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CLARIANT'S ZEOLITE SOLUTIONS

Catalyzing sustainable transformations for a greener future

Greater chemistry

Clariant's Zeolite Solutions:
Catalyzing Sustainable Transformations for a Greener Future

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1. Summary

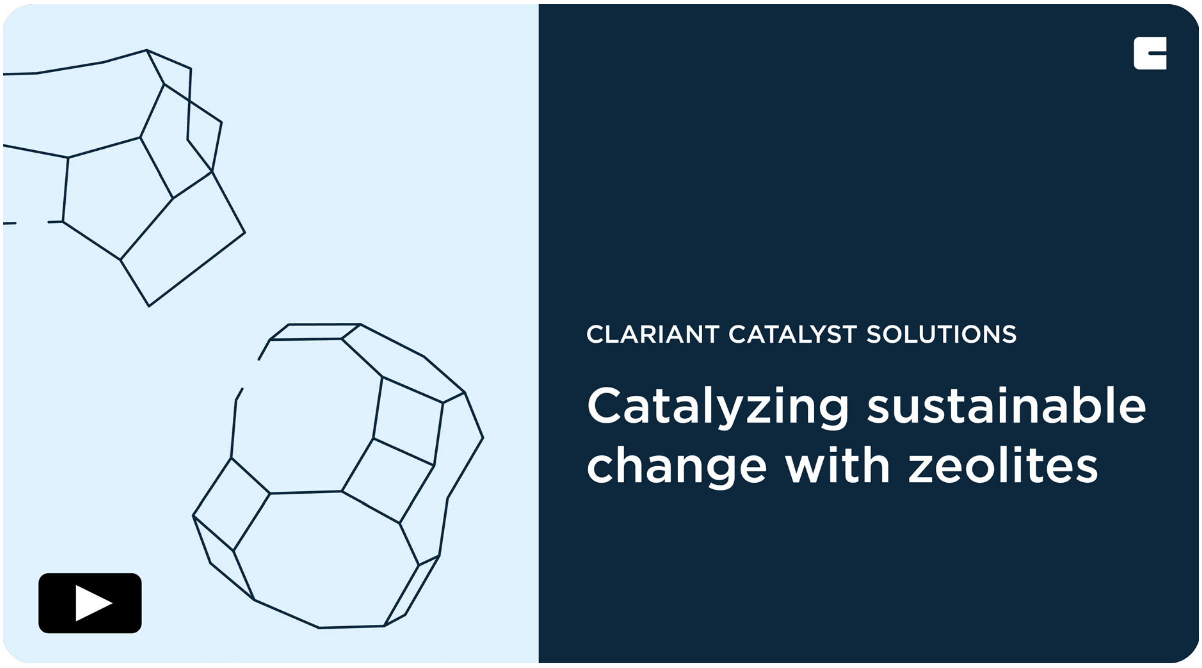
As industries strive to reduce their environmental footprint and align with global sustainability goals, innovative solutions are crucial for enabling sustainable transformations. Clariant, a leading specialty chemicals company, has developed cutting-edge zeolite solutions that address key sustainability challenges across various sectors, including aviation, plastics, and industrial emissions control.

This white paper explores Clariant's zeolite catalysts and their role in enabling the production of sustainable aviation fuel (SAF), carbon-neutral plastics, and effective industrial emission control systems. Leveraging the unique properties of zeolites, these solutions facilitate the use of renewable feedstocks, increase process efficiency, and minimize harmful emissions, contributing to a more sustainable future.

Key highlights of Clariant's zeolite solutions include:

- AEL-type zeolite catalysts for converting waste oils into high-quality SAF components via the HEFA (Hydroprocessed Esters and Fatty Acids) route.
- MFI zeolite catalysts enabling the ethanol-to-olefins (ETO) process for producing carbon-neutral plastics from renewable plant-based alcohols.
- Iron-modified beta zeolite catalysts for selective catalytic reduction (SCR) systems, achieving high NO_X removal efficiency and reducing operational costs in industrial emission control.

Watch Now:
Discover How Clariant's Zeolite Solutions Are Driving Sustainable Transformations Across Industries!



Video 1. **Clariant's zeolite catalysts** and their role in enabling the production of sustainable aviation fuel (SAF), carbon-neutral plastics, and effective industrial emission control systems. [Source: Clariant]

With an integrated global network for zeolite production, customization capabilities, and a commitment to continuous innovation, Clariant is well-positioned to support industries in their decarbonization journeys, drive the development of sustainable solutions and advance purposes aligned with environmental stewardship.

2. Introduction

The pursuit of sustainability has become a global imperative, with industries facing mounting pressure to reduce their environmental impact and align with international goals, such as the Paris Agreement and the United Nations Sustainable Development Goals. Key challenges include decarbonization, minimizing waste and emissions, and transitioning to renewable resources. Addressing these challenges requires transformative solutions that enable sustainable practices without compromising economic viability.

Defossilization of the aviation sector, in particular, is a clear priority in the fight against climate change, as demonstrated by the emergence of binding SAF mandates and policy incentives in an increasing number of jurisdictions across the globe. Despite efforts to improve efficiency, aviation still accounts for 2.5% of global CO_2 emissions and 12.5% of global transport emissions. Moreover, this share is increasing as other sectors decarbonize more rapidly, underscoring the urgent need for sustainable solutions in aviation.

Catalysts play a crucial role in enabling sustainable processes by increasing efficiency, reducing energy consumption, and facilitating the use of renewable feedstocks. By lowering activation barriers and enhancing reaction rates, catalysts unlock new pathways for sustainable chemistry, enabling the development of innovative and environmentally friendly processes.

As a leading specialty chemicals company, Clariant is committed to driving innovation and sustainability through its product portfolio and technological advancements. Leveraging its expertise in catalysis, Clariant has developed cutting-edge zeolite solutions that address key sustainability challenges across various industries, enabling its customers to achieve their sustainability goals while maintaining competitiveness.

This white paper will explore three main applications of Clariant's zeolite solutions:

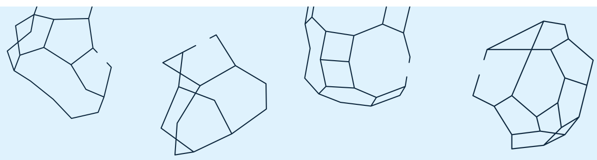
1. Sustainable Aviation Fuel Production
2. Carbon-Neutral Plastics from Renewable Feedstocks
3. Industrial Emission Control

We will examine how Clariant's zeolite catalysts are driving sustainable transformations in these areas and contributing to a greener future.

3. Zeolites: Unique Catalytic Materials

Before delving into specific applications, it's important to understand the fundamental properties of zeolites that make them exceptional catalytic materials.

Zeolites are crystalline aluminosilicate materials with a unique microporous structure consisting of interconnected channels and cavities. Their framework is composed of SiO_4 and AlO_4 tetrahedra linked through shared oxygen atoms, forming a negatively charged lattice balanced by exchangeable cations, such as sodium, potassium, or protons.



Key properties of zeolites include:

- High thermal stability
- Ion-exchange capacity
- Molecular sieving capabilities due to well-defined pore sizes and shapes (typically 3–10 angstroms)
- Shape selectivity, allowing for selective adsorption and discrimination of molecules based on size and shape
- High surface area
- Tunable acidity

These properties make zeolites exceptionally versatile catalysts for a wide range of chemical reactions.

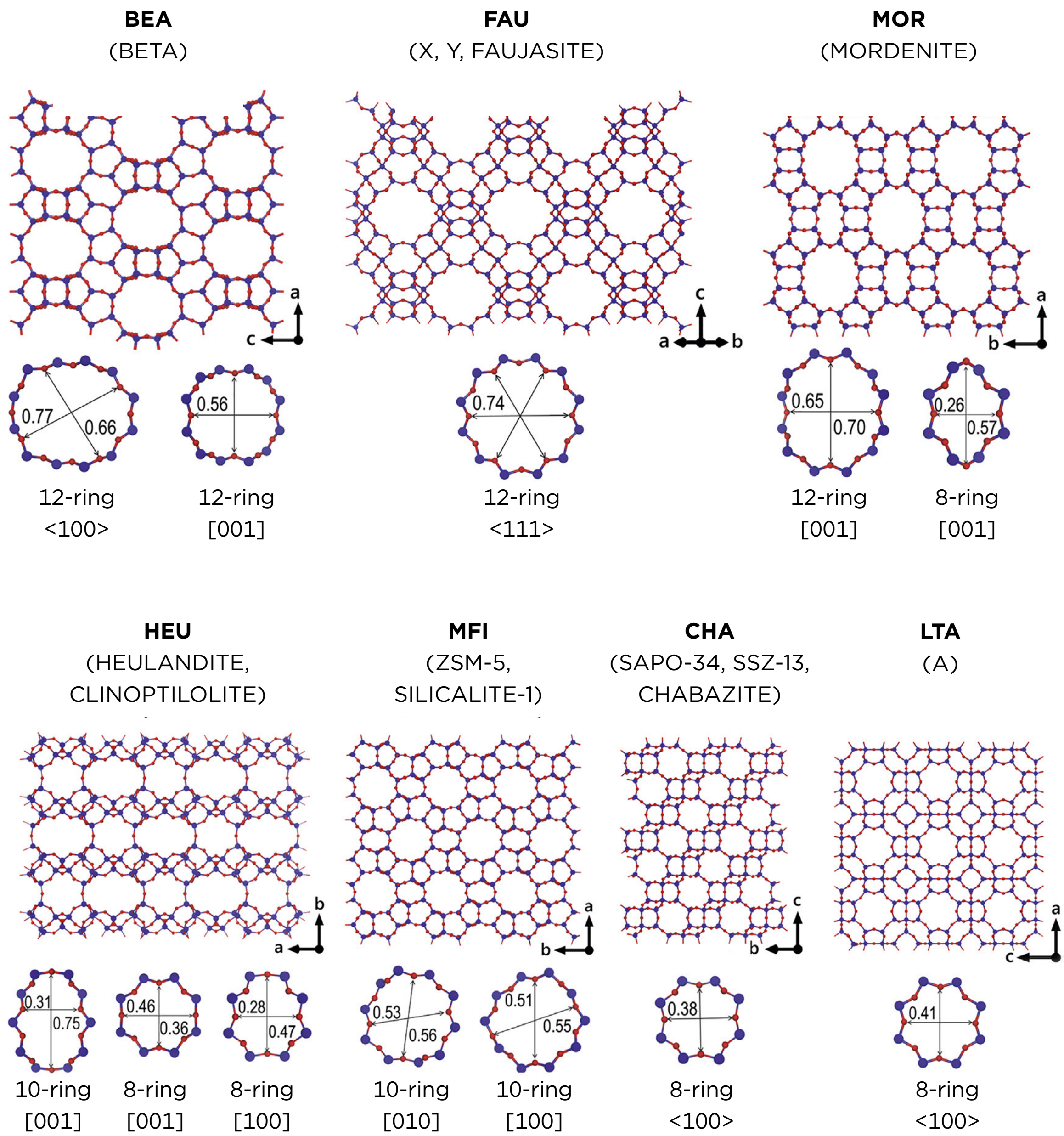


Figure 1. **Common zeolite frameworks**, showing for each type: three-letter IZA code, zeolite names, framework structure (blue: T atoms, red: oxygen), and pore windows with size (nm) and direction. [Source: 2. Li, et al.]

With decades of experience in zeolite synthesis and modification, Clariant has developed a deep understanding of these materials' unique properties and catalytic behavior. Clariant's state-of-the-art production facilities and continuous research efforts enable the development of tailored zeolite solutions for specific applications. The company's expertise spans zeolite synthesis, ion exchange, dealumination, and other modification techniques, allowing for the precise tuning of zeolite properties to meet specific catalytic requirements.

4. Sustainable Aviation Fuel from Waste Oils

4.1. CHALLENGE

The aviation industry is a significant contributor to global greenhouse gas emissions, accounting for approximately 2.5% of global CO_2 emissions. As the demand for air travel continues to grow, decarbonizing this sector is crucial for mitigating climate change and achieving global emissions reduction targets.

SAFs are considered one of the most promising solutions to reduce CO_2 emissions from the aviation sector in the near- to mid-term. This potential has been recognized by international organizations and authorities worldwide. The European Union, the United States, and many other governments and organizations around the world are establishing binding mandates and voluntary commitments to accelerate SAF adoption.

Cumulative CO_2 Emissions 2019–2050

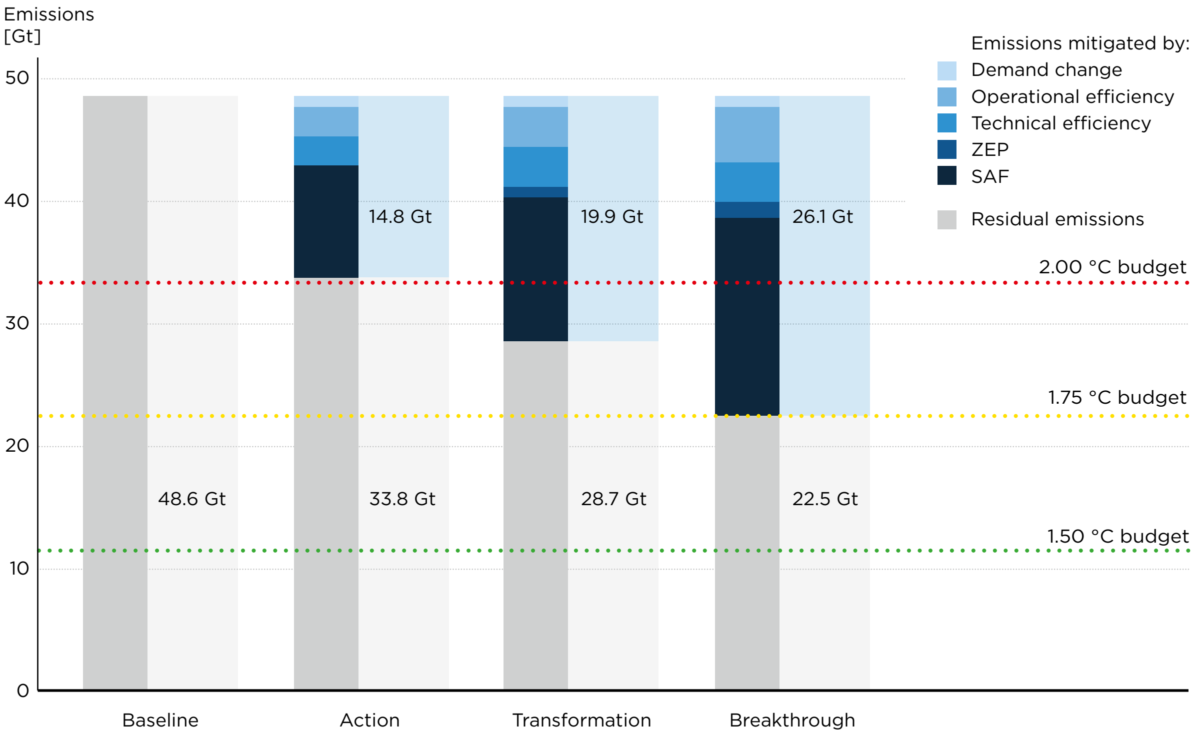


Figure 2. **SAFs accounting for** the largest share of CO_2 reduction potential based on cumulative global aviation CO_2 emissions by scenario and measure, 2019–2050. [Source: 3. Graver et al.]

Recent studies by respected organizations underscore the critical role of SAFs in aviation decarbonization. The International Council on Clean Transportation (ICCT) projects that SAFs could account for 59% to 64% of CO_2 reduction potential in the aviation sector by 2050. The International Air Transport Association (IATA) estimates that SAFs will contribute about 65% of the emission reductions needed by aviation to reach net-zero carbon emissions by 2050. The International Energy Agency (IEA) also emphasizes the importance of SAFs, particularly for long-haul flights where other technologies may not be feasible in the near future.

4.2. SOLUTION

Sustainable aviation fuel (SAF) derived from renewable sources offers a promising solution to reduce the industry's carbon footprint. Clariant has developed specialized zeolite catalysts that play a crucial role in various SAF production pathways.

4.3. CLARIANT'S AEL-TYPE ZEOLITE CATALYSTS FOR WASTE OIL-TO-SAF CONVERSION

Clariant has developed AEL-structured zeotypes for the hydroprocessed esters and fatty acids (HEFA) pathway of SAF production. This catalyst has been successfully produced at commercial scale in Clariant's zeolite plants and plays a crucial role in the isomerization step of the HEFA process.

The AEL zeotype catalyst facilitates the isomerization and branching of long-chain paraffins present in waste oils, converting them into branched isoparaffins with improved combustion properties. The unique pore structure and acidity of the AEL zeolite enable selective cracking and isomerization, resulting in a tailored distribution of branched isoparaffins ideal for jet fuel applications.

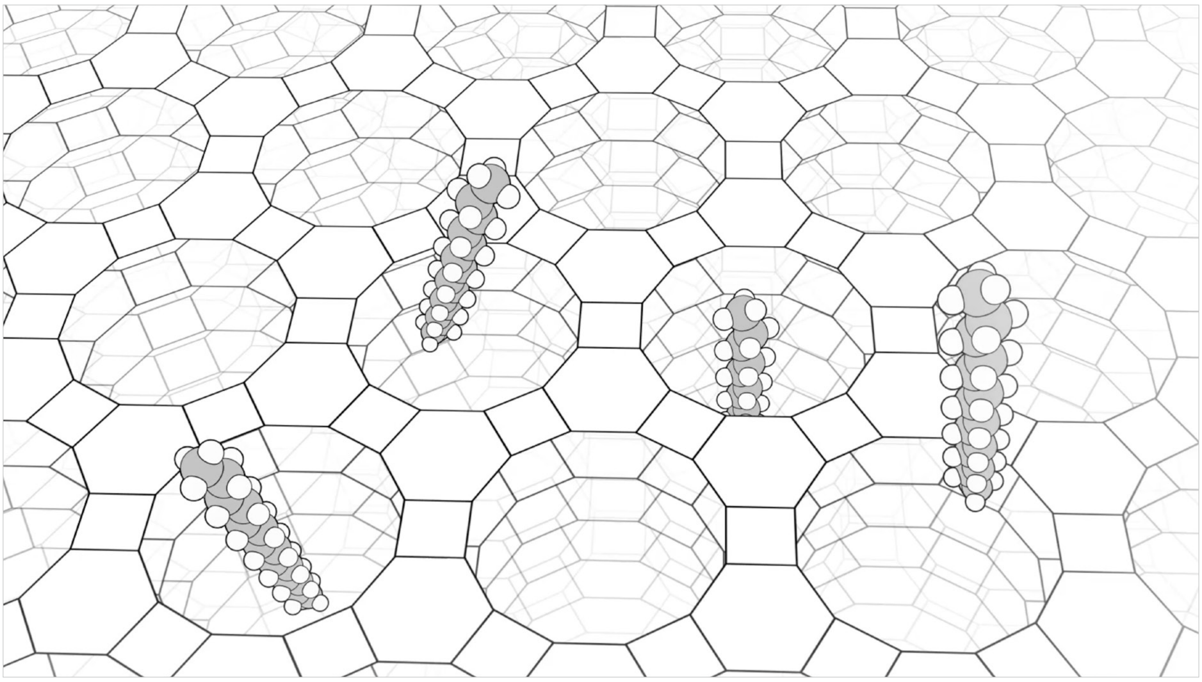


Figure 3. **Clariant AEL zeolites** sieve out and transform paraffins present in waste oils. [Source: Clariant]

4.4. BENEFITS

The branched isoparaffins produced using Clariant's zeolites exhibit:

- Higher energy density
- Better cold flow properties
- Lower emissions compared to conventional jet fuel components
- Enhanced combustion efficiency
- Reduced particulate matter formation
- Improved low-temperature operability

These properties make them ideal components for sustainable aviation fuel, potentially contributing to reducing the carbon footprint of the aviation industry by up to 80% compared to conventional fossil-based jet fuel.

4.5. SUCCESSFUL IMPLEMENTATION IN SAF PRODUCTION

Clariant has established key partnerships in the SAF industry, demonstrating the scalability and economic viability of its zeolite technology for SAF production. These collaborations have the potential to greatly reduce the carbon footprint of the aviation industry compared to conventional fossil-based jet fuel.

In one significant partnership, Clariant's specialized zeolite powder serves as a crucial component in the production of a specific catalyst used by a major SAF producer. This collaboration highlights the essential role of Clariant's advanced materials in enabling large-scale SAF production. The SAF producer's ambitious plans to significantly expand their output underscore the growing importance and viability of Clariant's zeolites in the sustainable aviation fuel industry.

Furthermore, Clariant has successfully introduced its specialized zeolite powder into another established SAF production process, demonstrating the versatility and applicability of its materials across different technological approaches. As full qualification nears completion, Clariant's zeolites are positioned to become a key raw material in multiple SAF production pathways, contributing significantly to the aviation industry's sustainability goals.

4.6. ETHANOL-TO-JET (ETJ) PATHWAY

Clariant's extensive expertise in specialized zeolite types positions its products as key enablers for the ethanol-to-jet (ETJ) pathway. Clariant zeolites have demonstrated their viability through successful qualification for ethanol-to-olefins conversion in collaboration with a leading industry partner.

The ETJ process relies on Clariant's catalysts at multiple critical stages:

- Ethanol dehydration to ethylene
- Oligomerization of ethylene to longer-chain hydrocarbons
- Hydrogenation to produce jet fuel

By facilitating these essential reactions, Clariant's zeolites play a pivotal role in enhancing the efficiency and sustainability of the entire ETJ process, contributing significantly to the advancement of SAF technology.

4.7. METHANOL-TO-JET (MTJ) PATHWAY

For the methanol-to-jet (MTJ) pathway, Clariant's zeolites demonstrate exceptional versatility and performance across various methanol conversion processes. Clariant's expertise is evident in the development of highly efficient catalysts for methanol-to-olefins and methanol-to-gasoline technologies. These specialized catalysts have proven their effectiveness in meeting exacting industry standards, underlining their consistency and quality.

As the SAF industry progresses towards MTJ implementation, Clariant's zeolites are well-positioned to support the scaling of these processes. The advancements in both ETJ and MTJ pathways highlight the adaptability and dependability of Clariant's zeolite solutions, reinforcing their critical role in the development of sustainable aviation fuel across multiple technological routes.

Figure 4. **Clariant zeolite samples** [Source: Clariant]

5. Carbon-Neutral Plastics from Renewable Feedstocks

5.1. CHALLENGE

The production of conventional plastics from fossil fuels contributes to greenhouse gas emissions and environmental pollution. A sustainable alternative is needed to reduce the environmental impact of plastic production while maintaining the material's versatility and performance.

5.2. SOLUTION

Renewable feedstocks, such as plant-based alcohols (e.g., ethanol, butanol) and biomass-derived sugars, offer a promising pathway for producing carbon-neutral plastics with a significantly lower environmental impact. Clariant has developed MFI zeolite catalysts that enable the efficient conversion of these renewable feedstocks into valuable olefins, the building blocks for various plastics.

5.3. CLARIANT'S MFI ZEOLITE CATALYSTS FOR THE ETHANOL-TO-OLEFINS (ETO) PROCESS

Clariant's MFI zeolite catalysts enable the ethanol-to-olefins (ETO) process, which converts plant-based ethanol into valuable olefins like ethylene and propylene, the building blocks for various plastics. The MFI zeolite's unique pore structure and acidity facilitate the dehydration of ethanol to ethylene, followed by oligomerization and cracking reactions to produce a range of olefins.

Conversion of Olefins

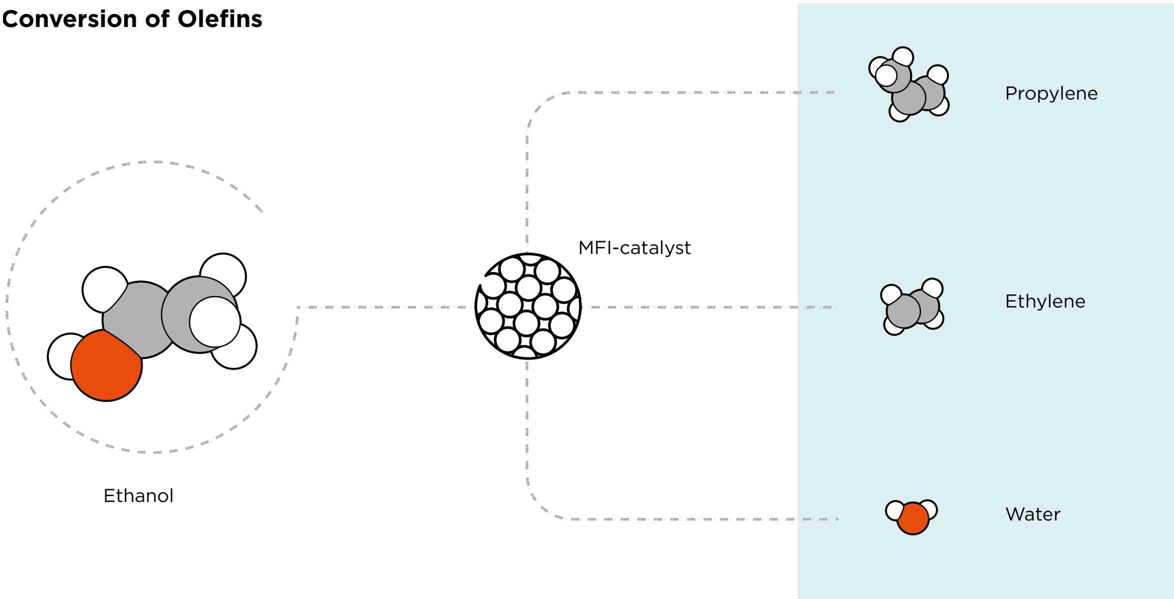


Figure 5. **The MFI catalyst** helps convert ethanol into the desired olefins – mainly ethylene and propylene, with water as one of the chief byproducts. [Source: Clariant]

5.4. KEY FEATURES OF CLARIANT'S MFI ZEOLITES

Shape selectivity and pore structure

- The pore structure of MFI zeolites (approximately 5.5 Å) is optimized to allow the diffusion of ethanol molecules while restricting the formation of larger hydrocarbon chains.
- This shape selectivity is crucial for controlling product distribution and avoiding unwanted side reactions in the ETO process.
- Studies have reported a shape selectivity factor of 7.5 for similar zeolite-catalyzed conversion processes [2].

Catalyst stability and reusability

- Clariant's zeolite catalysts maintain their activity and selectivity over multiple reaction cycles.
- Intermediate regeneration is possible through calcination.
- The stability is attributed to the restricted growth of oligomers within the zeolite pores, preventing substantial pore blockage and catalyst deactivation.
- Research has shown maintained activity and selectivity over six consecutive runs with intermediate calcination at 550 °C [2].

Process intensification

- The use of Clariant's zeolite catalysts in the ETO process allows for high volumetric productivities (space-time yields).
- This is essential for large-scale, economically viable production of carbon-neutral plastics.

5.5. BENEFITS

The use of zeolite catalysts in processes converting renewable feedstocks like biomass-derived ethanol can offer several potential sustainability benefits:

- Potential reduction in the carbon footprint of chemical production compared to fossil fuel-based routes
- Contribution to the circular economy by utilizing renewable resources
- Indirect support for the development of sustainable agriculture through the use of agricultural byproducts
- Alignment with broader industry trends towards more environmentally friendly production methods

Figure 6. **Clariant zeolite powder** [Source: Clariant]

Figure 7. **Clariant Hysopar™** [Source: Clariant]

6. Industrial Emission Control with Clariant Zeolites

Nitrogen oxides (NO_X) and nitrous oxide (N_2O) are major pollutants emitted from industrial processes, contributing significantly to air pollution and greenhouse gas emissions. N_2O, in particular, is approximately 300 times more harmful to the climate than CO_2. With annual N_2O emissions from nitric and adipic acid production amounting to more than 100 MtCO_2e (about 0.2% of global CO_2 emissions), effective abatement solutions are are urgently needed, also in the light of more stringent regulatory requirements.

6.1. CLARIANT'S ZEOLITE-BASED CATALYSTS FOR N_2O AND NO_X ABATEMENT

Clariant has developed iron-exchanged zeolite catalysts specifically designed for N_2O and NO_X abatement in industrial processes. These catalysts are particularly effective in nitric acid plants, where they can be implemented in tertiary abatement stages. The catalysts operate at lower temperatures (340–600 °C), achieving over 99% N_2O removal, though some engineering modifications may be necessary.

Zeolite-based Tertiary Catalyst: Over 35 Installations Reducing Emissions by 20 Mt CO_2eq annually

- Cutting-edge zeolite-based tertiary abatement technology
- Highly effective N_2O and NO_X emission reduction
- Continuously improved catalyst formulation
- Exceptional durability: 13+ years operational lifespan
- Ultra-low emissions: Consistently below 30 ppmv

Global impact: 35+ global installations

Environmental impact: 20Mt CO_2eq reduction annually

Figure 8. **Global impact of Clariant's zeolite-based tertiary catalysts.** Data presented by S. Sauerbeck et al. at the Ammonium Nitrate and Nitric Acid (ANNA) Conference, Montreal, October 2024. [Source: Clariant]

Clariant's zeolite-based catalysts have demonstrated impressive performance in real-world applications. With more than 35 installations globally, these catalysts are significantly reducing emissions, showcasing the effectiveness and scalability of Clariant's zeolite technology in addressing industrial emissions.

6.2. IRON-MODIFIED BETA ZEOLITES FOR SELECTIVE CATALYTIC REDUCTION (SCR)

In addition to N_2O abatement, Clariant has developed iron-modified BETA zeolite catalysts for selective catalytic reduction (SCR) of NO_X. These catalysts enable the efficient reduction of NO_X to harmless nitrogen and water vapor, using ammonia as a reducing agent. The unique pore structure and acidity of the BETA zeolite, combined with the iron-active sites, facilitate the adsorption and activation of NO_X and ammonia, enabling highly efficient reduction reactions. Compared to traditional SCR catalysts, Clariant's iron-modified BETA zeolites offer improved activity, selectivity, and thermal stability, leading to enhanced NO_X removal efficiency and reduced operating costs.

6.3. PROVEN TRACK RECORD IN ZEOLITE-BASED EMISSION CONTROL SOLUTIONS

The advantages of Clariant's zeolite-based catalysts include achieving N_2O and NO_X conversion rates exceeding 99%, demonstrating high efficiency. Their durability is evident in installations that have shown consistent performance for over 13 years, maintaining emissions below 30 ppmv. The catalysts' versatility allows them to be effective across various industrial processes and temperature ranges. Moreover, their composition of silicon, aluminum, oxygen, and iron, without precious metals, contributes to a smaller ecological footprint.

By leveraging over 20 years of experience in tertiary abatement and more than 40 years in zeolite synthesis and catalysis, Clariant continues to innovate and improve its catalyst offerings. The company's commitment to developing advanced zeolite structures and optimizing iron-exchange processes ensures that its catalysts remain at the forefront of industrial emission control technology.

7. Clariant's Global Capabilities and Commitment

Clariant's integrated global network for zeolite synthesis and manufacturing ensures consistent quality and reliable supply. This global footprint allows Clariant to serve customers across various regions and industries, providing localized support and minimizing transport-related emissions.

KEY STRENGTHS OF CLARIANT'S ZEOLITE SOLUTIONS:

1. Customization Capabilities

- Extensive expertise in zeolite synthesis and modification
- Ability to tailor zeolite materials to meet specific application requirements
- Close collaboration with customers to design customized zeolite catalysts

2. State-of-the-Art Facilities and Expertise

- Self-designed equipment, procedures, and tool sets for all stages of catalyst development
- Unique combination of extensive high-throughput expertise and knowledge in zeolite preparation and testing
- Fast and efficient turnaround times for customer requests and product development

3. 50+ Years of Zeolite Expertise

- Outstanding capability in manufacturing zeolites
- Deep understanding of zeolite properties and applications across various industries

4. Global Zeolites Network

- Cross-functional teams integrating R&D, Production, Sales, and Technical Support
- Seamless collaboration across departments to ensure optimal solutions for customers

5. Collaborative Partnerships

- Technical support and process optimization
- Ongoing innovation to ensure successful implementation and continuous improvement

6. Commitment to Innovation

- Continuous investment in research and development
- Focus on developing novel zeolite structures, improving synthesis methods, and exploring new catalytic applications
- Emerging sustainable technologies: carbon capture and utilization, hydrogen production, and renewable energy storage

This comprehensive set of capabilities positions Clariant as a leader in zeolite technology, enabling the company to provide cutting-edge solutions tailored to the specific needs of various industries. The combination of extensive experience, global presence, and commitment to innovation ensures that Clariant can effectively support its customers in their sustainability journeys and drive the development of sustainable technologies across multiple sectors.

8. Conclusion

Clariant's diverse portfolio of zeolite catalysts and ongoing collaborations in sustainable aviation fuel production, carbon-neutral plastics manufacturing, and industrial emission control position the company as a key enabler in the transition to more sustainable industries. By leveraging its expertise in zeolite synthesis, modification, and application, Clariant is driving innovation in these fields, contributing significantly to their decarbonization efforts.

The unique properties of zeolites, such as high selectivity, thermal stability, and molecular sieving capabilities, make them indispensable in addressing global sustainability challenges. Clariant's zeolite solutions offer a range of benefits, including:

- Improved catalytic performance
- Reduced environmental impact
- Facilitation of renewable feedstock utilization
- Increased process efficiency
- Minimization of harmful emissions

As the demand for sustainable solutions grows, Clariant remains committed to advancing zeolite technology through continuous research and innovation. Future developments will focus on novel zeolite structures, improved synthesis methods, and applications in emerging sustainable technologies such as carbon capture, renewable energy storage, and electrochemical processes. By integrating zeolite catalysts with other sustainable technologies like biocatalysis and electrocatalysis, Clariant aims to further advance sustainable chemical processes. Through ongoing expansion of its zeolite technology portfolio, Clariant continues to solidify its position as a leader in catalyzing a greener future.

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