Gasoline and diesel imbalances in the Atlantic Basin: part II

Options to re-orientate a refinery's production towards middle distillates

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European refineries currently produce a surplus of gasoline and insufficient diesel. This series of articles examines the prospects for evolution and the technological solutions available, to help re-orientate the production to better fit demand. This is the second and final in the series, following an article discussing the market outlook published in *PTQ* Q2 2011.[1]

The first article presented various scenarios for refinery output and demand in 2020. The evolution of the current situation was envisaged in light of different influences, including passenger car sales, incorporation of biofuels and reduction in refining capacity. Differences in gasoline and diesel supply and demand will persist in Europe, regardless of which scenario is envisaged, as these imbalances are structural. Moreover, the emergence of a similar but less marked supply/demand mismatch in North America is probable.

Technology and catalysts can play a major role in adapting production to market demand. Axens' solutions to address these challenges in the European context are presented in this article.

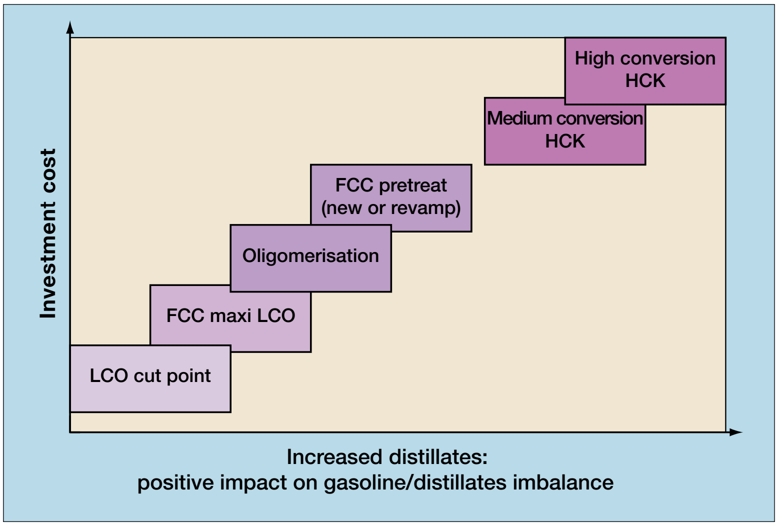

Figure 1 Technologies around the FCC unit to rebalance gasoline and distillates

Many refiners the world over are confronted with an increasing shift in demand towards distillate fuels and away from gasoline. Several of the options available to refiners to shift their fuels balance towards more diesel have been compared in a case study examining technologies around the FCC unit. This article describes the outcome of this study, with several of the technical options considered (see Figure 1). The options are positioned according to the magnitude of their impact on balancing the gasoline/distillate output and their investment cost.

The lowest-cost solutions, involving minor changes in the FCC operation to maximise the production of light cycle oil (LCO), are described first. Intermediate-cost options that add technologies around the FCC unit, with a medium impact on the mix of gasoline/

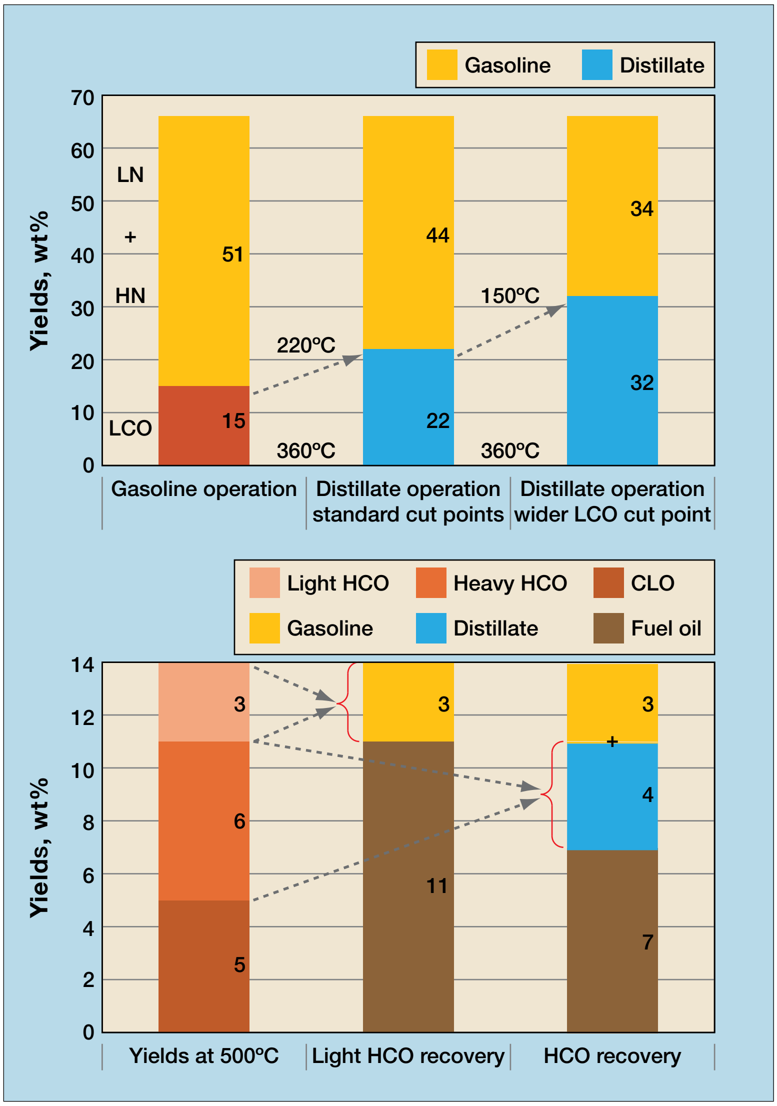

Figure 2 VGO FCC operation mode to maximise LCO yield

distillate output, are considered next. Finally, the addition of a high-conversion hydrocracking unit is described as the most effective option for resolving imbalances in gasoline/distillate supply and demand, but also as the most costly option.

Tuning FCC operation

Currently, refineries equipped with a FCC unit that wish to produce more middle distillates and less gasoline can fine-tune the operation of the unit as a first step towards optimising the production of distillate and gasoline. Various solutions exist to increase and maximise the production of LCO from the FCC unit.

After selecting the most appropriate catalyst to maximise LCO, a first approach is to operate the FCC unit in diesel mode by decreasing the severity (see Figure 2) with a reactor temperature of about 500°C. For the feed considered in the study, the LCO yield will increase by 7% from a baseline of 15% at normal gasoline operation to up to 22% at reduced severity. Subsequently, the gasoline cut point temperature can be reduced from 220°C to 150°C, to directly reduce the gasoline yield and increase the distillate. This will increase the distillate yield by about 10% to 32%.

Another solution that can improve upon the 32% distillate yield is to widen the LCO cut further by heavy cycle oil (HCO) management. The 360°C+ fuel oil is often separated into HCO and LCO cuts. The LCO cut point can be increased to about 390°C to recover another 3% yield of light HCO fraction as distillate (LCO).

An additional option is to recycle the remaining heavy HCO fraction to the FCC reaction section; from a typical yield of 6% heavy HCO, about 4% can be converted to distillate, with 2% as fuel oil.

Using these low-cost solutions, a significant impact can be made on refinery output. Experience demonstrates that distillate yield can be improved from 15% to around 40% and gasoline yield decreased from around 50% to 35%.

Adding a process unit: Polynaphtha oligomerisation

To further respond to the gasoline/distillate mix demand, an interesting solution is the Polynaphtha oligomerisation process. When gasoline is no longer the main process objective, co-produced C_4 olefins normally used for alkylate production and light gasoline olefins can be converted via oligomerisation into distillate products. The net result is an increase in distillate production at the expense of light gasoline and butenes.

The Polynaphtha oligomerisation process, originally developed to convert light LPG olefins to motor fuels, has been extended to the C_5/C_6 FCC olefins to maximise refinery profitability by reducing gasoline production. The LPG (C_4 separately or mixed C_3/C_4) and C_5 olefins produced in the FCC unit are sent to the oligomerisation unit, where they are converted into olefinic C_6+ oligomers boiling at up to 350°C. The Polynaphtha unit utilises a fully regenerable solid acid catalyst that is environmentally friendly with no waste effluents and a long on-stream life. An important feature designed into the process is the ability to alter the selectivity to C_6+ oligomers by adjusting the operating conditions, thereby changing the gasoline/distillates balance as required. To counter the imbalances in the gasoline/distillates mix, the maxi-distillate mode is chosen.

The olefinic gasoline produced by the Polynaphtha unit is often partially hydrotreated to moderate the olefins in the gasoline pool. Distillates produced are fully hydrotreated, resulting in excellent blending properties for light distillate products. When used in conjunction with the FlexEne solution, this can even bring about a bonus by increasing propylene in the FCC unit (see Figure 3).

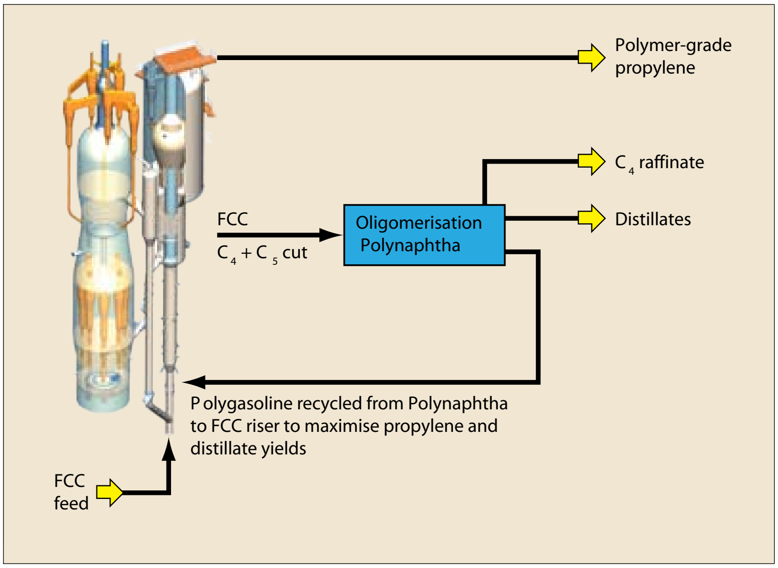

Figure 3 Polynaphtha oligomerisation technology and FlexEne solution

When operated in distillate mode, the FlexEne concept consists of recycling the gasoline olefinic oligomers boiling in the gasoline range back to the FCC riser for further cracking to propylene. The olefinic oligomers are highly reactive and can be selectively cracked towards propylene and butenes in the FCC unit under normal cracking conditions. The excess of butenes production in the FCC unit contributes to further increase the production of distillate after oligomerisation.

The other advantage of FlexEne is its flexibility. This solution can be implemented while there is an excess of gasoline or a deficit of distillates. Should the market change, the operator can change the feeds to the Polynaphtha unit or alter the balance of gasoline and distillate oligomers produced to recover the desired product and recycle the undesired product. When maximum propylene is desired, all of the oligomers can be recycled to the FCC unit as opposed to just the gasoline oligomers, as shown above.

After exploring the options associated with the FCC operating mode and with the addition of a downstream unit, let us turn our attention to units that can be integrated upstream of the FCC unit. The investment that can provide the best results is mild hydrocracking.

Adding a process unit: HyC-10 mild hydrocracking

Where the FCC VGO feed is already pretreated in a catalytic feed hydrotreater (CFHT), this unit can be revamped into a mild hydrocracking unit in order to increase the conversion of VGO to diesel. The catalysts that are implemented in Axens' proposal replace the VGO hydro-treatment catalyst (HR 500 series) with a combination of VGO hydro-treatment catalyst (HR 500 series) and a hydrocracking catalyst (HDK series). The HDK series is designed to maximise diesel production while delivering a higher activity than conventional amorphous hydrocracking catalysts.

For refineries equipped with a VGO FCC unit, mild hydroc-

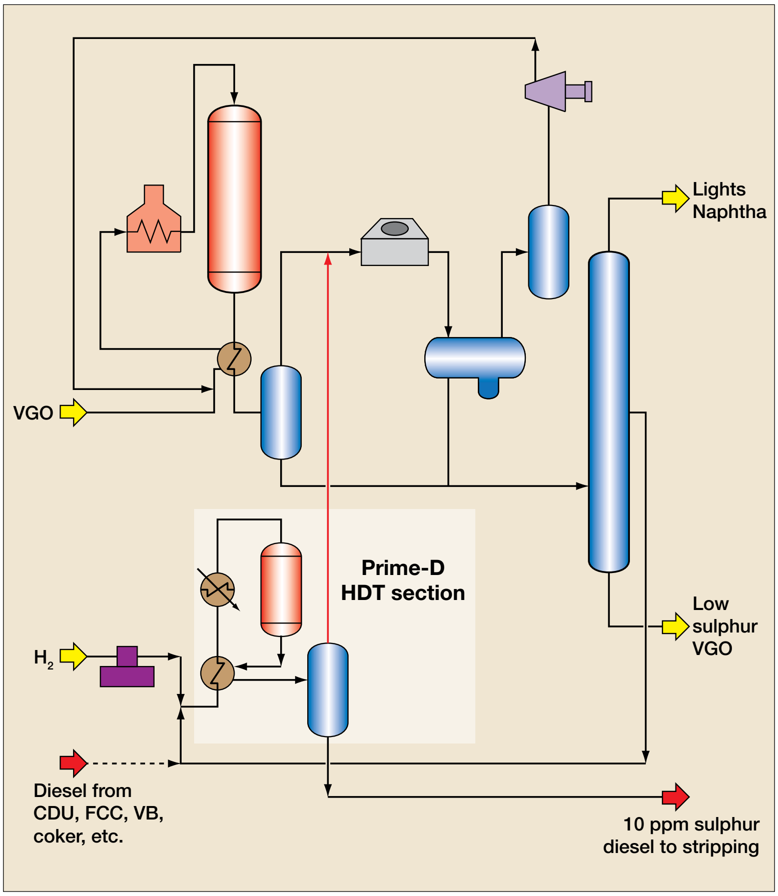

Figure 4 HyC-10+ technology integrating FCC pretreatment and diesel hydrotreatment

racking enables increased diesel production through VGO hydroconversion. This process simultaneously improves the quality of the treated VGO, which, once converted in the FCC unit, offers higher gasoline yields, higher octane retention, lower SO_x emissions and lower sulphur products.

While mild hydrocracking provides some remarkable improvements in FCC operations, it is not a panacea, especially for our concern: the gasoline/distillates output mix. Indeed, the relatively mild conditions employed — for instance, a moderately low H_2 partial pressure (40–80 bar) — do not permit attainment of the ultra-low-sulphur diesel (ULSD) specifications. This cut requires further hydrotreatment, but due to its aromatics and organic-nitrogen content it is more refractory to additional hydrotreating than straight-run diesel. This has led to the commercialisation of the HyC-10 process, which meets the ULSD challenge.

With HyC-10 technology (see Figure 4), the mild hydrocracking diesel receives the entire H_2 make-up needed for both reaction sections and is sent to a polishing reactor operated in once-through mode. In addition, HyC-10 systems can be designed to co-process other difficult feedstocks present in the refinery, such as LCO, light cracked gas oil and visbroken gas oil (HyC-10+ process).

Adding a process unit: HyK high-conversion hydrocracking

An efficient way to address imbalances in gasoline/distillate supply and demand is HyK high-conversion hydrocracking technology. On a refinery that already has a FCC unit, the implementation of a high-conversion hydrocracking unit requires a reduction in the capacity of the FCC unit or its shutdown. This solution is more capital intensive than those presented previously. Its impact on the reduction in gasoline production and the increase in diesel production is presented in the following section.

For high-conversion hydrocracking, the three HyK configurations described below and shown in Figure 5 can be implemented. Each configuration is associated with a catalyst combination using the catalysts from the HRK, HDK and HYK series:

- **HyK single-stage scheme** The feedstock is sent through two reactor sections in series containing first hydrorefining then hydrocracking catalysts. This configuration can achieve up to 90% feedstock conversion
- **HyK single-stage scheme with recycle** When unconverted residue is recycled to the hydrocracker, the feed is almost completely converted and higher selectivity to middle distillates is achieved compared to the once-through configuration. Conversion per pass is typically 60 vol%
- **HyK two-stage scheme** This

design leads to the maximum yield in middle distillates and the maximum diesel vs kerosene ratio. In the first stage, mild conversion is targeted and the unconverted fraction is separated and sent to a second stage, where final conversion is obtained.

In the case study that follows, the HyK single-stage once-through scheme with recycle is considered.

Case study: how can the best option be selected?

To quantify the impact of the different solutions described previously, a case study has been carried out based on a configuration typical of European refineries today and including the following units:

- Atmospheric and vacuum distillation
- Naphtha block equipped with a naphtha hydrotreating unit, a once-through isomerisation unit and CCR reforming
- Separated hydrotreaters for kerosene and diesel
- A FCC unit fed with hydrotreated light VGO and heavy VGO (not hydrotreated). Downstream of the FCC unit to ensure production of on-specification gasoline are an etherification unit to produce ETBE and a Prime-G+ unit for the selective hydrogenation and hydro-treatment of FCC cracked naphtha
- A visbreaker unit that upgrades the vacuum residue.

Figure 6 illustrates this setup.

Two different crude slates have been taken into consideration in this work. They represent a typical crude slate for European refineries:

- High-sulphur (HS) crude with an API of 30 and an atmospheric residue (AR) yield of around 50%
- Low-sulphur (LS) crude with an API of 39 and an AR yield of around 30%.

The detailed characteristics of these crude slates are shown in Figure 7.

Initially, the individual impact of each solution is examined, looking at the following three options:

- Option A consists of revamping the VGO HDT unit into a mild hydrocracking unit, enabling the operator to reach 35% conversion on the full-range VGO
- Option B consists of reducing the FCC capacity and building a new HyK hydrocracker unit operating at 50% conversion (high-conversion hydrocracking)
- Option C consists of shutting down the FCC unit and building a new HyK hydrocracker unit operating at maximum conversion (98%) and maximum distillate selectivity (high-conversion hydrocracking).

Figure 8 shows the reduction in gasoline attained by each of the three modifications. The ranking is in line with expectations, as the most costly solution (option C) is the most effective for reducing gasoline production. However, the most interesting and important point is that the impact of each option differs considerably, depending on which crude

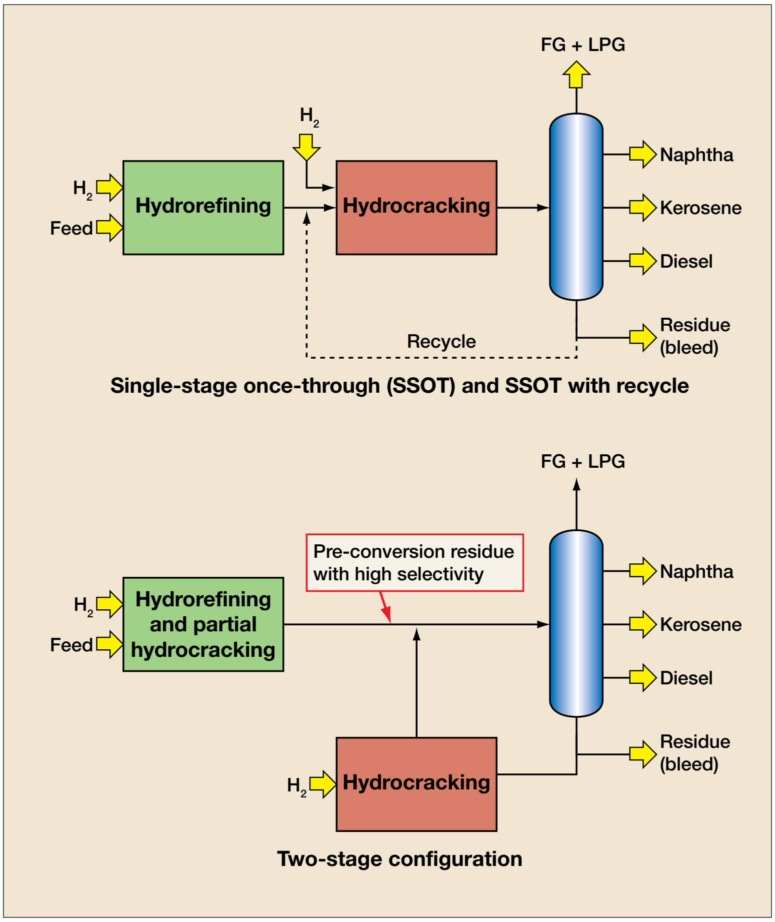

Figure 5 Three high-conversion hydrocracking configurations available

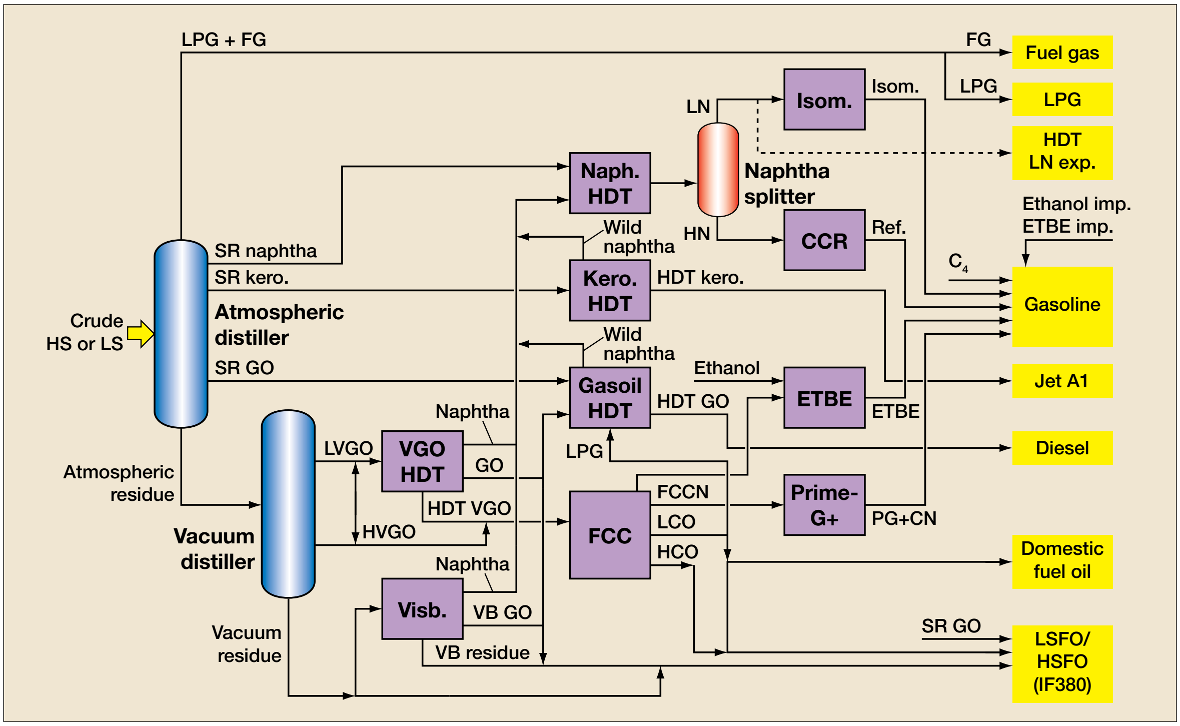

Figure 6 Refinery configuration in the case studied

slate is considered. Option C, which involves building a new HyK unit with 98% conversion, would reduce gasoline production by 22% for the HS-grade slate, but only by 12% for the LS-grade slate. The LS crude is lighter and has a lower yield in residue, hence conversion units such as the FCC unit weigh less on the refinery's mass balance. Conversely, heavier crudes such as the HS crude in this case have a higher yield of residue, which means that the conversion units will make a bigger impact on overall refinery production.

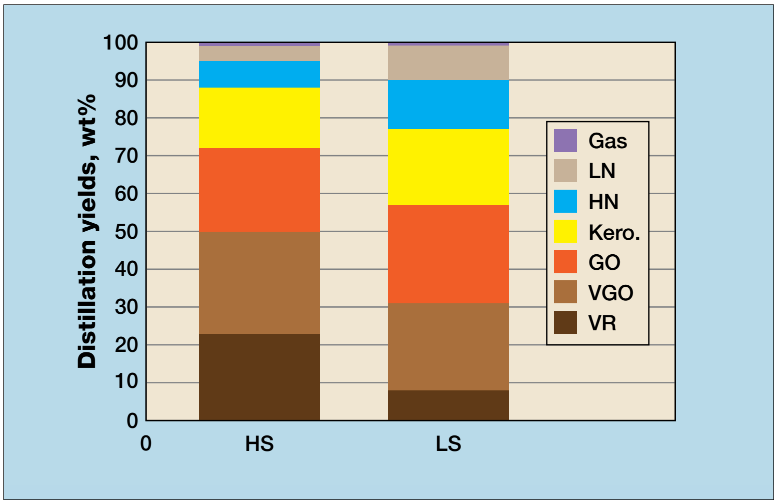

Figure 7 Crude slate considered for case study

Moreover, another element that can influence the outcome is the refinery's configuration. Several common European refinery configurations have been modelled, and the results show that the original configuration influences considerably the benefits obtained from each solution.

These impact studies demonstrate that the most suitable solution is not predetermined. Each case is different and case specific, and will depend on the refinery configuration, the crude and products market opportunities, and the investment capabilities of the operator. A first approach for operators to pursue this issue is to perform a master plan study that models the overall refinery process scheme and to evaluate the impact of each solution based on the different crude supply scenarios and

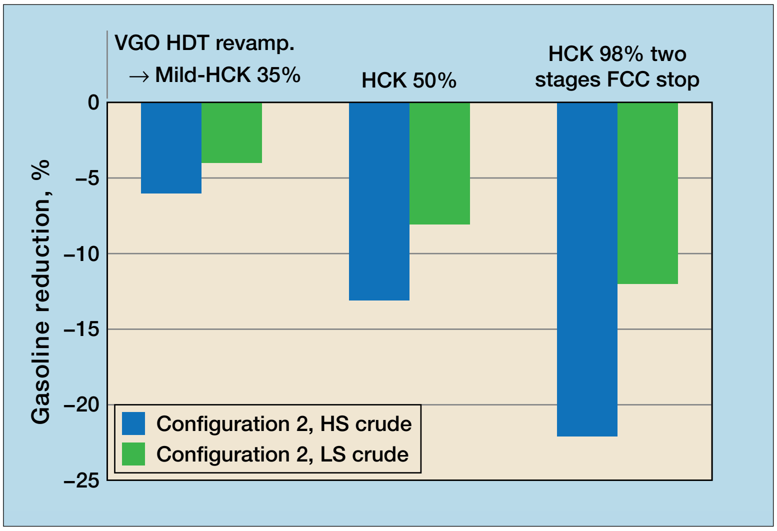

Figure 8 Individual impact of solutions

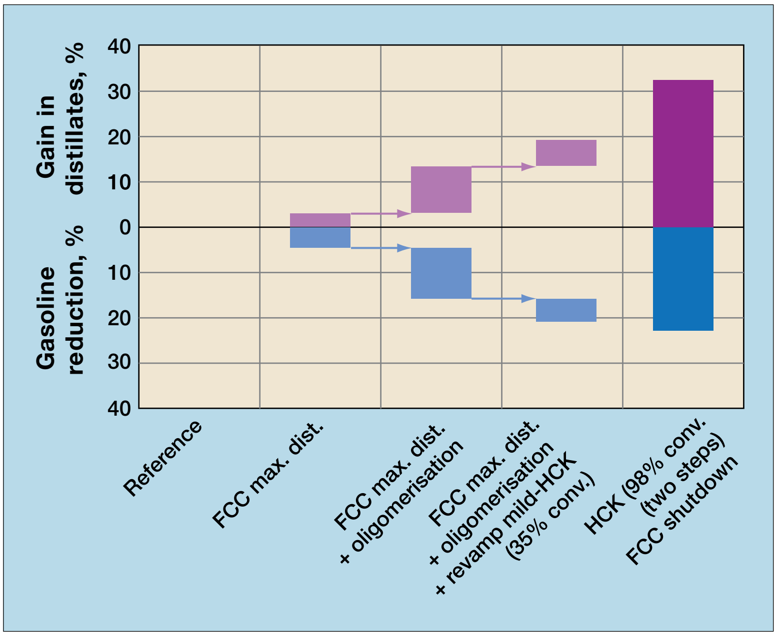

Figure 9 Combined impact of solutions

opportunities on the refined products market.

The last section of this article evaluates the impact of combining the lower-cost solutions. The reference case is a refinery with the configuration shown in Figure 6, processing a HS crude feedstock. The following solutions for reducing the gasoline/distillate imbalance have been gradually implemented and combined:

- FCC unit operating in maximum distillates mode: cut point adjustment and severity decrease to maximise LCO production
- Polynaphtha oligomerisation unit downstream of the FCC unit fed with C_4 olefins and light cracked naphtha (LCN)
- Revamping of the VGO hydro-treatment unit into a mild hydrocracking unit upstream of the FCC unit.

These various combined solutions have been compared with an investment into a two-step HyK high-conversion hydrocracker coupled with the shutdown of the FCC unit.

Figure 9 shows that in terms of a reduction in gasoline production (blue bars), the final combined solution leads to a result that is close to that of high-conversion hydrocracking but with a significantly lower cost. However, the two-step HyK high-conversion hydrocracker remains a better option to maximise distillate production. This type of unit is clearly designed to maximise selectivity towards distillate production. The other advantage of the combined solution is that investments can be carried out in stages over several years.

Before concluding, it is important to note that only a portion of the solutions available have been presented in this article. Indeed, where integration with petrochemical sites is possible, many other opportunities exist.

Conclusion

Imbalances between gasoline and diesel supply and demand are structural in Europe. In order to cope with this situation, the different solutions proposed here can help to reorientate part of a refinery's production towards middle distillates.

There is no one-fits-all or universal solution and the case study presented here demonstrates that the best solution is specific to each site, taking into account the site configuration, the type of crude treated and other local parameters.

To select the most profitable options, the modelling of an existing refinery and an in-depth analysis of the impact of individual and combined solutions is required, to propose the optimal flowsheet that will glean each per cent of distillate production at the lowest investment cost.

Reference

1 Benazzi E, Gasoline and diesel imbalances in the Atlantic Basin, part 1: market outlook, *PTQ* Q2 2011.

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