

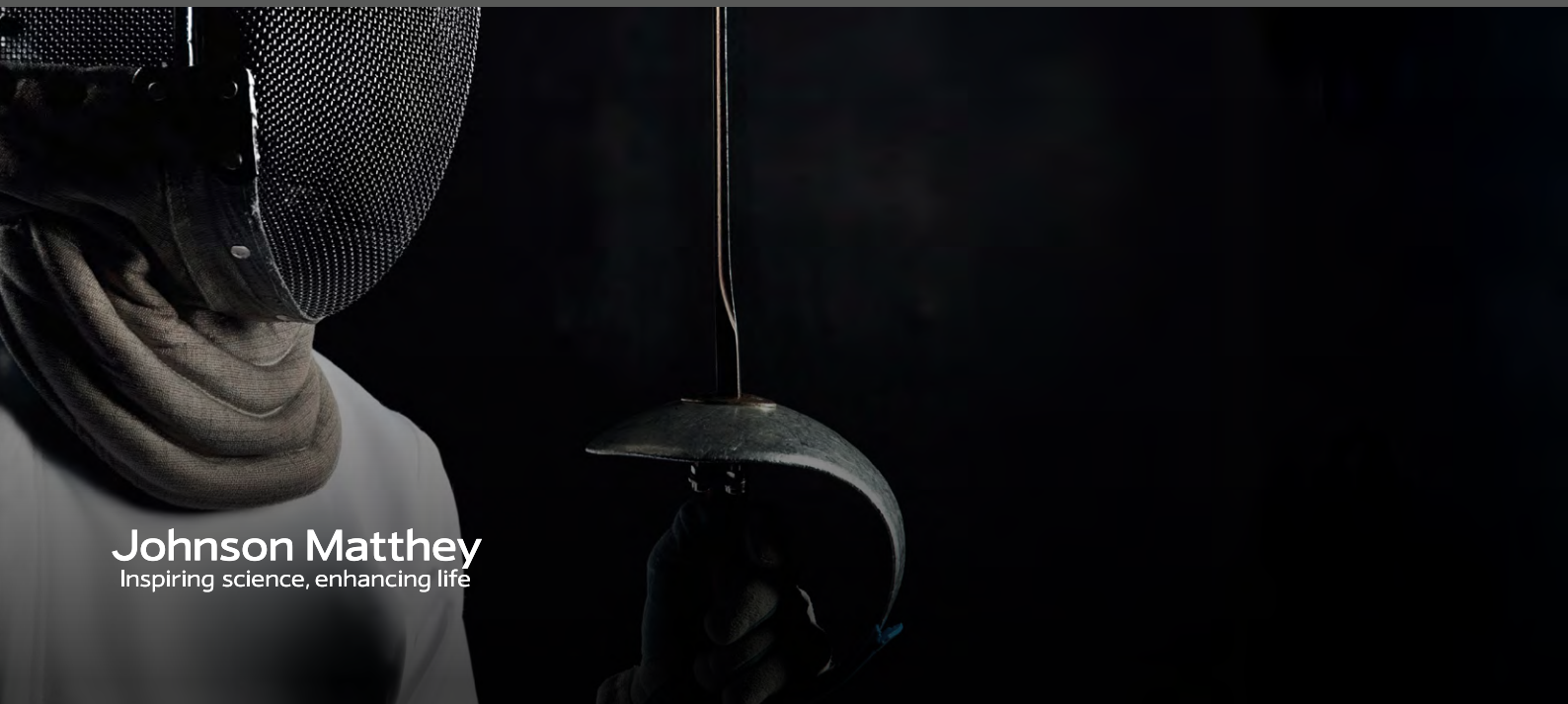
# JM

# Combating Metal Contamination in FCC Operations:

A Refiner's Guide to Effective Mitigation with CAT-AID Additive

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**As the refining industry continues to pursue profitability through lower-value feedstocks, the prevalence of unconventional crude sources has introduced a new layer of complexity.** Over the past decade and a half, oil sands, shale oils, and other opportunity crudes have gained traction. These feeds, while cost-effective, tend to contain higher levels of contaminants such as iron and vanadium, which present unique challenges in Fluid Catalytic Cracking (FCC) units. Iron and vanadium contamination have emerged as key causes of catalyst deactivation, undesired dehydrogenation reactions, and operational inefficiency.

When metals such as iron and vanadium accumulate on the FCC base catalyst surface, the result is a progressive loss of activity, reduced conversion, and an increase in both hydrogen and coke. The challenge for refiners is to maintain optimal performance while processing high-metal feeds without escalating operating costs. Johnson Matthey has developed a specialised metals trap solution, the **CAT-AID™** additive, which has proven to be highly effective in capturing and immobilising these metals. This article explores the mechanisms by which the additive mitigates iron and vanadium poisoning and shares commercial data demonstrating its impact on FCC unit performance and refinery profitability.

## Understanding the sources and impact of iron and vanadium contamination

Iron contamination in FCC operations typically originates from two main sources: organic iron derived from the feedstock (including porphyrins and naphthenates), and inorganic iron from equipment corrosion<sup>1</sup>. Of the two, feed-derived iron poses the greater risk. Once deposited on the base catalyst, it accumulates on the outer surface of the particles, forming low-melting-point eutectics that dramatically change catalyst morphology.

Extensive microscopy studies carried out by Johnson Matthey show that iron accumulation leads to the formation of thick, rough surface coatings, typically 0.5 to 3 µm thick<sup>2</sup>. These coatings are made of iron nodules which consist of amorphous iron phases that bind with silica and alumina. High-resolution TEM reveals 5–20 nm iron oxide particles embedded within a glass-like matrix. This surface coating acts as a physical barrier that blocks pores and restricts heavy hydrocarbon molecules access to active sites in the interior of the particles, leading to reduced conversion, lower LPG olefinicity, and increased coke and hydrogen. Iron-contaminated catalysts also behave as inverse SO<sub>x</sub> reduction agents, capturing H<sub>2</sub>S in the riser and releasing SO<sub>x</sub> in the regenerator.

Similarly, vanadium is present in many FCC feedstocks and deposits on the circulating catalyst, causing permanent and irreversible damage. Literature suggests that vanadium, initially present as porphyrins in the feed, deposits on the catalyst as vanadium oxides and forms acidic vanadium species in the presence of steam. It may react with sodium in the zeolites leading to the collapse, destruction and/or deactivation of the zeolite<sup>3</sup>.

Like iron, vanadium also promotes dehydrogenation and coke formation. Added Iron levels exceeding ~0.2 wt% have been shown to cause a measurable decline in performance<sup>1</sup>. Vanadium contamination can have similar severe effects, even at lower concentrations, due to its high chemical reactivity and mobility<sup>4</sup>.

Traditional countermeasures, such as increasing catalyst make-up rates or adding purchased equilibrium catalyst (Ecat), provide only temporary relief and raise operating costs. Reformulating the base catalyst to improve metals tolerance offers some benefit, though not complete protection<sup>5</sup>. A more cost-effective and targeted approach involves the use of a dedicated metals trap additive designed to capture and immobilise iron and vanadium<sup>6,7</sup>.

## Inter-particle mobility of metals and its implications

One prerequisite for metals traps to function effectively is the inter-particle mobility of the metals. Johnson Matthey conducted a statistical study of metal concentrations on the surfaces of thousands of Ecat particles using SEM/EDS (Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy). If a metal exhibits high inter-particle mobility, its concentration tends to be similar across Ecat particles; conversely, a broad concentration distribution indicates low mobility. As shown in Figure 1, vanadium displays the highest mobility (i.e., lowest spread of metal content), nickel the lowest mobility, and iron falls in between. The inter-particle mobility of iron and vanadium enables metals traps to capture them effectively.

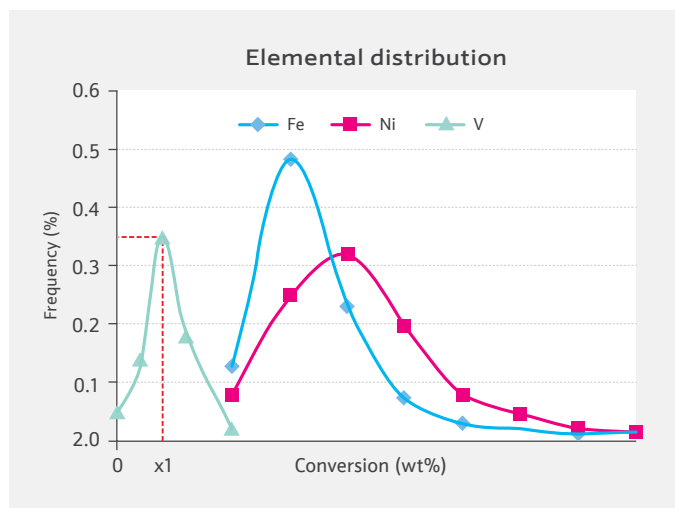


Figure 1: Statistical frequency distribution of metal concentrations on Ecat particle surfaces measured by SEM/EDS of a commercial Ecat. The X-axis represents the metal concentration on the Ecat surface, while the Y-axis shows the frequency distribution. For example, the V content is approximately X<sub>1</sub> wt% for about 35% of the particles.

## The role of silica mobility

It is reported that silica mobility plays a critical role in the inter-particle transfer of metals, especially iron<sup>8-10</sup>. In the FCC unit, silica is mainly present in the Y-zeolite portion of the base catalyst. Silica from the Y-zeolite framework decomposes under regenerator conditions. Elevated temperature and steam (i.e., conditions seen in a regenerator) can cause silica to migrate from particle to particle, including from base catalyst particles to additive particles<sup>11</sup>. This migration explains the presence of distinct silica-rich rings observed on Johnson Matthey's **CAT-AID** metals trap additive particles recovered from commercial units. EDS mapping and chemical analysis reveal that over 20% SiO<sub>2</sub> can be present on **CAT-AID** additive surface despite the additive being initially silica-free. This confirms that mobile silica is coming from the base catalyst. The presence of these silica rings serves as clear evidence of the additive's interaction with mobile species and demonstrates its ability to intercept and immobilise silica and silica bonded with iron/vanadium (Figure 2).

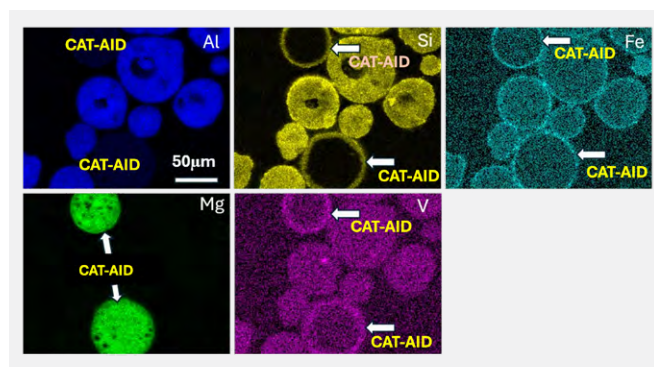


Figure 2: Scanning Electron Microscopy with Energy-Dispersive Spectroscopy (SEM-EDS) mapping of Ecat showing the elemental distribution on the cross-section of particles including Ecat and **CAT-AID** additive. **CAT-AID** particles effectively trap iron, vanadium and silica as evidenced by the rings on the surface.

## Benefits of stand-alone metals trap additives

Under FCC conditions, high temperatures and steam facilitate material transfer between catalyst and additive particles through collisions and deposition of volatile species. This mechanism not only promotes the spread of contamination but also creates an opportunity for metals-trap additives to capture iron and vanadium.

Because silica is believed to facilitate metal transfer between particles, metals traps capable of binding acidic, silica-containing species have a distinct advantage. The basic components in the **CAT-AID** additive effectively capture iron and vanadium, preventing further cross-contamination of the base catalyst.

It might appear attractive to integrate metal-trapping functionality directly into the base catalyst, but this approach is fundamentally limited since incorporating these materials into a base catalyst would significantly reduce its acidity, compromising cracking performance. Moreover, since iron within the glassy outer shell is immobile, any internal trapping sites would be inaccessible. The result would be an inactive catalyst that cannot mitigate poisoning. Therefore, an external, free-circulating additive is the only practical method for effective remediation.

## CAT-AID additive functionality

The **CAT-AID** additive is engineered to capture iron and vanadium species. Upon introduction into the FCC unit, its basic component reacts with mobile silica to form stable alkaline earth metal silicates, immobilizing both silica and the associated iron/vanadium. This conclusion was drawn based on an in-depth study conducted by JM on several commercial samples (data not shown).

The additive is built on a SO<sub>x</sub>-adsorbing substrate, enabling SO<sub>x</sub> capture and protecting other metal-trapping sites (such as those for vanadium) from attack by sulfur. This integrated design allows refiners to reduce consumption of SO<sub>x</sub> reduction additives and/or caustic soda when operating a wet gas scrubber.

Commercial and laboratory evidence shows that, after **CAT-AID** additive introduction, Ecat particles develop smoother surfaces with less pronounced nodules (Figure 3). Advanced statistical analysis of Ecat samples before and after additive use reveals a clear shift toward lower surface iron concentrations<sup>2</sup>, along with increased silica accumulation on the additive itself confirming its metals-trapping effectiveness. Figure 4 further demonstrates **CAT-AID** additive's sustained ability to attract vanadium, with both silica and vanadium penetrating to the center of the particles, fully utilizing its capacity.

In both cases, refiners have observed that the lower delta coke enabled by the additive improves unit heat balance, allowing higher contaminated-feed processing and providing more flexibility of severity and feed rate optimization.

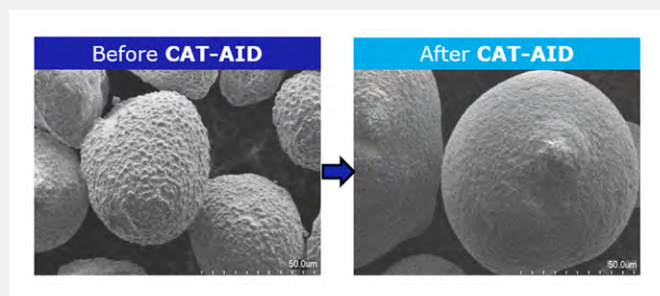


Figure 3: SEM images from Ecat samples (0.9 wt% Fe<sub>2</sub>O<sub>3</sub> (bulk)) before and after the addition of **CAT-AID** additive

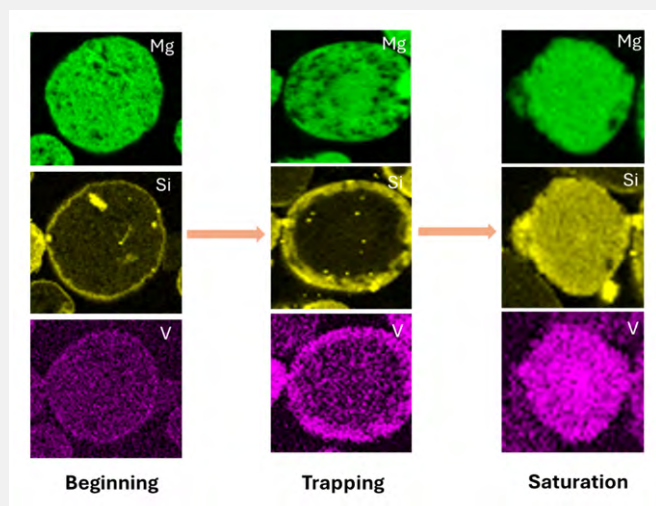


Figure 4: SEM images showing propagation of Vanadium-Silica layer formation on **CAT-AID** particles obtained from a commercial unit

## Laboratory validation: ACE study

The performance of the **CAT-AID** additive was evaluated using an Advanced Cracking Evaluation (latest generation ACE-C) unit to simulate FCC conditions. A steamed Ecat sample, confirmed by SEM to exhibit early stages of iron nodulation, contained 5600 wppm nickel and 4160 wppm vanadium, representative of resid (RFCC) refinery operation. When 10 wt% of the additive was co-steamed in the laboratory with this Ecat, the resulting surface morphology was notably smoother, with reduced nodule density.

ACE testing revealed clear quantitative benefits. Coke yield decreased from 6.2 wt% to 5.1 wt%, dry gas yield fell from 2.6 wt% to 2.1 wt%, and hydrogen yield declined from 0.6 wt% to 0.4 wt%, all at constant conversion (Figure 5). These changes were statistically significant within the 95% confidence interval ( $\pm 0.5$  wt% for coke,  $\pm 0.03$  wt% for dry gas,  $\pm 0.01$  wt% for hydrogen). Propylene, C<sub>4</sub> and total LPG remained relatively constant. No increase in bottoms or Total Cycle Oils and an increase in naphtha was observed (32.1 to 33.9 wt%). These results demonstrate that the additive not only mitigates metal poisoning but also preserves desirable selectivity and conversion efficiency.

## Commercial refinery application

Commercial trials continue to validate the laboratory findings. One Asian refiner operating a two-stage RFCC unit processing a blend of light Vacuum Gas Oil, Coker Gas Oil, and heavy Atmospheric Residue (Heavy AR) from

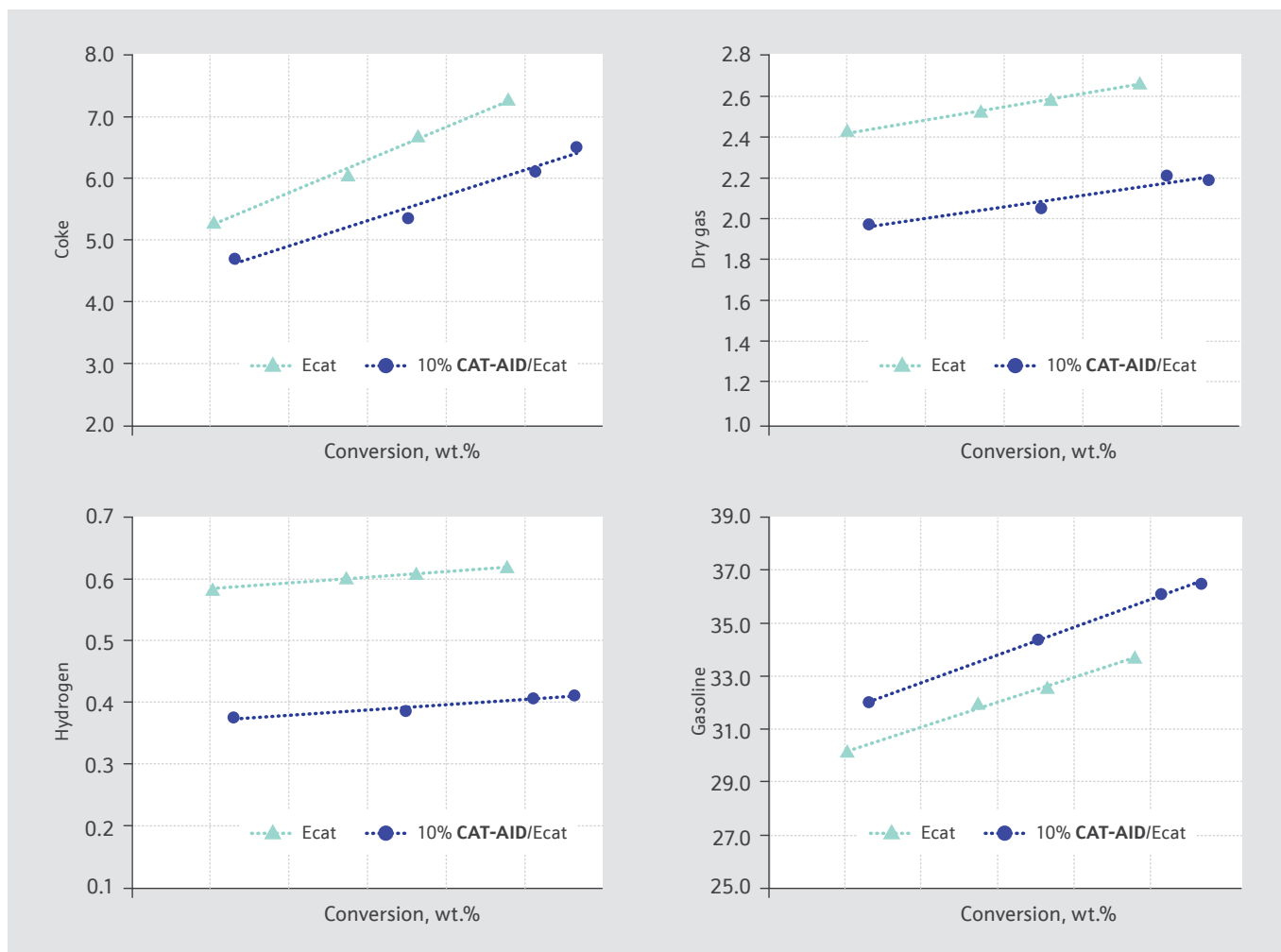


Figure 5: Selected ACE yields for a high iron Ecat steamed and after co-steaming with **CAT-AID** additive

Arabian and local crudes implemented the **CAT-AID** additive to manage rising metal contamination. Prior to the trial, the refinery relied on high fresh catalyst addition rates to maintain conversion and metals control. To accelerate additive build-up, the **CAT-AID** additive was base-loaded and subsequently maintained at a steady-state concentration of approximately 10 wt% of the circulating catalyst inventory.

Following introduction of the additive, the refinery achieved a range of operational and economic benefits (Table 1):

- Increased processing of heavier feed.
- Improved conversion at constant riser severity despite heavier feed.
- Reduced regenerator temperature at equivalent coke yield, confirming lower delta coke.
- Higher Ecat activity despite elevated metal levels,

enabling deeper cracking and reduced coke on spent catalyst for equivalent coke yield per feed.

- Enhanced gasoline and LPG yields, consistent with refinery optimisation targets.

Overall, the refinery realised an additional \$0.80 per barrel of feed margin, equating to approximately \$10 million per year in net profit, inclusive of additive cost. The improvements confirmed **CAT-AID** additive's capability to restore catalyst performance, stabilise regenerator operation, and expand the feasible processing window for high-metals feeds.

### Broader operational benefits

Across various refinery applications, the **CAT-AID** additive has demonstrated a consistent ability to reduce delta coke, stabilise regenerator operation, and enhance yields. Its capacity to trap iron and vanadium, coupled with integrated SOx capture, provides refiners with greater

	Without CAT-AID	With CAT-AID	Delta
Feed rate (KBPD / TPD)	33.7 / 4,847	34.2 / 4,926	+0.5 / +79
Percent heavy AR (%)	42.0	46.7	+4.7
Riser Temp (F / °C)	912 / 489	915 / 490	+3 / +1
Regen 1 Temp (F / °C)	1,201 / 650	1,179 / 637	-22 / -12
Regen 2 Temp (F / °C)	1,313 / 712	1,302 / 706	-11 / -6
Delta Coke Regen 2 (wt%)	0.68	0.65	-0.03
ECAT Activity (wt%)	71.0	72.2	+1.2
ECAT V (ppm)	6,043	6,250	+207
ECAT Fe <sub>2</sub> O <sub>3</sub> , (ppm)	5,776	5,961	+185
Conversion (wt%)	75.0	78.7	+3.7
Dry gas yield (wt%)	4.6	4.3	-0.3
LPG yield (wt%)	21.1	22.6	+1.5
Gasoline yield (wt%)	41.6	44.2	+2.6
LCO yield (wt%)	18.4	15.3	-3.1
Slurry yield (wt%)	6.6	6.0	-0.6
Coke yield (wt%)	7.7	7.6	-0.1

Table 1: Results of the CAT-AID additive trial

operational flexibility. Improved catalyst fluidisation and circulation are further benefits, resulting from the additive's role in preventing iron and vanadium contamination.

Refiners can use the improved heat balance in several ways, depending on their optimisation goals:

- Increase feed rate and residue processing
- Lower delta coke and regenerator temperature
- Enhance conversion and reduce hydrogen and dry gas
- Improve LPG olefinicity
- Reduce fresh catalyst and/or flushing Ecat consumption
- Support stable operation via improved Ecat circulation/fluidization
- Lower flue gas SO<sub>x</sub> emissions, SO<sub>x</sub> reduction additive usage, and/or scrubber caustic soda consumption

## Outlook and conclusions

The shift toward processing lower-value feedstocks offers opportunities for increased profitability but also brings heightened risk of catalyst deactivation due to metal contamination. Advanced additive solutions enable refiners to manage iron and vanadium more effectively, enhancing base catalyst performance.

Future research continues to build on these insights. The use of advanced characterisation techniques (HR-TEM and EDS) continues to refine understanding of metals behaviour at the nano-scale, driving innovation in FCC catalyst enhancement.

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