Managing corrosion risk in SAF and renewable diesel processes

Non-intrusive, real-time monitoring solutions can help manage the unique corrosion risks associated with biofuel feedstocks and processes

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As the world grapples with climate change and seeks to reduce its carbon footprint, the transportation sector has come under increasing scrutiny. Aviation and long-haul trucking, in particular, have faced challenges in transitioning away from fossil fuels. Sustainable aviation fuel (SAF) and renewable diesel have emerged as two promising alternatives that are reshaping the landscape of transportation fuels.

However, the shift to these sustainable fuels brings its own set of challenges. The production of SAF and renewable diesel involves complex processes and the use of diverse feedstocks, ranging from used cooking oils to agricultural residues. These new feedstocks and processes introduce novel corrosion risks that threaten the integrity of production facilities.

This article explores the evolution of biofuels, delves into the production processes of SAF and renewable diesel, examines the corrosion challenges faced by producers, and discusses the innovative monitoring solutions being employed to mitigate these risks.

Evolution of biofuels

To understand the significance of SAF and renewable diesel, it is essential to look at the evolution of biofuels over the past decade. Biofuels have gone through several generations, each addressing the limitations of the previous one.

First-generation biofuels, popular in the early 2000s, were primarily derived from food crops like corn, sugarcane, and other energy crops. While these fuels offered a renewable alternative to fossil fuels, they faced criticism for competing with land use for food production, consequentially driving up food prices and deforestation.

Second-generation biofuels, which gained traction in the 2010s, aimed to address these concerns by utilising non-food biomass such as agricultural and forestry residues likes wood chips. These fuels offered improved sustainability and reduced the risks of land use change and competition with food production. As these biofuels were not capable of directly replacing their hydrocarbon counterparts, blending limits were imposed, which limited their adoption.

Third-generation biofuels, emerging in recent years, focus on waste streams, including municipal solid waste (MSW), sewage sludge, and more advanced feedstocks like algae. These feedstocks promise even greater sustainability and potential for scalability and are available as a direct replacement to legacy fuels without blending limitations.

The latest development, sometimes referred to as fourth-generation biofuels, involves engineered organisms and carbon capture technologies to produce fuels with a negative carbon footprint.

Sustainable aviation fuel

SAF represents a significant leap forward in the aviation industry's efforts to reduce its environmental impact. Unlike traditional jet fuel, SAF is produced from sustainable feedstocks such as used cooking oil, agricultural residues, and even MSW.

The International Air Transport Association (IATA) reports that in 2022, more than 300 million litres of SAF were produced (IATA, 2023). This figure is set to grow dramatically, with more

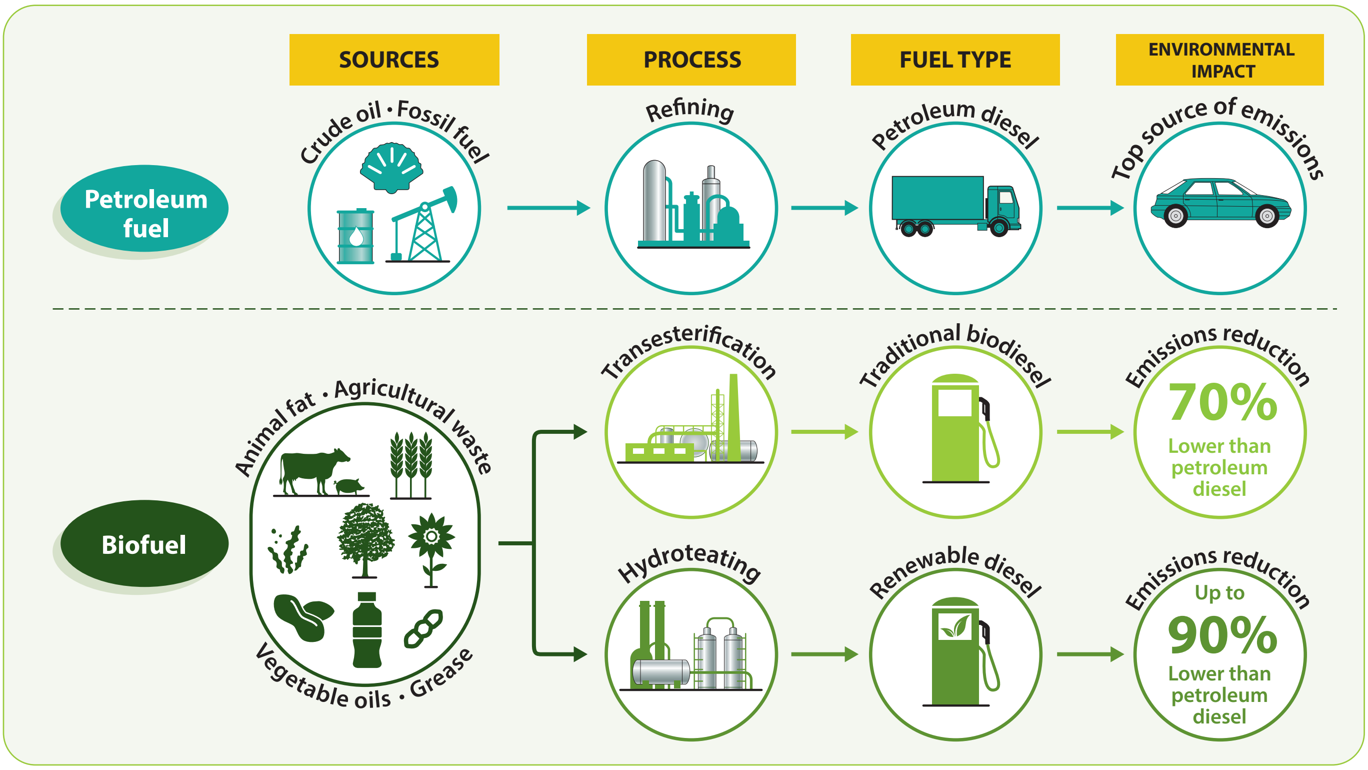

Figure 1 Progression of biofuels development has resulted in up to 90% lower emissions than from petroleum diesel

than 130 renewable fuel projects announced by more than 85 producers across 30 countries globally (*Thomsen, Mistry, & Block*, 2023).

Government incentives are playing a crucial role in driving SAF adoption. In the US, the Sustainable Aviation Challenge sets an ambitious goal for the airline industry to use 11 billion litres of SAF by 2030, equivalent to 15% of current jet fuel demand (*US DOE*, 2021), (*IATA*, 2022). The EU's Fit for 55 package includes a proposed 2% SAF blending mandate by 2025 under the ReFuelEU Aviation initiative (*European Commission*, 2022).

One of the key advantages of SAF is its drop-in capability, meaning it can be used in existing aircraft engines without modification. This characteristic makes it an attractive option for airlines looking to reduce their carbon footprint without investing in new aircraft or engine technologies.

Renewable diesel

While SAF is focused on decarbonising aviation fuels, renewable diesel is transforming the road transportation sector, particularly for heavy-duty vehicles and long-haul trucking. Renewable diesel should not be confused with biodiesel, an earlier biofuel that gained popularity in the past decade.

Renewable diesel offers several advantages over biodiesel. It burns more cleanly and efficiently, produces lower emissions, and can be used in high concentrations without blending with traditional diesel (see **Figure 1**). These characteristics make it an attractive option for fleet operators looking to reduce their environmental impact without significant changes to their existing vehicles.

The International Energy Agency (IEA) projects that renewable diesel production will triple by 2026 (*IEA*, 2022). This growth is driven by increasing demand from road and sea haulage sectors, which have limited options for transitioning away from traditional combustion engines in the short term.

Feedstock challenges and innovations

The choice of feedstock is crucial in the production of both SAF and renewable diesel. Early biofuel production relied heavily on vegetable oils, resulting in fatty acid methyl esters (FAME) or biodiesel. However, concerns about fuel blending and engine compatibility have shifted focus to hydrotreated processes for drop-in fuels.

Hydrotreated vegetable oils (HVO) have emerged as a popular option for producing drop-in fuels. These fuels closely resemble fossil-based fuels and offer better engine compatibility than traditional biodiesel.

To avoid first-generation biofeedstocks, producers are increasingly turning to waste materials including animal fats, used cooking oils, and greases. However, potential supply limitations have resulted in extending the use of wastes to include MSW and sewage sludges. An additional benefit of using these waste products is that they minimise landfill costs and offer financial benefits. However, maintaining consistent quality and supply can be challenging.

New regulations are emerging that require a minimum use of such third- and fourth-generation feedstocks, driving further innovation in this area.

Production processes and corrosion challenges

The production of SAF and renewable diesel involves significant modifications to existing refinery processes along with investment in advanced chemical processes that differ significantly from traditional petroleum refining. Most waste feedstocks require a pretreatment step, followed by hydrodeoxygenation (HDO) to remove oxygen and other contaminants, isomerisation or hydrocracking to achieve the desired fuel properties.

However, these new processes and feedstocks introduce novel challenges, particularly in terms of corrosion risk. The high acidity of some renewable feedstocks, combined with high temperatures and pressures in the refining process, can accelerate corrosion rates in equipment (see **Figure 2**). The main corrosion risks in biofuel production include:

- **Acidic corrosion:** Renewable feedstocks often contain a combination of fatty acids, long carbon chains with single or multiple double bonds, and branched acidic components like resin acids. These feedstocks typically have a much higher total acid number (TAN) compared to fossil fuel feedstocks, ranging from 0 to 200 mg KOH/g feed. This high acidity leads to localised thinning of metal surfaces, which intensifies with increased process temperatures and flow rates. While temperatures above 230°C pose a risk for fossil feeds, this threshold drops to 150°C for renewables due to their elevated acidity. The corrosion products, soluble iron salts, lack protective scales and can accumulate in catalyst beds, causing pressure drops and clogging. This type of corrosion can lead to significant equipment damage, potentially causing leaks or even catastrophic failure if left unchecked.
- **Microbiologically influenced corrosion (MIC):** MIC is caused by the metabolic byproducts of living organisms such as bacteria, algae, or

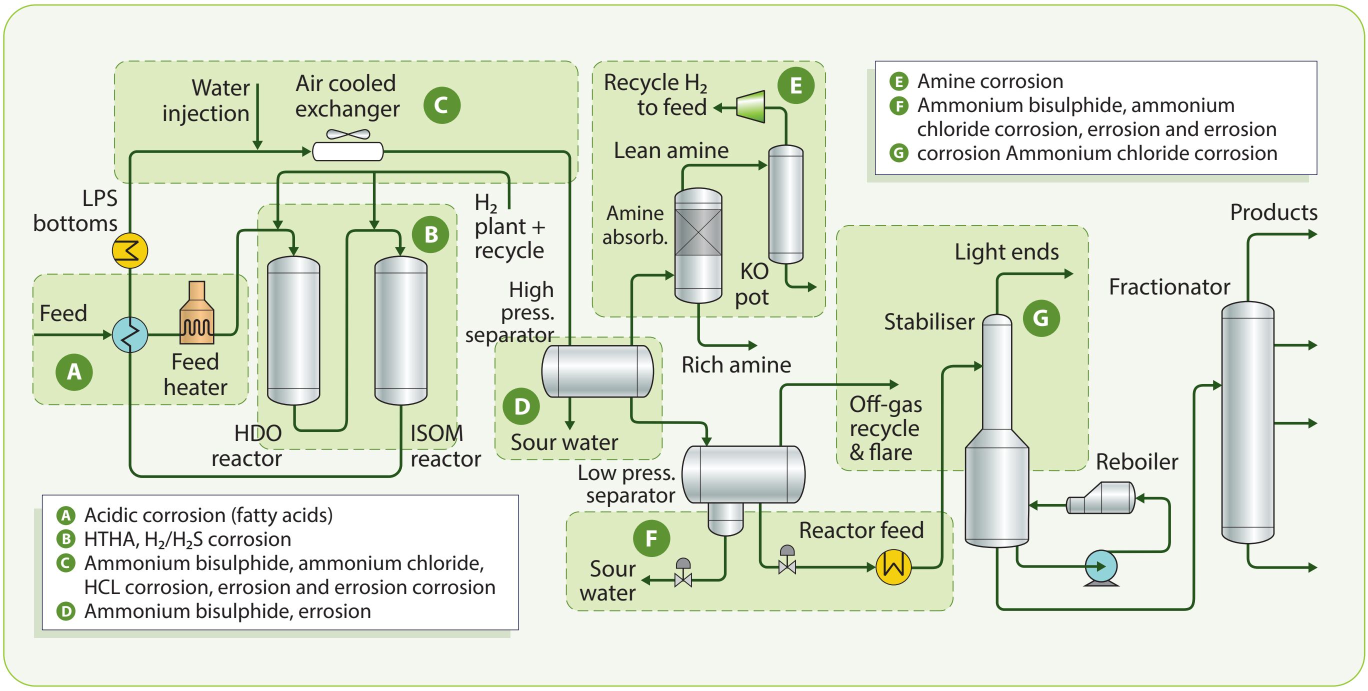

Figure 2 A basic overview of a biofuel production process, with the main corrosion mechanisms and areas of concern highlighted

fungi. It results in distinct localised corrosion, characterised by pitting, tubercles, and crevice corrosion, often occurring beneath biofilm deposits. MIC affects low-temperature areas throughout the process, from feedstock handling and tank farms to processing unit air coolers and final wastewater treatment facilities. The diverse nutrients available in biofuel processes, including inorganic elements and organic hydrocarbons and acids, promote micro-organism proliferation. MIC can cause severe localised damage, potentially leading to through-wall penetration and leaks. The unpredictable nature of MIC makes it particularly challenging to manage without proper monitoring.

- **High-temperature hydrogen attack (HTHA) (hydrogen embrittlement):** HTHA affects all equipment and piping operating above 430°F (221°C) and at partial pressures exceeding 200 psi (1.3 MPa). Under these conditions, hydrogen disintegrates into atomic hydrogen and infiltrates exposed steels. The gases formed cannot diffuse through the component, resulting in blister and bubble formation along grain boundaries and laminations. This progression leads to micro fissures, which amalgamate into larger fissures, ultimately causing cracks and equipment failure. HTHA is particularly insidious as it can occur without visible surface damage until catastrophic failure occurs.
- **High-temperature H_2/H_2S corrosion:** This generalised corrosion mechanism occurs at temperatures surpassing approximately 450°F (230°C) downstream of the hydrogen injection point in the presence of H_2S-containing process streams. The resultant scale exhibits strong adhesion and swells to five times its original volume relative to the lost metal. Its shiny grey appearance can be misleading, often masking the extent of the underlying damage. This type of corrosion can lead to significant wall thinning and potential equipment failure if not properly monitored and managed.
- **Carbonic acid (wet CO_2) corrosion:** When carbon dioxide (CO_2) dissolves in water, it creates carbonic acid (H_2CO_3), which results in a decrease in pH and consequently triggers generalised corrosion in carbon and low alloy steels. Areas characterised by higher process flow velocities, impingement, and turbulence may experience pitting and localised corrosion. Corrosion rates typically rise in the presence of both oxygen and CO_2 partial pressures, particularly where CO_2 condenses from the vapour phase. Within hydroprocessing effluent streams, the risk of severe corrosion emerges when process temperatures fall below the dew point. This type of corrosion can lead to general wall thinning as well as localised attacks, potentially compromising equipment integrity.
- **Ammonium bisulphide corrosion:** This localised corrosion phenomenon is particularly prevalent in hydroprocessing reactor effluent systems and has led to numerous reported failures. It also affects areas with entrained or condensed sour water, such as hydrocarbon lines, reactor effluent separators, and vapour lines from high-pressure separators. High concentrations of NH_4HS and the presence of cyanides contribute to accelerated corrosion. The corrosion manifests differently depending on flow regimes: areas with high flow experience general wall loss, while turbulent sections see intense localised corrosion. This can lead to rapid, localised metal loss and potential equipment failure if not properly managed.
- **Hydrochloric acid corrosion:** Chlorides within the feedstock undergo conversion into hydrochloric acid (HCl) within the hydrotreating reactor. This transformation poses a corrosion risk not only within the reactor effluent stream but also extends downstream to units like the sour water stripper. HCl can cause both general and localised corrosion, particularly affecting stainless steels and leading to pitting-like attacks. As HCl traverses process streams through fractionation sections, it can instigate severe dew point corrosion, especially when the first dew point droplet forms. This phenomenon is observed across overhead sections as process temperatures drop. The corrosion rates are highest under conditions of elevated concentration and temperature, posing a significant risk to equipment integrity.

Each of these corrosion mechanisms presents unique challenges in biofuel production facilities. Their complex and often interrelated nature underscores the importance of comprehensive monitoring strategies, such as the use of advanced, non-intrusive ultrasonic sensors. These monitoring solutions provide real-time data on equipment condition, enabling operators to detect and address corrosion issues before they lead to significant damage or failure.

Managing corrosion risks

Traditional methods for measuring the risk of corrosion are based on processes that have existed for many decades, such as rudimentary corrosion modelling, manual inspection, and risk-based inspection (RBI). The main challenge posed by using these techniques is that in many of these novel processes, the process is far less predictable, introducing previously unforeseen levels of risk. To properly manage these unknown levels of risk, refiners are adopting innovative strategies, with a particular focus on advanced monitoring technologies. One increasingly popular approach is the use of online, non-intrusive corrosion monitoring systems.

Emerson's Rosemount Wireless Corrosion and Erosion Transmitters (see **Figure 3**) are designed to measure wall thickness in real-time, allowing operators to detect corrosion quickly and take preventive action. They can be installed without the need to penetrate the pipe or vessel wall, minimising installation costs and allowing monitoring in previously inaccessible locations.

These transmitters employ a patented Adaptive Cross-Correlation (AXC) technique, which significantly improves measurement accuracy, especially in challenging conditions such as those encountered in biofuel production (see **Figure 4**). This technology allows the transmitters to achieve a repeatability of up to 2.5 microns (0.0001in) in field conditions.

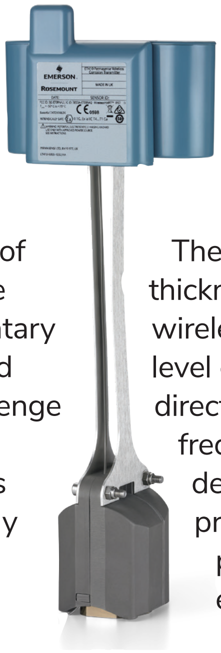

Figure 3 The Rosemount ET410 Corrosion and Erosion Transmitter allows high-temperature online thickness monitoring, ideal for biofuel applications

The transmitters typically transmit wall thickness measurements twice daily using wireless data retrieval, giving operators a high level of insight into the health of their assets directly from the desk (see **Figure 5**). This frequent data collection allows for the early detection of corrosion trends, enabling proactive maintenance strategies and potentially preventing costly shutdowns or equipment failures.

A case study from a major European refiner illustrates the effectiveness of this approach. The refiner repurposed an old hydrotreating unit to utilise renewable feedstocks such as vegetable oils and used cooking oil. Recognising the increased corrosion risk, they installed Rosemount Wireless Corrosion and Erosion Transmitters.

The transmitters were strategically placed in areas prone to corrosion, such as reactor effluent systems, high-temperature zones, and areas with potential for ammonium chloride or amine corrosion. By providing continuous data on wall thickness, the transmitters allowed the refiner to correlate corrosion rates with specific feedstocks and operating conditions. This insight has been invaluable in optimising processes and maintenance schedules. Moreover, thanks to their non-intrusive nature, the transmitters could be installed without any modifications to the existing equipment, minimising downtime and installation costs.

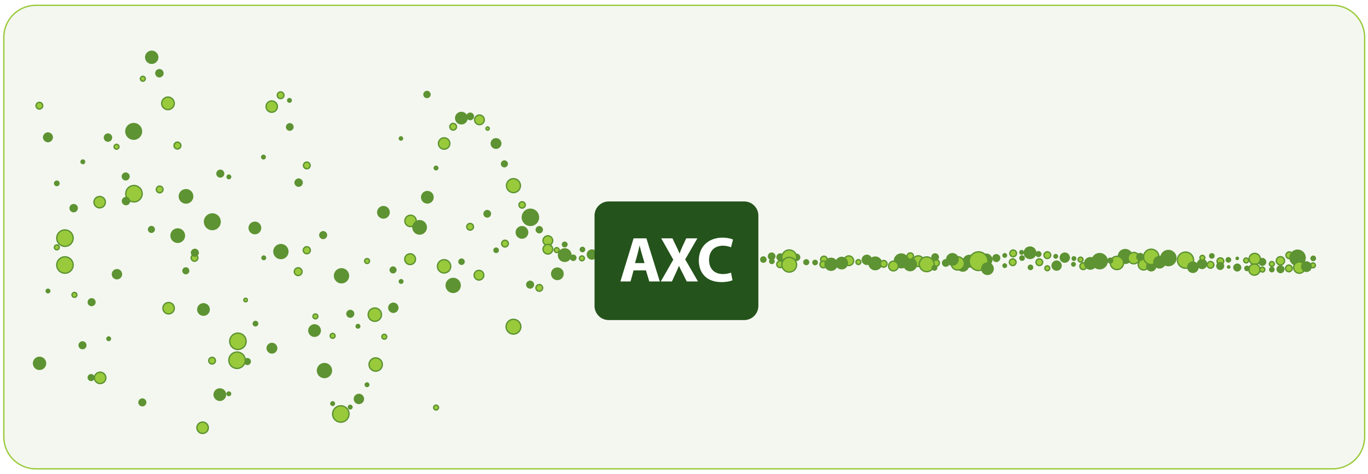

Figure 4 Adaptive Cross-Correlation (AXC) significantly improves the accuracy of the wall thickness and corrosion rate calculation

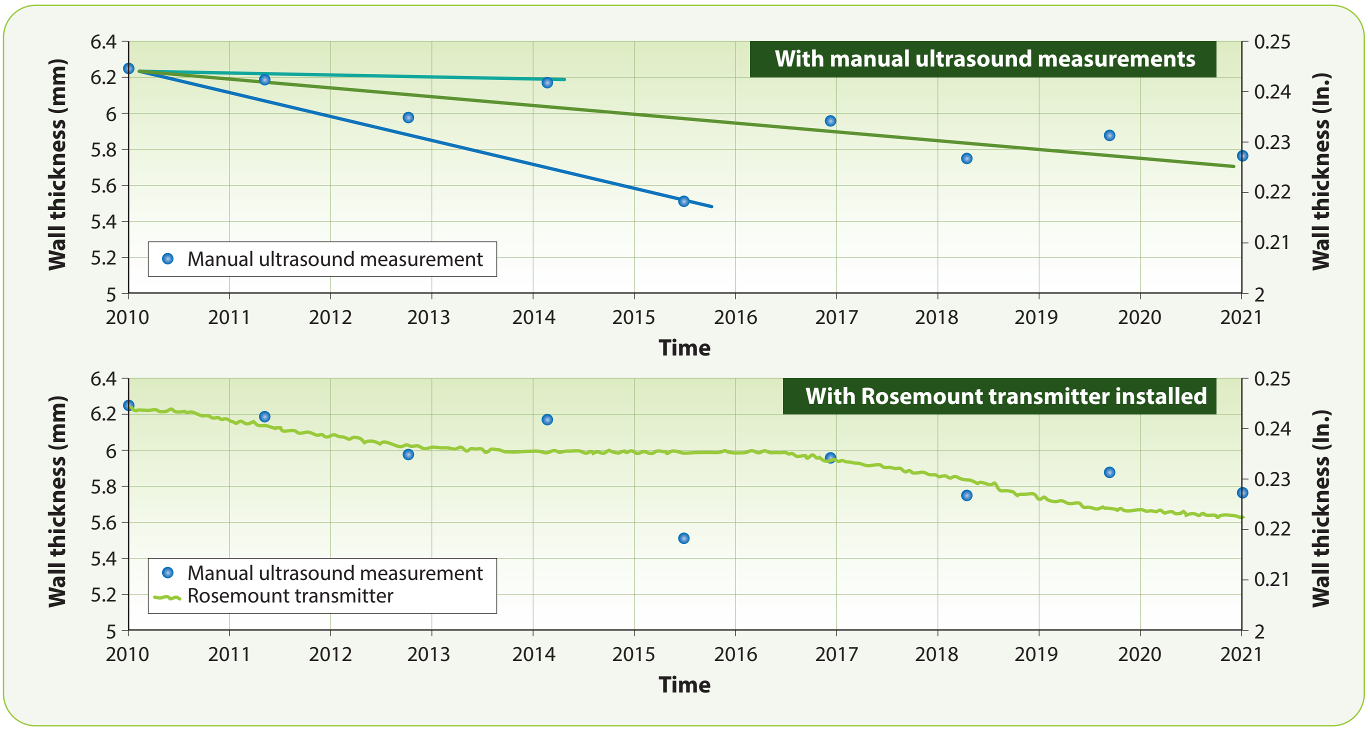

Figure 5 Online thickness monitoring provides the granularity in data required to understand periods of high and low corrosion, which can be correlated to process changes to minimise risk

Conclusion

The rise of SAF and renewable diesel marks a significant milestone in the decarbonisation of transportation. These advanced biofuels offer a path to reduce greenhouse gas emissions without requiring a complete overhaul of existing infrastructure, presenting a pragmatic solution to one of our most pressing environmental challenges.

The journey from first-generation biofuels to today's sophisticated SAF and renewable diesel has been characterised by continuous innovation and learning. This evolution extends beyond just the fuels themselves to encompass the entire production process, including how we monitor and manage the integrity of production facilities.

Online corrosion monitoring, once a novel technology, has now become an industry standard in biofuel production. The widespread adoption of solutions like Emerson's Rosemount Wireless Corrosion and Erosion Transmitters (see **Figure 6**) underscores the industry's commitment to safety, efficiency, and sustainability. These non-intrusive, real-time monitoring solutions have proven invaluable in managing the unique corrosion risks associated with biofuel feedstocks and processes. By providing continuous, accurate data on equipment condition, they enable proactive maintenance strategies, optimise operations, and ultimately contribute to the reliable, cost-effective production of sustainable fuels.

Figure 6 Example installation of Rosemount WT210 Transmitters

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