Lessons from FCC history: through Covid and post economic recovery

An updated and in-depth look at FCC catalyst history, spanning two decades, reveals trends pre-Covid, during Covid, and post the recent economic recovery

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A previous publication explored 15 years' worth of fluid catalytic cracking (FCC) history.[1] Today, we update this to include two decades worth of history, inclusive of the impacts during the Covid-19 pandemic and, more recently, during the economic recovery of 2022. The data explored span different regions of the world, catalyst suppliers, FCC designs, and types of FCC unit operations.

The current update reviews both catalyst properties and catalyst performance. Furthermore, regional trends within specific areas are explored. The regions are broken into three parts of the globe: The Americas (which includes North and South America), Asia (excluding China), and EMEA (Europe, Middle East, and Africa), which also includes the CIS (Commonwealth of Independent States). The global average in all cases is also presented. To further add context to the data, upper and lower bands are included as a shaded area, representing the 90th and 10th percentiles, respectively.

Trends

A significant catalyst parameter in **Figure 1** shows how the global average rare earth oxide (REO) content has fluctuated greatly over the past two decades. REO stabilises the Y-zeolite, where high REO gives higher catalyst activity and selectivity to gasoline, and lower REO gives lower catalyst activity and higher light olefins such as propylene and higher gasoline octane. In 2011, there was a massive global shift to lower REO due to the REO crisis, in which the pricing of REO skyrocketed. REO levels slowly rebounded but never to the peak from previous years, largely due to product economics favouring a more moderate level.

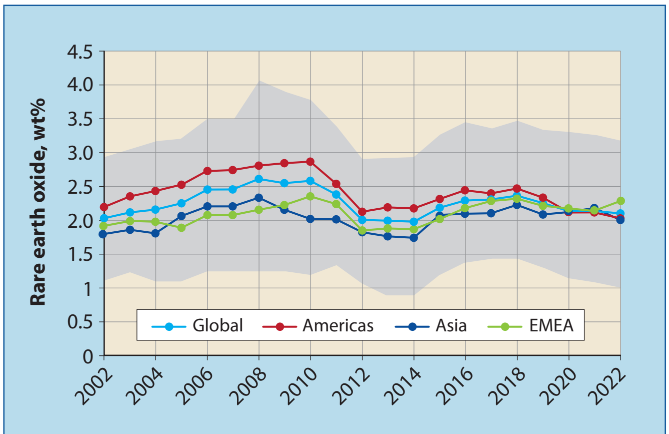

Figure 1 Global rare earth oxide trend

Since 2017, we see a global trend towards decreasing REO content. This is due to product economics, suggesting that naphtha (a gasoline precursor) has slightly taken a back seat to other products, including LPG (liquefied petroleum gas). This is especially true in the Americas due to the drive from strong butylene pricing. The low REO trend was further exacerbated by the low gasoline demand during Covid years. Another interesting point this graph demonstrates is that all regions converged in terms of REO levels, rather than the trend over the first 15 years, with the Americas utilising higher REO catalysts than other regions.

Figure 2 gives insights into catalyst surface areas. To offset the activity loss due to lower REO, we see a global trend of higher total surface area (TSA). This trend is

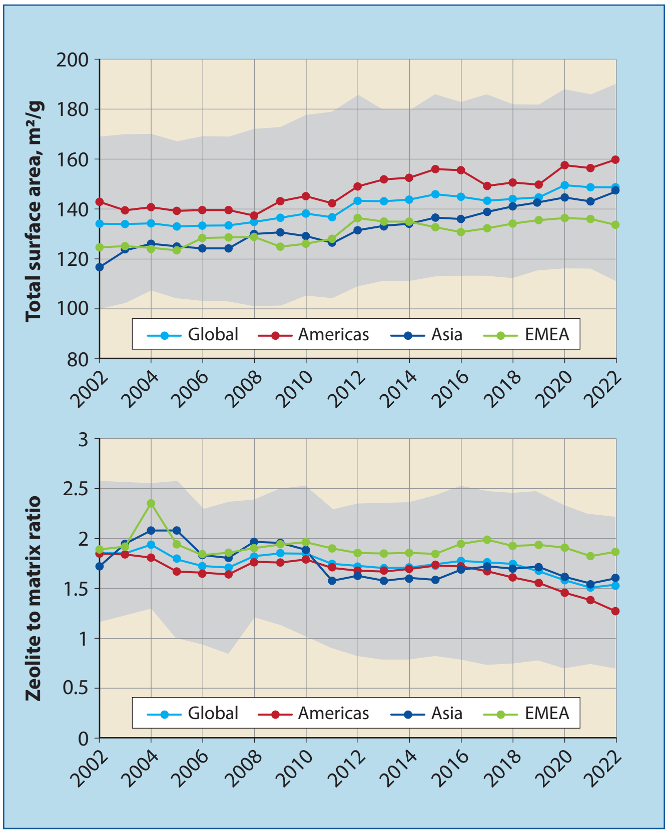

Figure 2 Global total surface area (top) and zeolite-to-matrix ratio (bottom) trends

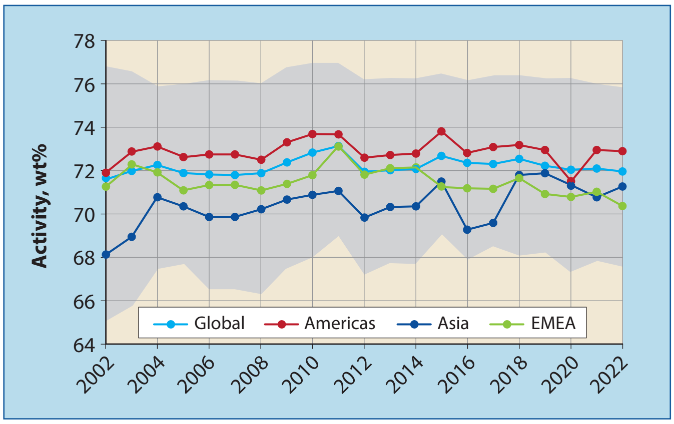

Figure 3 Global fluidised catalyst activity trend

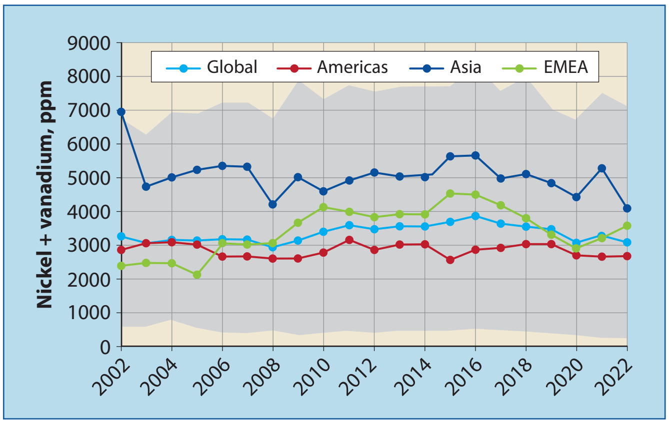

Figure 4 FCC Feed contaminants: nickel and vanadium

consistent over the entire 21-year history, with the most significant shifts happening at the same time REO drops are observed, i.e., during the REO crisis (2011) and since 2017. The higher catalyst surface area partially accommodates the loss in activity from lower REO. Higher surface area is achieved through several ways: higher fresh catalyst surface area, higher catalyst addition rate, and/or improved surface area retention.

An equally compelling trend emerging since our last analysis in 2015 is the zeolite-to-matrix ratio (Z/M) significantly decreased in all regions, favouring lower Z/M values. For such a drastic change, this requires not just one unit but entire regions to change their catalyst appetite. The Americas has seen the steepest curve, meaning its adoption of lower (lowest) Z/M ratio is the most drastic. This is likely due to two factors: matrix activity helps with LPG olefins generation (especially butylenes), and active matrix is very effective at bottoms cracking. The fact that bottoms is typically one of the least valued products from a refinery drives most refineries to minimise this product from the FCC unit. This change is also in favour of more LCO or diesel production, which currently is experiencing record-high prices.

The Ecat activity is a function of both rare earth and TSA (among other variables) and is shown in **Figure 3**. Ecat activity and all Ecat yields are measured using an ACE[2] technology laboratory unit. This unit mimics a commercial FCC unit and is run at constant conditions, so any changes are due solely to the catalyst. Great fluctuations have been observed during the two-decade Ecat activity history. Most recently, a global trend favouring lower activity is observed, particularly during the Covid-19 pandemic (2020 and 2021) and has started to rebound during the economic recovery period (2022). Not only was total demand for refined products lower during the pandemic, but there was a shift in product mix.

With fewer passenger vehicles on the road, demand for gasoline was down, while diesel (needed to transport goods) and chemical precursors (such as propylene for manufacturing medical face masks and other polyolefin plastics as single-use material demand increased for sanitary reasons) were still needed. The low catalyst activity in 2020 and 2021 favours production of light cycle oil (LCO), a diesel precursor. This graph also shows that outside the Americas region, other regions run lower activity overall due to the higher demand for diesel over gasoline. Additionally, the Americas region processes, on average, lower contaminant feed (see **Figure 4**), which leads to higher activity needed to meet heat balance constraints.

Figure 4 shows common Ecat contaminant metals, a result of contaminants coming in with FCC feed. The two most prevalent contaminant metals include nickel and vanadium. Both have been on the downturn in recent years after reaching a peak in 2016. The global average today hovers around 3,000 ppm Ni+V. This suggests that global access to lower contaminant metal feeds has increased due to cleaner crudes (such as tight oils) and/or increased pretreating hydroprocessing capacity. Also noticeable is the lower 10% shaded area, which shows that the very low metals units have even lower metals today, likely due to more severe hydrotreating to meet increasingly stringent gasoline sulphur specifications.

Catalyst selectivity

Catalyst selectivities, which are impacted by contaminant metals, will be reviewed in the following discussion. Hydrogen yield is a function of the metals levels, which catalyse dehydrogenation reactions to produce hydrogen and coke. The hydrogen yield follows the metals (Ni+V) trend, as shown in **Figure 5**, peaking in 2016 and since has declined. Lower hydrogen levels are also influenced by catalyst metals passivation technologies. Hydrogen yields decrease as catalyst suppliers continue to innovate new and improved metals-tolerant catalysts.

Coke is a product with zero value but is also required to maintain the heat balance in the FCC unit and is impacted by contaminant levels coming from the FCC feed. Coke in the ACE reactor increases with higher activity and higher metals. Over the past 10 years, activity and metals were steady enough not to increase coke selectivity. We originally expected to see coke decline due to improvements in catalyst coke selectivity and metals tolerance technology; however, we found that coke selectivity has stayed relatively consistent. It is believed that the improved catalyst coke selectivity is offset by units needing higher coke selectivity due to processing cleaner feeds, such as tight oils or more severely hydrotreated feeds to meet gasoline sulphur regulations. We have seen more hydrotreating in recent years, especially in the Americas, due to sulphur regulations.

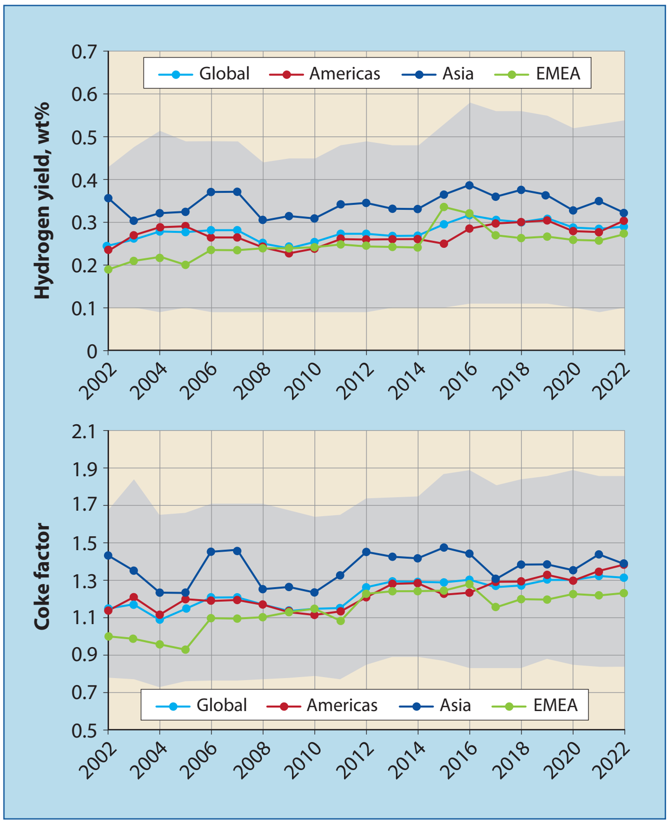

Figure 5 Global hydrogen yield and coke factor trends

Olefins additives

Ecat phosphorous, shown in **Figure 6**, is a marker for olefins additive, which converts gasoline range olefins into LPG (especially the olefinic products) and boosts gasoline octane. In the years since the last update, olefins additive levels increased significantly, especially in Asia with the highest curve/slope in this graph (Asia's current level of phosphorous correlates to 5-9 wt% olefins additive in the unit). Despite the drastically different usage levels of additives in all three regions, every region experienced a significant increase.

Economics across the globe are driving an increase in LPG olefins production, and a decrease in low-value LPG saturates such as propane and normal butane

The higher increases in Asia and EMEA (particularly in the Middle East) are due to a higher degree of integration between refineries and petrochemical plants. Though at a lower starting level, the Americas also saw an increase over the past three years after 10 years of almost stagnant levels. The increase shows how refineries with spare LPG processing capacities (and units that have debottlenecked their LPG systems) are prioritising propylene (whose main outlet is polypropylene production) and butylenes (which goes to make high octane alkylate) over gasoline. As mentioned previously in the activity review, during the

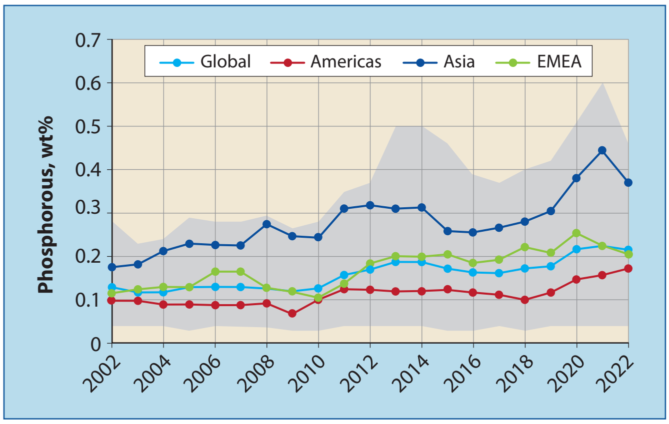

Figure 6 Global phosphorous levels

pandemic, demand for gasoline dropped while propylene remained high. Refiners used olefins additives to produce olefins, particularly propylene, at lower activity.

LPG olefins trends

Economics across the globe are driving an increase in LPG olefins production, and a decrease in low-value LPG saturates such as propane and normal butane. As expected from the Ecat phosphorous and Z/M trends, LPG olefins yields have increased significantly, as shown in **Figure 7**. Regional differences are still seen in these yields, with EMEA and Asia trending higher than the Americas due to higher degrees of petrochemical integration. Another interesting feature is the variability of the data, which has widened over time. The units in the bottom 10th percentile have not increased their olefins selectivity much (likely due

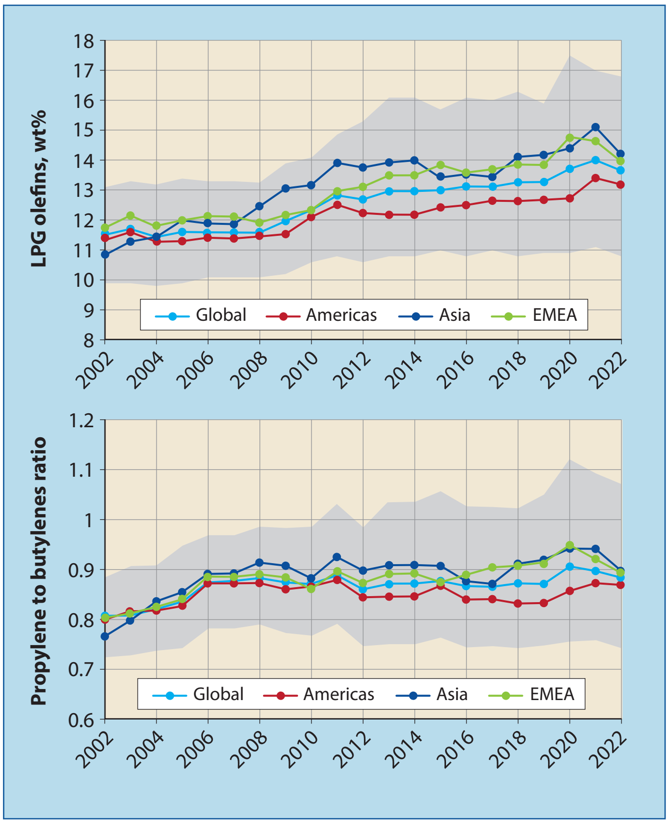

Figure 7 Global LPG olefins yield trends; total LPG olefins (top) and propylene-to-butylenes ratio (bottom)

to unit bottlenecks and niche regional economies), while those in the 90th percentile show a significant increase over the years of ~4 wt%!

In addition to the LPG olefin yields, we also looked at the selectivity within the LPG olefins stream and, in particular, the propylene-to-butylenes ratio. This ratio is a factor of many variables, including catalyst activity, REO, olefins additive, and Z/M ratio. For olefins additives, the most widely used variant is ZSM-5 based, which significantly increases the propylene-to-butylene ratio. Based on the increase of phosphorous, which indicates higher ZSM-5 usage, we would expect higher propylene-to-butylene ratios. The global ratio increased in 2020 during the pandemic with the rise in phosphorus, but in the two years following it decreased despite global phosphorous levels staying the same (indicating a similar level of ZSM-5 usage).

This implies that catalyst selectivity, aside from additive selectivity, is driving towards higher butylenes. This is in line with recent technology advancements in the maximum butylenes segment, with refiners adapting the latest technologies to drive profitability from butylenes. This is further supported by the trends within the regions, with Asia and EMEA showing higher propylene-to-butylenes ratios. The Americas, with the largest alkylation capacity globally, has the lowest ratio and has historically been the greatest adopter of the max butylenes catalyst technologies. Similar to the total LPG olefins graph, we see the spread of data widening over time with units geared towards maximising propylene (high C_3=/C_4= ratio) and others geared towards the other extreme of maximising C_4=s (low C_3=/C_4= ratio).

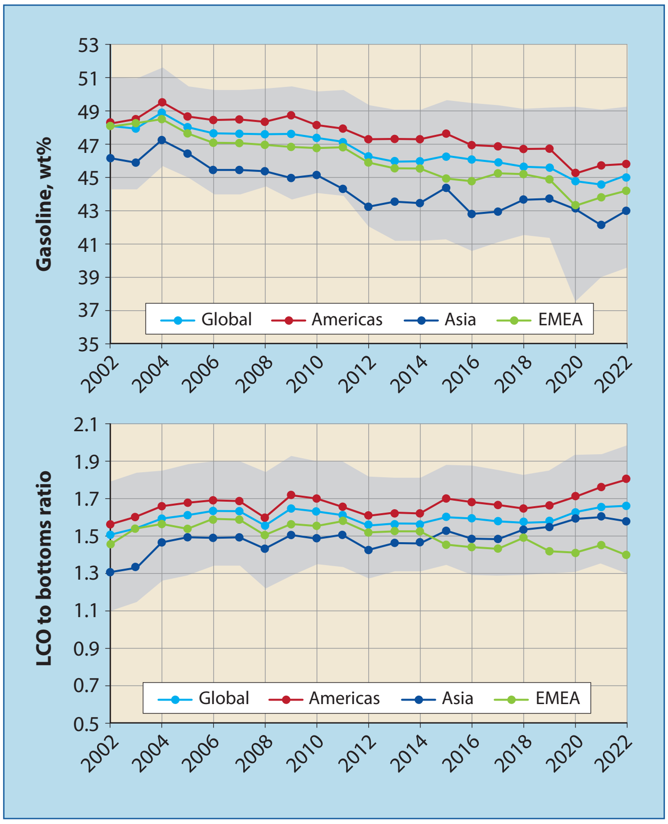

Figure 8 Global transportation fuels and bottoms upgrading trends; gasoline yield (top) and LCO-to-bottoms ratio (bottom)

Fuels and bottoms upgrading

Lastly, **Figure 8** was generated for a historical understanding of transportation fuels and bottoms upgrading over two decades. As expected from the previously discussed points, namely the drop in REO content and the increase in phosphorous content on Ecat, the gasoline yield has decreased significantly in all regions. Over the 21-year history, the global gasoline yield has decreased from 48% to 45%, indicating a major shift in FCC operating strategy.

The decrease is driven by the lower gasoline need from refined oil and the higher need for light olefins for chemicals. Other global drivers are contributing to this trend, such as renewable fuel sources, improved fuel efficiency, and increase in the adoption of light-duty electric vehicles. As seen with the prior LPG figures, the spread in the data has increased over the years. Back in 2002, most gasoline selectivities were between 45-51 wt% (Δ6 wt%), and in 2022 that spread is now 40-49 wt% (Δ9 wt%).

The Ecat LCO-to-bottoms (LCO/BOT) ratio is a measure of the bottoms upgrading selectivity of the catalyst to LCO. Since the start of the pandemic, the LCO/BOT ratio has increased in all regions except EMEA. This also corresponds to when IMO 2020 went into effect, limiting the amount of sulphur in bunker fuel, which is an outlet for FCC bottoms product, for marine vessels without SOx capture technology. The improvement in LCO/BOT correlates well with the decrease in Z/M for the previously shown regions.

Conclusions

In summary, two decades of FCC catalyst trends are covered, providing insights into refiner and consumer behaviours, with the focus on recent trends through Covid-19 and post economic recovery. The FCC, which historically has been the gasoline machine of the refinery, shows a drastic gasoline selectivity decline over the two-decade history in favour of other more valuable products like LPG and LCO, the latter being a diesel precursor. This trend is expected to continue, given recent regulations, such as the Inflation Reduction Act in the US and various policies in the European Union, which will drive the long-term adoption of electric vehicles and more stringent fuel economy standards on internal combustion engine vehicles.

During the pandemic, catalyst activity decreased as units targeted the production of LCO, a diesel precursor, over gasoline. In addition to diesel, during the pandemic, demand for chemical precursors including propylene (used in the production of medical face masks and other medically necessary equipment and supplies) was stronger than gasoline. Refiners used olefins additives to selectively crack gasoline range molecules into LPG.

An increase in olefins additive usage through the phosphorous chemical marker is seen. With the economic recovery of 2022, catalyst activity is increasing again. However, instead of olefins additives decreasing, it is increasing or holding steady in all markets. This shows a larger global trend toward making LPG olefins during the economic recovery.

This trend of higher LPG olefin production from the FCC is expected to continue with recent investments in petrochemical integration, particularly in the Middle East and

Asia. Also notable is the increase in the variance of the yield data over the years, suggesting a diversion in operating strategies between refineries and FCCs that was not seen in the past, with some units pushing the envelope to maximise olefin yields through innovative catalyst designs and unit configuration not seen 10 years ago.

In addition to the usage of olefins additives to increase LPG olefins production, the Z/M ratio of the catalyst decreased over the past five years. With refiners favouring higher matrix catalysts, this provides higher LPG olefinicity and improved bottoms upgrading. In addition, utilisation of lower REO catalysts, which also favour LPG olefin production, has increased.

The FCC, historically the gasoline machine of the refinery, shows a drastic gasoline selectivity decline over the two-decade history in favour of other more valuable products

The result of these catalyst property changes manifests as higher yields of LPG olefins and higher LPG olefin selectivity. With the steady activity and lower Z/M ratio, it seems that refiners recently have focused on obtaining bottoms upgrading through catalyst selectivity rather than activity and conversion. This trend will likely continue, given the recent and expected future demand for diesel and jet fuels. Finally, we see improvements in bottoms upgrading to LCO.

In summary, as we enter the post-pandemic recovery period, we see trends to increase selectivity towards LPG olefins and LCO, as well as reductions in gasoline, bottoms, and LPG saturates (propane and normal butane).

References

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