

[6] Extracted from ThomsonReuters – Concawe subscription

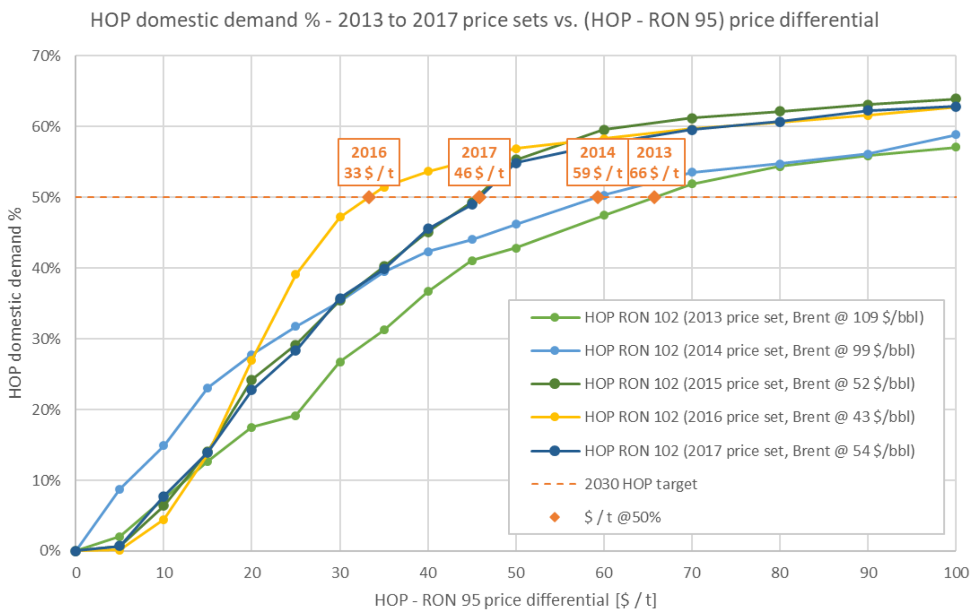
which is a conservative approach, as already mentioned, as the refiners have always reacted to Market Demand signals.

Figure 10 HOP cost sensitivity - 2016 yearly average price set, Brent at 43 $/bb



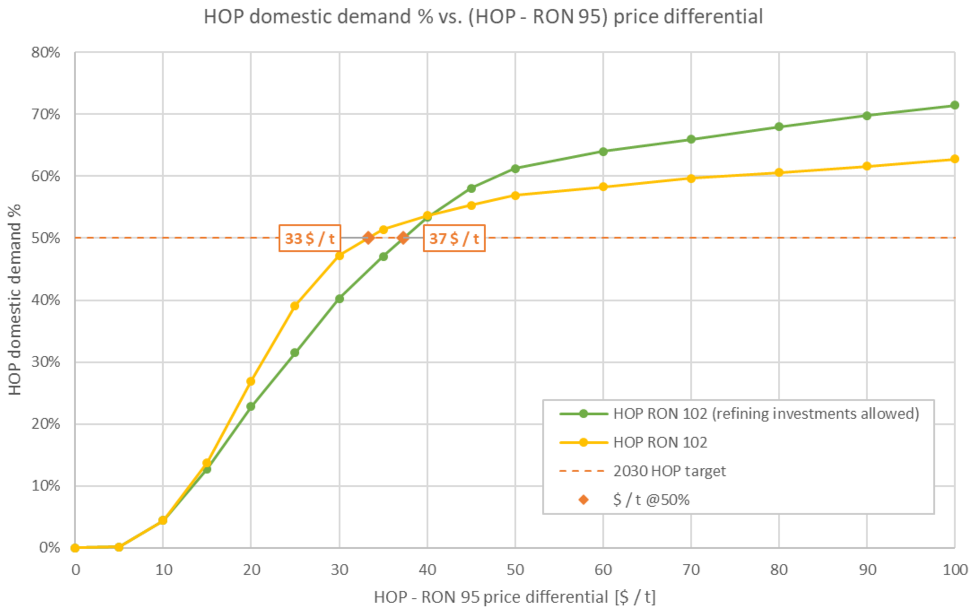
The same cost sensitivity was reproduced on HOP 102, but at different price sets (figure below). It can be noticed that the HOP differential versus RON 95 consistently represents from 7% to 8% of the RON 95 price, regardless of the year considered (Brent price varying from 43 to 109 $/bbl).

Figure 11 HOP RON 102 cost sensitivity - 2013-2017 yearly average price sets



So as to evaluate the profitability of the investment case presented in section 3.9.1 Investments, the cost sensitivity was reproduced with open investments. The figure below shows that at 50% of the domestic demand, the investment case requires a higher HOP – RON 95 differential, meaning that importing oxygenates remains more attractive at this level (at the 2016 yearly average price set). However, at 60% of the market, investments become more attractive. This trend could be expected, to be profitable, investments in refining units should be balanced by a high HOP demand.

Figure 12 HOP RON 102 cost sensitivity – Investments allowed – 2016 yearly average price set



5.3. HOP COST STRUCTURE

As additional RON is mainly brought by MTBE, it is expected that HOP – RON 95 differential is driven by MTBE cost. However, calculations below tend to show that MTBE cost cannot fully explain the differential, refinery components costs also increase due to the constraints on the refining system. Refining components are always required to increase the HOP RON and/or volume (MTBE cannot be added alone, due to the limitation in oxygen and bio specification).

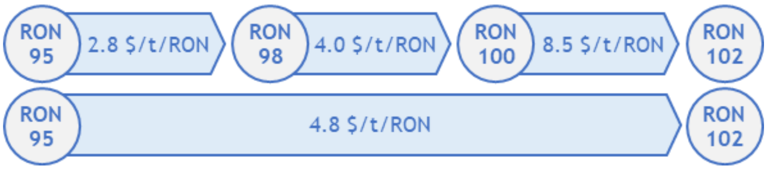
If MTBE would be only the cost driver, it would mean that the fossil material cost would be always the same. RON 95 price being fixed (2016 yearly average), knowing the MTBE import price, it is possible to estimate the fossil cost. We then obtain the following cost structure, for the 3 HOP RON levels (98 / 100 / 102), presented in the table below. It can be observed that the MTBE cost is small compared to the differential required to produce HOP at 50% of the domestic demand. The differential required obviously needs to cover for the additional oxygenates required, but also for the refinery costs increase due to the additional constraints on the system (more RON-bbl required, at a higher level).

Table 35 HOP cost sensitivity drivers

HOP - RON 95 differential, $ / t	HOP 98	HOP 100	HOP 102
Total differential	8	16	33
MTBE contribution	1	2	4
Other components contribution (i.e. refining system costs)	7	14	29

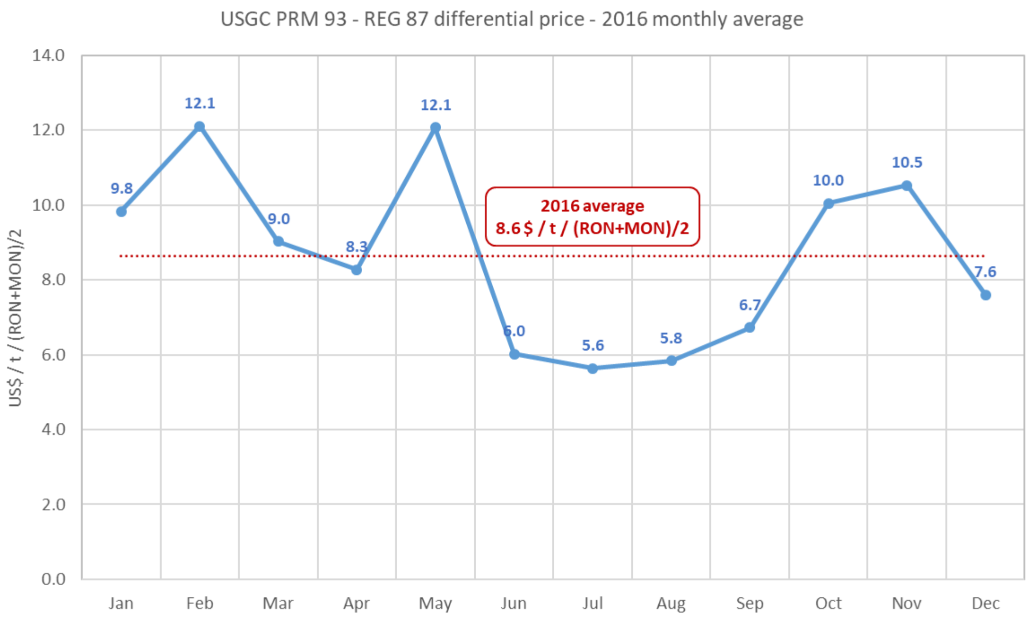
From the previous table, it can be derived that the average RON point cost (HOP RON 102) is about 4.8 $ / t / RON. It can be seen on the figure below that the higher the HOP RON target, the more expensive is the next RON point. This is expected as the higher the RON level, the more constrained is the refining system and the more expensive is the production of the next ton of HOP.

Figure 13 Cost of average RON point



This value can be compared with the United States Gulf Coast (USGC) octane price reported on the graph below. This comparison should be taken cautiously, as it cannot be asserted that US Regular / Premium price differential is only due to octane difference (though octane is first order of magnitude).

Figure 14 Average cost of octane - USGC 2016



CONCLUSIONS

In a global trend to reduce Green House Gas (GHG) emission, multiple paths are potentially available. However, as for every sector facing an urgent need to reduce its GHG, improving the efficiency is the first steps as it is always the most certain and cost effective way to have a real and immediate impact on GHG.

The transport sector, and especially passenger cars for this study, is expected to evolve quickly in Europe towards the electrification of new passenger car fleet. However, as evidence in a study published by Concawe, "Impact analysis of mass EV adoption and Low Carbon intensity fuel scenarios[7]", a scenario with ICE (Hybrids) representing half of the fleet would lead to the same GHG reduction and for a similar cost.

Therefore, it is crucial to keep improving the development of both the Internal Combustion Engine (ICE) and the refinery operations to deliver engines with high thermal efficiency and high quality fuels respectively.

In this environment, developing High Octane Petrol is an opportunity for both OEMs and refiners to prove their adaptation to market and societal expectations, setting Europe in the leading role for passenger cars efficiency.

In the central scenario of this study, 50% of the fleet using optimized engines for 102 RON, the CO_2 saving is more than 3Mt per year on a WtW basis, which is a significant CO_2 emission reduction (refining process + combustion in internal combustion engines (ICE) at high compression ratio). Other sensitivity scenarios have been developed, high bio, refinery Investment, lower efficiency, showing different results, but all of them, with conservative hypothesis, are showing positive impacts on GHG emission. Furthermore, many other positive effects linked to the persistence of efficient, such as employment, efficient and affordable mobility, etc. are not taken into account; these elements are crucial for a prosperous future for the European Union.

For refineries, producing HOP is one more steps towards liquid fuels quality improvement. The sector showed in the past a strong resilience, adapting gasoline parameters such as sulphur, benzene, octane, etc. Open to international competition, being proactive and ahead in product development is key. The dialogue with OEM's is key as well to get the best fit between engine and liquid fuels.

The modelling study shows a feasible evolution, on EU average and as well for each regions as defined in the model. These regions, representing different refinery configuration, are adapting their refinery operations, imports of oxygenates (and/or through internal production) and trade between regions. The economic analysis shows a cost for refiners, which is an expected result as today, the high octane grades, in every region of the world, are traded with a premium over the standard grade (RON98 versus RON95 in EU, RON93 versus Regular 87 in US, etc.). An octane estimate of 4.8$/t/pt RON for an evolution RON95 to RON102, though not negligible, remains well below the market estimate in the US (8.6 $/t/pt RON). The impact on long term Demand due to the development and relevance of the ICE in Europe, is an element not evaluated, but for the long term strategic analysis and decision from the refiners (and OEM's) is from a 1st order of magnitude.

The case for 100% HOP in 2030 has been investigated. More flexibility (degree of freedom) is required for the model with more trade flows, investments and full E10 in all EU regions (oxygen saturated at 3.7%). The cost of octane increases significantly (6.8 $/t/RON pt), the model is strongly constrained (translating significant efforts and adaptation from the refining sector), but a solution is found.

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7 https://www.concawe.eu/publication/impact-analysis-of-mass-ev-adoption-and-low-carbon-intensity-fuels-scenarios

LP modelling study set of assumptions demonstrate the feasibility of producing a HOP in the EU refining system. The pathways for the refining industry in Europe (102RON and 50% Demand in the 2030 Demand scenario) will require major refinery adaptation (process unit operation, increased trade flows within Europe and more gasoline export).

GLOSSARY

Table 36 Glossary

Acronym	Definition
ALK	Alkylation
CCR	Continuous Catalytic Reforming
CDU	Crude Distillation Unit
CN HDT	Cracked Naphtha Hydrotreatment
E10	European gasoline 10% Ethanol equivalent
E5	European gasoline 5% Ethanol equivalent
ETBE	Ethyl Tert-Butyl Ether
EU	European Union
FCC	Fluid Catalytic Cracking
H2 Plant	Hydrogen production plant
HOP	High Octane Petrol
ISOM OT	Isomerisation Once-through
ISOM REC	Isomerisation Recycle
LP	Linear Programming
MTBE	Methyl Tert-Butyl Ether
MTPY	Million tons per year
NHT	Naphtha Hydrotreating
OEM	Original Equipment Manufacturers
REF	Reformer
RON	Research Octane Number
RVP	Reid Vapor Pressure
SC	Steam Cracker
SR	Semi Regenerative
SRU	Sulphur Recovery Unit
TAEE	Tert-Amyl Ethyl Ether
USGC	United States Gulf Coast
WTW	Well to wheel

APPENDIX 1 – DETAILED ASSUMPTIONS

LP model gasoline specifications 2016 & 2030

Table 37 Gasoline specification (blending margins included) – All grades – 2016 & 2030

Quality	RON 95	HOP	US Export	Other Export
Specific Gravity	0.720 - 0.775	0.720 - 0.775	0.725 - 0.775	0.700 - 0.780
RON	≥ 95.3	≥ 98.3/100.3 102.3 /104.3	≥ 92.3	≥ 91.3
MON	≥ 85.3	-	≥ 82.3	≥ 81.3
Sulphur content, wt ppm	≤ 7	≤ 7	≤ 7	≤ 500
Olefins content, vol%	≤ 17	≤ 17	≤ 9	-
Aromatics content, vol%	≤ 33	≤ 33	≤ 26	-
Benzene content, vol%	≤ 0.9	≤ 0.9	≤ 0.5	≤ 1.4
Oxygen content, wt%	≤ 2.7 / 3.7 *	≤ 2.7 / 3.7 *	0	0
RVP, kPa	≤ 58	≤ 58	≤ 56	≤ 58
Evaporated @ 70°C, vol%	22 - 48	22 - 48	20 - 45	20 - 45
Evaporated @ 100°C, vol%	46 - 71	46 - 71	47 - 65	47 - 65
Evaporated @150°C, vol%	≥ 75	≥ 75	-	-
Bioenergy content, energy %	3.4 (fix)	3.4 (fix)	0	0

** E5 and E10 specification respectively*

LP model products demand 2016 & 2030

Table 38 Main products demand (bio included), MTPY – 2016 & 2030

Product	2016	2030
Petrochemicals	53	51
LPG	17	15
Naphtha	2	1
Gasoline	83	77
Jet	60	73
Road Diesel	217	204
Bunker Diesel	15	13
Other Diesel	68	51
Bunker FO	36	32
Other FO	13	8
Other products	26	19

LP model crude slate 2016 & 2030

Table 39 Crude slate, wt% – 2016 & 2030

Crude oil	2016	2030
Brent	41.3%	40.0%
Forcados	7.0%	6.9%
Russian Export Blend	27.0%	26.0%
Iranian Light	5.0%	7.7%
Kuwait	17.3%	10.4%
Algerian Condensate	0.5%	4.4%
Brent Short Residue	1.9%	4.6%
Average properties	**2016**	**2030**
API	34.2	34.0
Sulphur content, wt%	1.03	0.98

Main calibration capacities 2016 & 2030

Table 40 2016 Calibration capacities per region, wt% of installed capacities

2016	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Mediterranean	South East EU	ALL EU
CDU	95%	100%	100%	98%	92%	98%	79%	84%	76%	**92%**
FCC	100%	100%	98%	70%	86%	87%	100%	100%	68%	**92%**
NHT	60%	60%	60%	62%	70%	60%	60%	60%	77%	**62%**
CN HDT	60%	100%	60%	100%	60%	71%	60%	60%	-	**63%**
SR REF	90%	100%	100%	100%	92%	100%	98%	100%	100%	**98%**
CCR REF	60%	78%	92%	100%	60%	60%	60%	89%	-	**79%**
ALK	100%	100%	100%	100%	100%	100%	100%	100%	99%	**100%**
ISOM OT	60%	60%	60%	60%	60%	60%	60%	60%	60%	**60%**
ISOM REC	60%	60%	60%	88%	-	60%	60%	-	93%	**66%**
MTBE/ETBE	99%	100%	100%	88%	99%	101%	100%	99%	34%	**91%**
TAME/TAEE	100%	-	-	99%	-	-	-	100%	-	**100%**
SRU	58%	51%	63%	100%	56%	56%	66%	57%	52%	**61%**
H2 Plant	99%	100%	60%	72%	102%	74%	73%	92%	102%	**82%**

Table 41 2030 Calibration capacities per region, wt% of installed capacities

2030	Baltic	Benelux	Germany	Central EU	UK & Ireland	France	Iberia	Mediterranean	South East EU	ALL EU
CDU	100%	81%	93%	84%	86%	96%	77%	76%	80%	**85%**
FCC	100%	92%	74%	78%	86%	70%	88%	83%	60%	**82%**
NHT	60%	60%	60%	60%	60%	60%	60%	60%	82%	**61%**
CN HDT	60%	60%	60%	100%	60%	60%	60%	60%	-	**61%**
SR REF	80%	100%	100%	100%	78%	100%	85%	100%	95%	**92%**
CCR REF	60%	86%	60%	88%	60%	60%	60%	79%	-	**70%**
ALK	100%	100%	100%	100%	100%	100%	100%	100%	99%	**100%**
ISOM OT	60%	60%	60%	60%	60%	60%	60%	60%	100%	**61%**
ISOM REC	93%	60%	60%	64%	-	60%	60%	-	100%	**70%**
MTBE/ETBE	99%	100%	100%	81%	99%	101%	100%	101%	40%	**91%**
TAME/TAEE	60%	-	-	59%	-	-	-	100%	-	**83%**
SRU	50%	43%	53%	116%	50%	60%	70%	55%	92%	**59%**
H2 Plant	99%	120%	65%	100%	127%	99%	105%	100%	163%	**102%**

Oxygenates levels 2016 & 2030

Table 42 Oxygenates levels - 2016 & 2030

Oxygenates in RON 95 & HOP	2016	2030
Bio Ethanol	Fix @ 3.6 wt%	Fix @ 3.6 wt%
Bio ETBE	Limited by bio energy content specification	Limited by bio energy content specification
MTBE	Min @ 1.1 wt%, limited by oxygen specification	Min @ 1.1 wt%, limited by oxygen specification
TAEE	Limited by EU refining production	Limited by EU refining production

Table 43 Imported oxygenates Well-To-Tank assumptions

Oxygenate	LHV, GJ/t	Bio energy content	WTT CO_2 emissions gCO_2 / MJ
Bio Ethanol	26.8	100%	44.0
Bio ETBE	36.3	37%	32.3 From SC isobutene
MTBE	35.1	0%	19.6 From SC isobutene

Here are presented the average gasoline components properties for the 2030 HOP 102 case (oxygenate pathway). Depending on refining operations, properties may slightly differ for other cases.

Table 44 Main gasoline components properties - Oxygenate pathway - HOP 50% of domestic demand

	Specific Gravity	RON	MON	Aromatics, vol %	Benzene, vol%	Olefins, vol%	Oxygen, wt%	RVP, kPa	Evap @ 70°C, vol%	Evap @ 100°C, vol%	Evap @ 150°C, vol%
C4s	0.580	95.5	92.2	0.0	0.0	0.0	0.0	435.0	130	100	100
Naphtha	0.725	74.7	72.7	3.7	0.1	0.0	0.0	22.8	20	40	96
Isomerate	0.656	83.0	80.9	0.0	0.0	0.0	0.0	85.8	92	99	100
Alkylate	0.708	96.5	94.0	0.0	0.0	0.0	0.0	18.0	-2	27	80
Reformate	0.809	100.5	88.3	68.7	2.0	1.3	0.0	30.3	6	30	82
FCC Cracked Naphtha	0.708	91.1	79.9	13.1	0.7	32.0	0.0	72.1	40	76	93
BTX / SC Gasoline	0.713	88.0	78.2	11.5	0.1	20.0	0.0	76.1	48	79	80
TAEE	0.690	97.0	85.3	0.9	1.1	43.0	2.9	56.4	90	100	100
ETBE	0.750	118.8	103.3	0.0	0.0	0.0	15.7	30.0	30	100	100
Ethanol	0.794	129.0	96.0	0.0	0.0	0.0	34.8	234.0	188	97	105
MTBE	0.745	116.5	102.1	0.0	0.0	0.0	18.2	55.0	110	110	100

Environmental Science for European Refining

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