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Automation In Chemical Manufacturing

From Batch To Continuous Process

Striving Towards Efficiency

MAY 2025

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Introduction

Automation has long shaped the trajectory of chemical manufacturing. In the early days, this meant simple mechanisation: devices that could operate independently to save time or reduce physical labour.

By the mid-20th century, the sector had embraced pneumatic and electronic controllers, setting the stage for fully automated processes. The rise of Programmable Logic Controller (PLCs) and distributed control systems (DCS) in the 1970s and 1980s further transformed operations, bringing consistent product quality and improved safety. Over time, automation evolved from task-based support to an essential operational framework in both batch and continuous manufacturing.

Continuous manufacturing adopted automation early across several stages, and batch processing has since followed with similar integrations. With AI, machine learning, IoT, and advanced analytics, there's enhanced responsiveness, scalability, and traceability.

What is interesting, is that automation is now moving beyond mere streamlining of processes.

It's about preparing both shop floors and executive decision-making for an uncertain future. Volatility in global demand, aging infrastructure, regional cost disparities, and sustainability pressures are reshaping strategic priorities.

For a sector valued at USD 6,182 billion in 2024 and expected to grow to USD 6,324 billion by 2025 at a CAGR of 2.3%, this shift is timely.

As demand patterns grow more complex (driven by evolving end-user industries, geopolitical shifts, and regulatory changes), the balance between supply and demand will become more dynamic and harder to predict.

Automation and AI are emerging as critical tools to stay ahead of this curve. They enable companies to respond faster, optimize operations in real time, and build the agility needed to tap into new growth opportunities while maintaining resilience.

> ***We see AI as a key strategic enabler for our effectiveness, to do things better, faster and more economically, while delivering essential products to our customers.***
>
> *Sreedhar Sistu, Vice President, AI Offers, Schneider Electric*

Chemical manufacturers are deploying automation solutions to create business value, reduce exposure to risk, and position their organizations for long-term resilience. AI can now detect process inefficiencies in real time, help anticipate equipment failures, and even recommend operational changes based on external variables like market demand or energy prices.

For batch and continuous manufacturers alike, the implications are significant.

Automated systems are reducing manual interventions, aligning production more closely with actual demand, and improving product consistency across global facilities. For leadership teams, this translates into higher margins, improved resource allocation, and faster decision-making.

This paper explores how smart, automated manufacturing is moving beyond process improvement. It addresses how chemical manufacturers are using automation and AI to manage overcapacity, ensure compliance, reduce operational costs, and meet sustainability targets.

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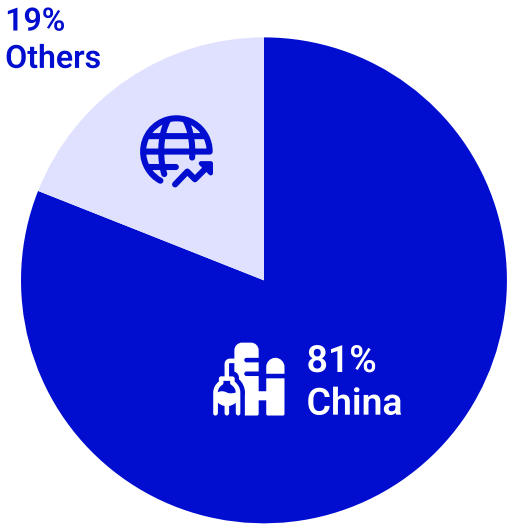
Ripple Effects of Economic Strain on Chemical Manufacturers

The chemical industry is tackling global challenges coming in many forms and faces.

Key among them is a persistent overcapacity issue that is rippling through value chains, depressing margins, and forcing major strategic resets.

Distribution of Global Chemical Capacity Growth



Overcapacity is when production capabilities outstrip demand.

Since Covid-19 this issue has been exacerbated by global economic slowdowns, trade tensions (this being the most recent development), and region-specific energy cost disparities.

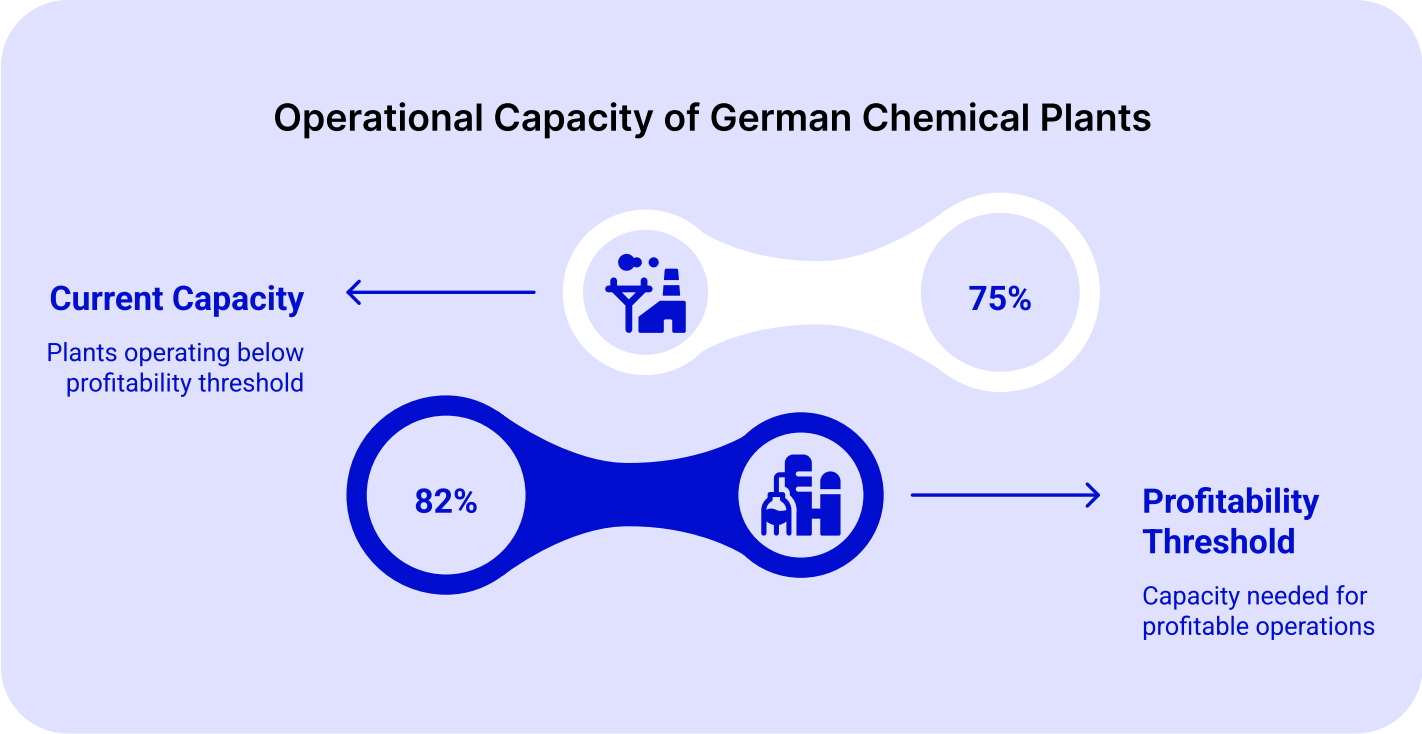
Europe is among the hardest-hit regions. Record high energy prices have undermined the competitiveness of European chemical producers. In contrast, manufacturers in the U.S. and the Middle East benefit from access to cheaper feedstocks like natural gas liquids.

This imbalance is pressuring European plants to downsize or shut down altogether. The ripple effect is visible in significant facility closures, including ExxonMobil's Gravenchon plant, Sabic's multiple crackers in the Netherlands, and LyondellBasell's polypropylene units in Italy, Spain, the UK, and Germany.

China, once a demand engine for global chemicals, is also seeing shifts. The real estate downturn, aging population, and trade frictions with the West have contributed to demand slowdown. Meanwhile, it continues to expand supply.

The global oversupply of petrochemicals is expected to continue, with China forecast to add 18.7 million tonnes/year of capacity in 2024 in the six chemicals-building blocks, following record increases in 2022 and 2023.

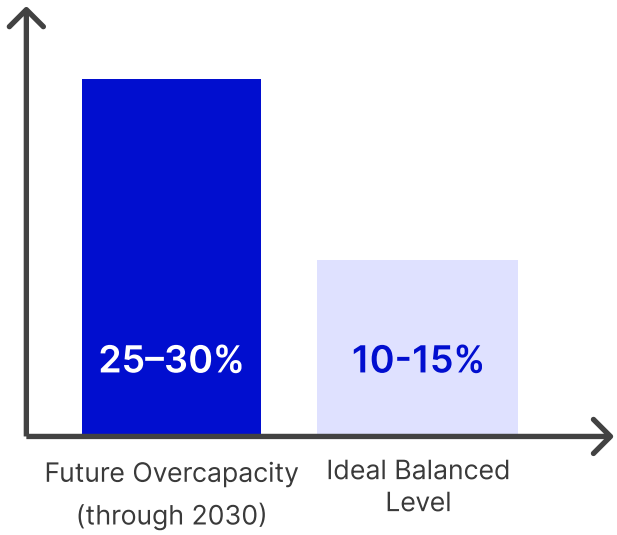
Adding to this, developed markets are seeing structural shifts in demand.



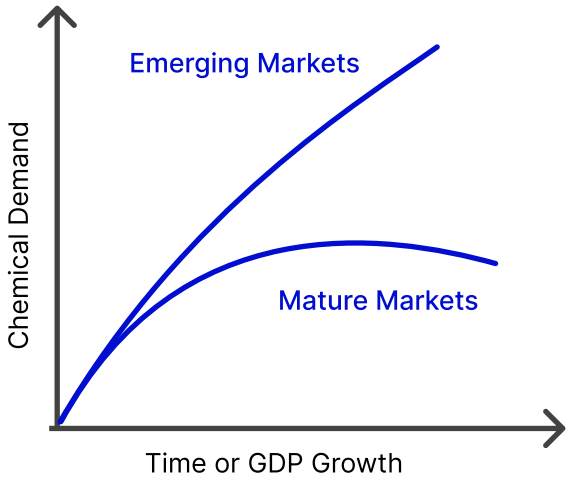
> *"The industry is reaching the limits of linear demand growth. As GDP grows, chemical consumption typically matches or exceeds the rate of growth. But as economies mature, this correlation weakens, and the curve flattens."*
>
> *McKinsey*

Mature economies like parts of Europe and East Asia are already seeing this flattening, further straining ROI on traditional growth investments.

Chemical Industry Capacity Balance Projections



The Changing Growth Pattern of Chemical Demand



Source: Independent Commodity Intelligence Services

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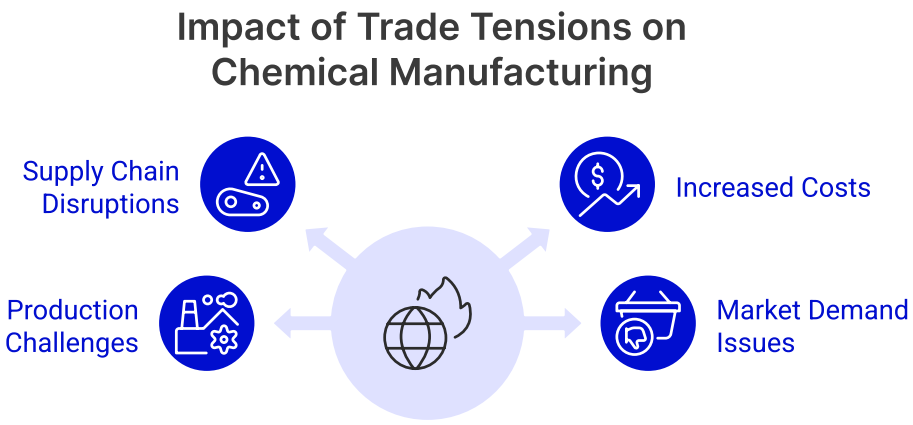
Trade Tensions and Its Impact on Chemical Manufacturing

As if market imbalances weren't enough, geopolitics is creating further instability. The US-China trade war has entered a new phase in 2025.



Chemical manufacturers are feeling the brunt of this instability. Tariffs have been imposed on hundreds of products, affecting everything from steel and plant components to raw chemicals and plastics.

This policy shock is disrupting billions in cross-border trade and forcing companies to reevaluate sourcing strategies, regional investments, and their supply chains' resilience.

> ***There is no acceptable tariff rate for global chemicals trade with China or any US trading partner. Only zero tariffs will maximize our industry's potential to deliver innovative products to new regions and increase social, environmental and economic sustainability around the world,***
>
> *said ACC President Cal Dooley*

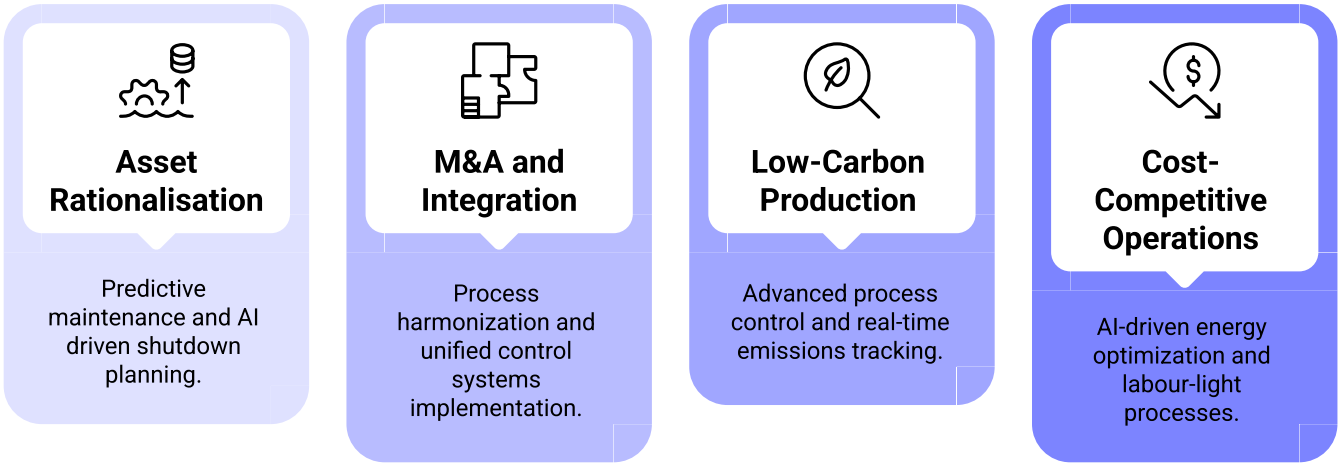
For global chemical players, agility and responsiveness are part of their survival toolkit.

> *"The next decade will prove critical in the evolution of chemical supply chains as suppliers adapt to slower growth, further market consolidation, changing demand and increased competition from China, as well as greater use of technology and automation."*
>
> *ICIS*

Faced with this reality, chemical companies can deploy multiple strategies:

- Rationalising assets by shutting down underperforming or expensive facilities
- Pursuing mergers and acquisitions to consolidate capacity
- Shifting production toward specialised or low-carbon chemicals
- Focusing on efficiency and cost competitiveness

So how does automation synergise with these strategies?



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Safety and Cost of Compliance

Lapses in chemical plant safety can turn into dangerous accidents, often fatal.

The consequences escalate quickly, impacting lives, operations, and the environment.

From high-temperature reactions to hazardous materials, every stage of production involves inherent risks.

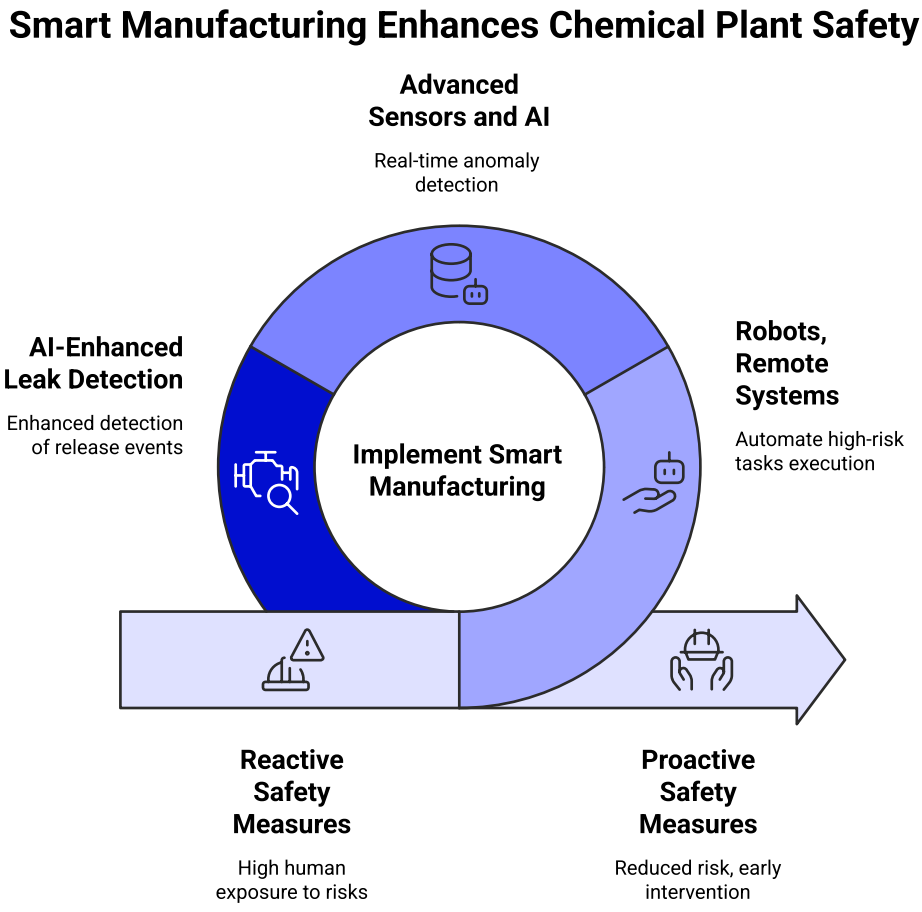
Plant operators and business leaders know this well and have long invested in systems, training, and protocols to prevent incidents. Yet, despite these efforts, accidents still happen. And when they do, the consequences extend far beyond the plant floor.

In fact, on average a major chemical accident occurred in the US roughly every four days since 2020. At least 57 were fatal, according to PoplarResistance.org. The accidents are in the forms of fires, explosions, and toxic releases- events that can injure employees, endanger communities, and shut down operations for days, even weeks.

The financial toll of such incidents is enormous. A single accident can cost millions. Beyond immediate property damage, there are ripple effects: legal fees, insurance hikes, production halts, and strained relationships with customers and regulators. Then there's the reputational fallout. One headline is all it takes to erode public trust and investor confidence.

How Automation and Smart Manufacturing Reduce Safety Risks

In the chemical industry, smart manufacturing tools help shift plant safety from reactive to proactive. Robots and remote-operated systems can now perform high-risk tasks like handling corrosive chemicals or operating in high-temperature environments. This reduces human exposure considerably. Advanced sensors combined with AI models detect irregularities in temperature, pressure, or emissions in real-time.



This allows instant intervention before small deviations escalate into major incidents. For example, computer vision systems equipped with convolutional neural networks (CNNs) can enable better gas leak detection by automating the identification of anomalies in visual and thermal data.

Dow, a materials science company, implemented an AI-enhanced leak detection system that significantly outperformed traditional methods. According to a 2023 case study published by Dow, this system detected 78% more potential release events than traditional methods, with a false positive rate below 3%. The technology proved particularly valuable for identifying small leaks (≤ 100 g/hr) from flanges and valve packings that conventional monitoring missed entirely.

Technology will boost how chemical manufacturers manage safety and risks now and in the future.

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Traditional vs Automation-enhanced Approach to Risk Management

Traditional

- Manual Inspections → Error prone & slow
- Incident Reviews → Reactive Approach
- Safety Protocols → Static & Outdated
- Compliance Focus → Just Box-Ticking
- Delayed Response → Late Hazard Alerts

Data Gaps

Infrequent Data
Data collection is not frequent

Lack Early Warnings
Absence of timely risk alerts

Poor Agility
Inability to adapt to changing risks

Siloed Systems
Data systems operate in isolation

Missed Insights
Predictive insights are not captured

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Traditional vs Automation-enhanced Approach to Risk Management

Automated

• Real-Time Detection	→	AI Spots Risks Early ☑
• Predictive Analysis	→	ML Flags Failures ☑
• Automated Protocols	→	Instant Safety Actions ☑
• Compliance Tracking	→	Alerts & Digital Logs ☑
• Exposure Analysis	→	Data Maps Vulnerabilities ☑

AI Enablers

Cloud Sensors
Sensors connected to the cloud

ML Diagnostics
Diagnostics based on machine learning

Remote Monitoring
Dashboards for remote monitoring purposes

AI Co-pilots
AI systems assisting human operators

Data Access
Cross-functional access to relevant data

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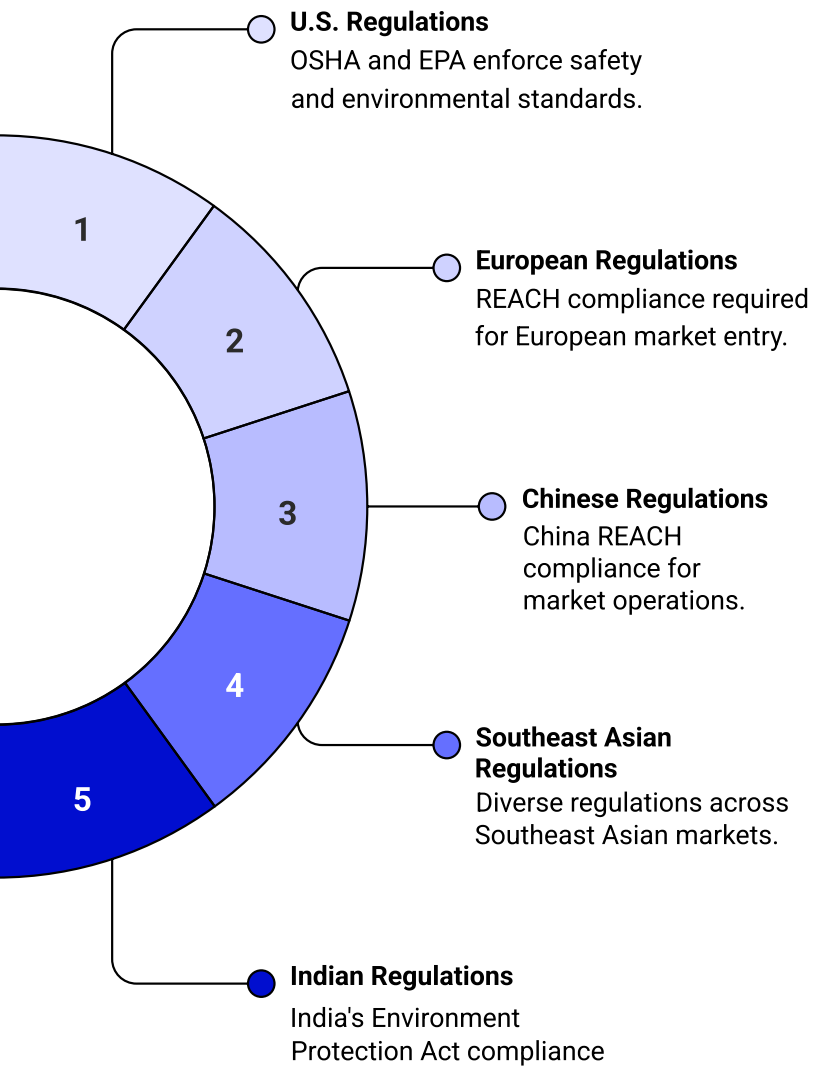
The Cost of Compliance

Navigating Compliance in Chemical Manufacturing



For chemical manufacturers, compliance is the foundation of lawful, safe, and sustainable operations.

In the U.S., agencies like OSHA and the EPA require strict adherence to safety, environmental, and worker protection standards. Globally, entering or operating in markets like Europe, China, Southeast Asia, or India demands familiarity with a maze of regulations like REACH (Europe), China REACH, and India's Environment Protection Act, among many others.

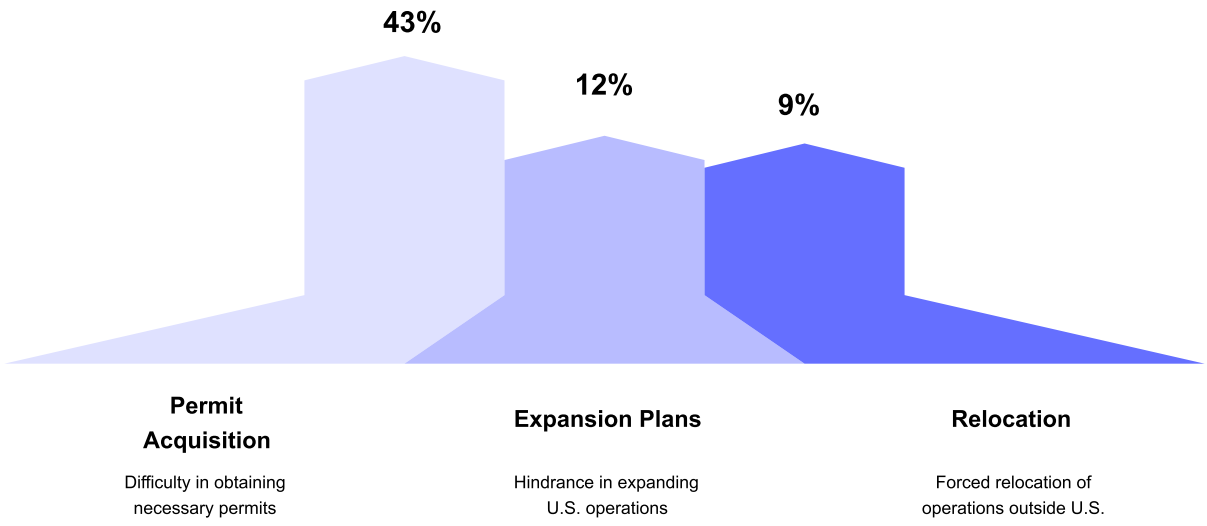
Each region has multiple layers of requirements: national laws, local/state-level regulations, and international shipping standards. That's a lot to manage. And regulations evolves, sometimes suddenly, demanding swift action, policy changes, or system overhauls. This complexity drives up compliance costs significantly.

These costs cover:

- **Legal counsel and regulatory consultants**
- **Training and upskilling staff**
- **Tech investments in compliance management systems**
- **Operational changes for new protocols**
- **Monitoring and reporting tools**

According to a recent survey by the American Chemistry Council, about two-thirds of chemical manufacturers reported being **adversely affected due to government delay** in making a regulatory decision or taking regulatory action on a permit, license, or product approval in the U.S.

Impact of Regulatory Delays on Chemical Manufacturers



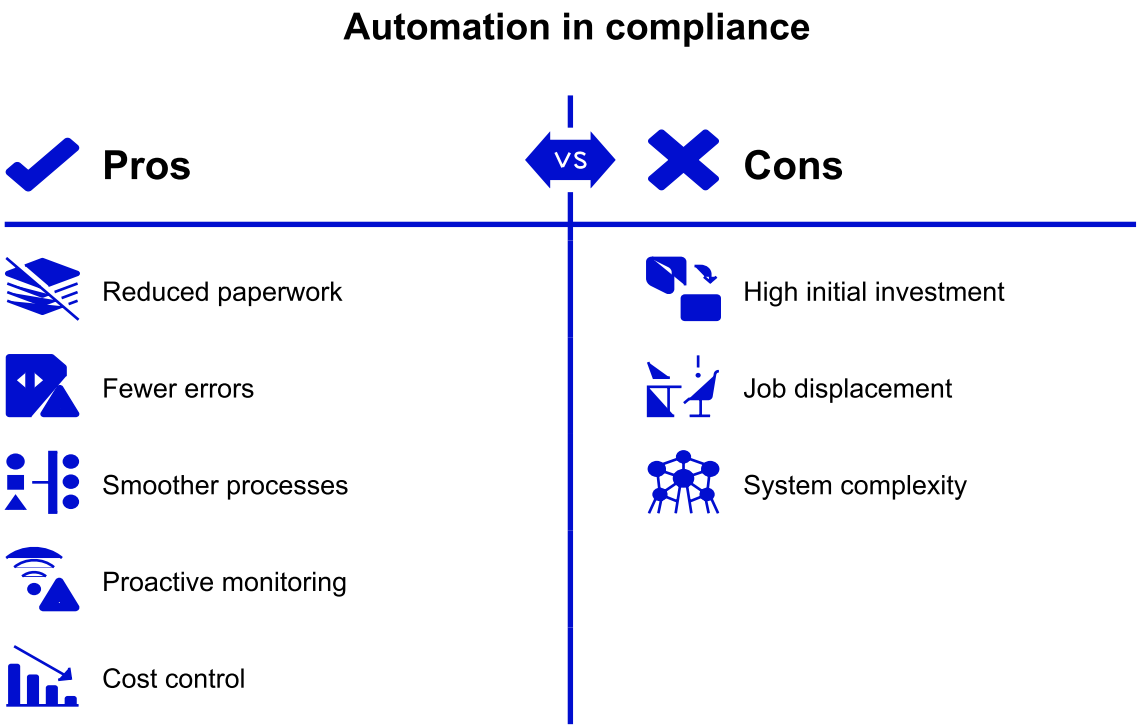
Automation: The Answer in More Ways Than One

The obvious benefits of automation in the realm of compliance and regulatory acts are well-known: lesser paperwork, fewer errors, and smoother processes.

But today, smart technology is doing more than just streamlining compliance. It's becoming a strategic asset for chemical manufacturers.

With AI-powered tools, companies can proactively monitor regulations, auto-update compliance protocols, and generate real-time reports that reduce the burden of audits. Automated systems make it easier to track complex multi-jurisdictional laws, cutting down the risk of non-compliance and associated penalties.

As a result, the overall cost of compliance (that was once driven by manual labour, legal consultations, and delayed reactions), is going down. Instead of scrambling to meet changing rules, businesses can now stay ahead of them, using automation as a long-term cost control lever.



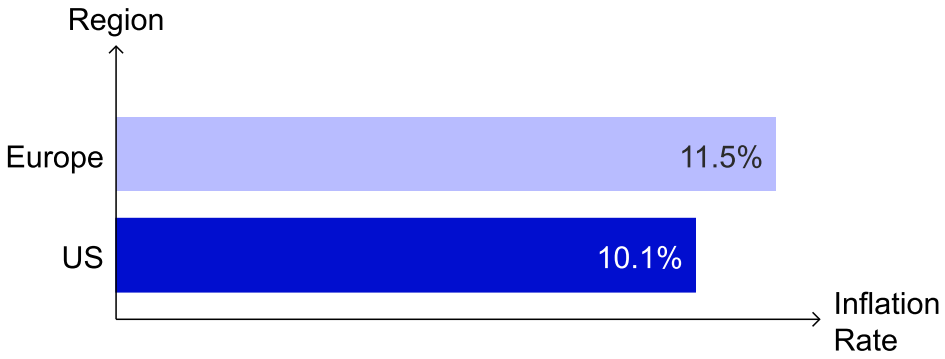
Operational Efficiency in the Face of Inflation

Inflation brings disruption.

With rising costs of natural gas, petroleum, and raw materials, production budgets are getting squeezed. Specialty chemical makers feel the pinch the most, as margin pressure increases and passing on the cost to customers becomes harder.

According to the 2025 Chemical Industry Outlook by Deloitte, plants in Europe have encountered challenges with inflation and high energy prices in 2022 and 2023, reducing demand and putting pressure on chemical margins. In the European Union, inflation reached a high of 11.5% in October 2022, compared to the US peak of 10.1% in June 2022.

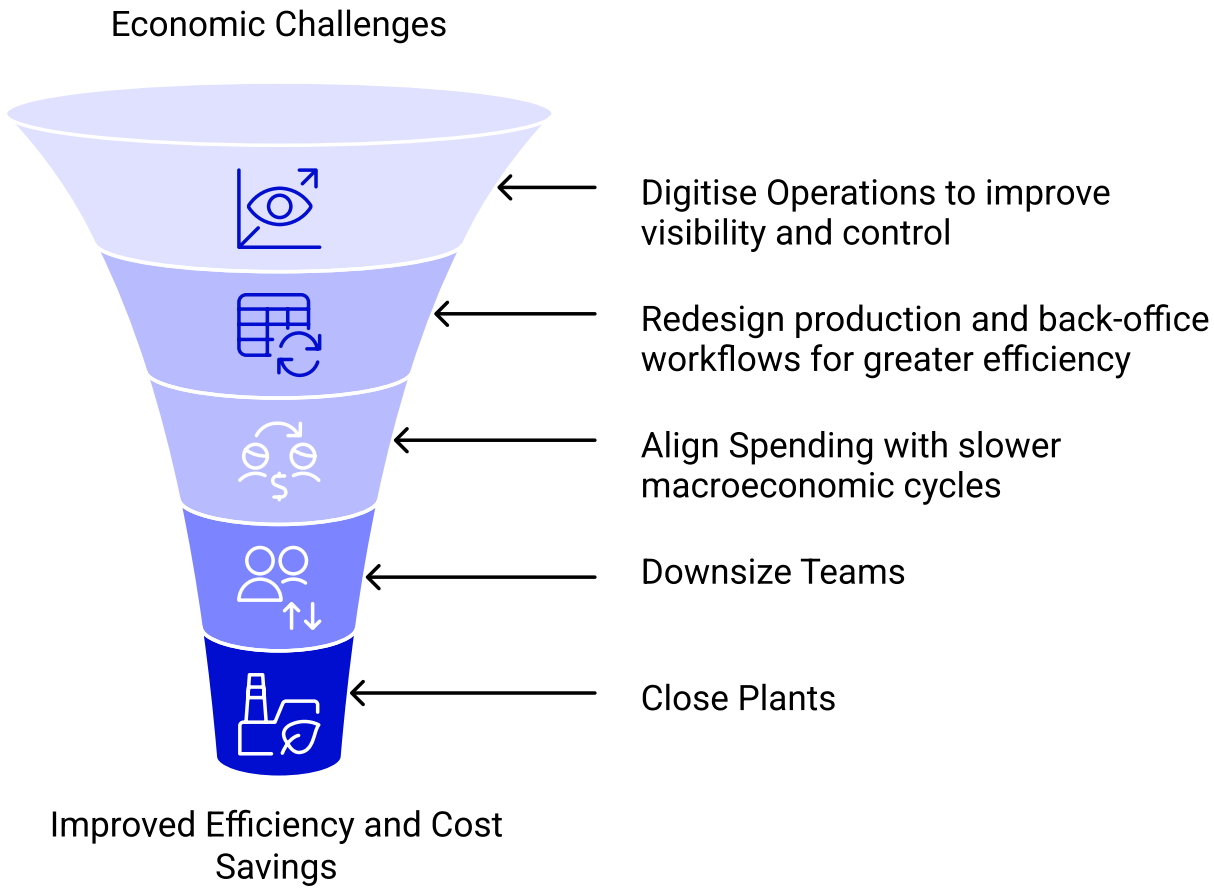
Peak Inflation Rates in Europe and the US (2022)



Feedstock volatility only adds to the complexity. Since December 31, 2020, U.S. corn prices have increased by 42% while U.S. soybean oil prices have increased by 55%. These surges drive up costs for biofuels, ethanol, and any downstream processes that depend on them.

Other factors such as geopolitical instability, ongoing wars, and tariff shifts are creating unpredictable supply chain issues. These further increase the costs of raw materials.

Chemical Companies' Asset Rationalisation Strategies



Cost-cutting measures are coming up fast and downsizing is a stark reality. Dow, for instance, announced $1 billion in cost-cutting measures, which include 1,500 job reductions and contracted third-party labor. Eastman Chemicals, another big name in the industry, laid off dozens of Springfield employees last August. They're not alone. Across the board, firms are making tough calls.

So where does automation come in?

AI and automation are often touted as the precursors of downsizing. While this might be true in some cases, these technologies are known to enhance operational efficiency and help in strategic realignment. They can create a better, more sustainable system for chemical manufacturers. Here's how they're stepping up during uncertain times:

- Dynamic Production Scheduling: AI can optimize run rates based on real-time cost inputs and demand forecasts. This helps in maximizing output when margins are favourable and scaling down when not.
- Predictive Energy Management: Machine learning models reduce energy usage by predicting and adjusting peak loads. This is highly critical when energy prices are unstable.
- Automated Procurement Intelligence: Smart systems flag the best time to buy feedstock based on market trends, minimizing overpayment risks.
- Digital Twins: Virtual replicas of plants help simulate changes before they're rolled out. This leads to saving time, reducing costly errors, and identifying the most efficient setup.
- Lean Back-Office Operations: RPA (Robotic Process Automation) takes over repetitive admin tasks, enabling leaner support teams with higher accuracy and fewer bottlenecks.

In turbulent times, efficiency is survival and smart technology is proving to be a strategic partner.

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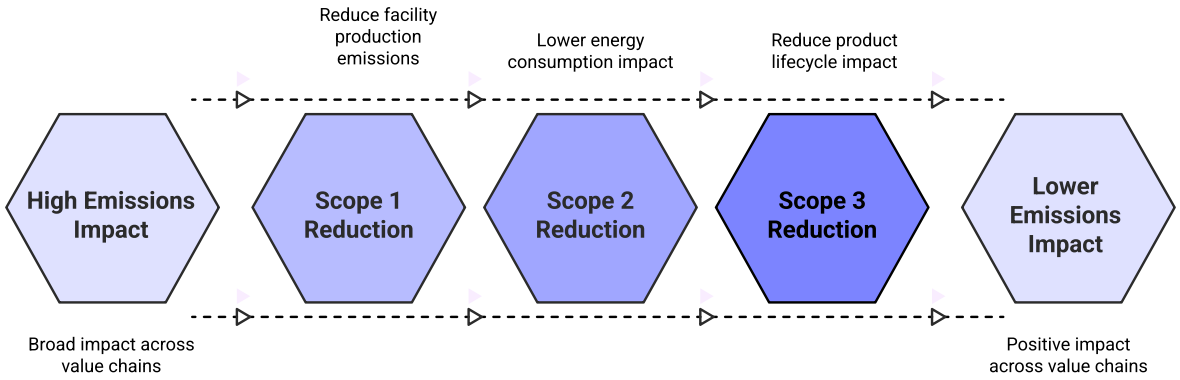
Sustainability and Resource Optimization

As environmental regulations tighten and stakeholder expectations evolve, sustainability is fast becoming a defining metric of performance. Pressure is rising from all sides- governments, investors, consumers. There is increased demand for cleaner operations and more transparent reporting.

Reducing Chemical Industry Emissions



The aforementioned Deloitte report states, the chemical industry is involved in 96% of all manufactured goods. Consequently, reducing scope 1, 2, and 3 emissions of this industry likely impacts nearly all product value chains.

ESG compliance covers all aspects of chemical manufacturing: from upstream emissions at production facilities (Scope 1), to energy used in operations (Scope 2), and the lifecycle impact of chemical products (Scope 3). Thus, it's a core business requirement. Energy-intensive chemical processes, particularly those reliant on fossil fuels, are under increasing scrutiny.

Also, stakeholders today expect companies to disclose how they source materials, manage emissions, and improve transparency across supply chains.

Per a 2024 survey of chemical industry executives, conducted with support from the American Chemistry Council, almost two-thirds of respondents said improving sustainability is their top priority over the next two years. Almost half, 47%, identified it as the industry's single biggest challenge.

Still, meeting these goals isn't straightforward. Despite the growth of renewable energy globally, many chemical companies report limited access to renewable electricity as a major barrier to reducing emissions.

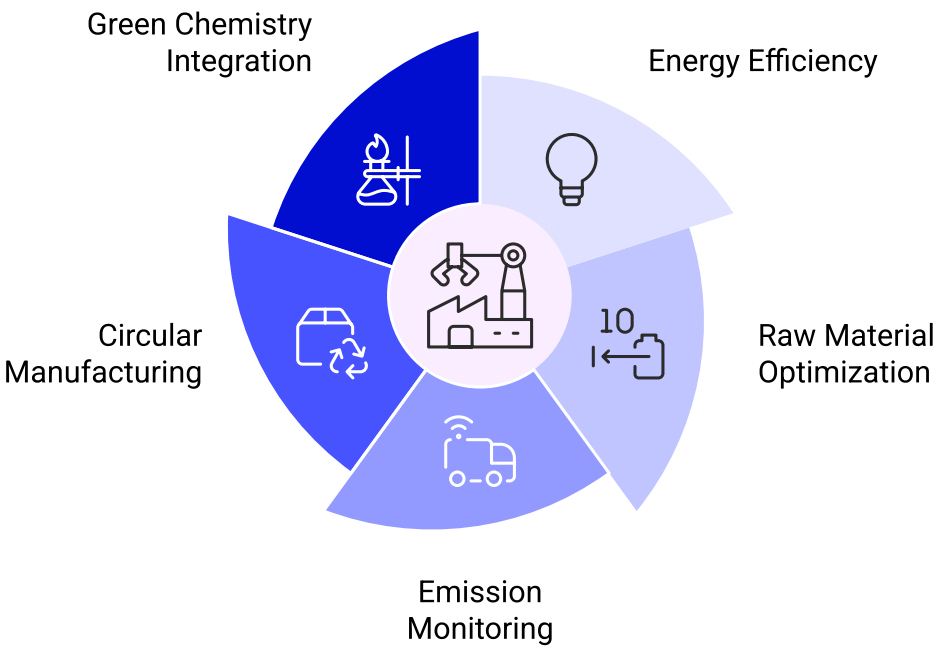
So where can the industry turn for support? The answer lies in smart technology: specifically, AI and automation.

Automation as a Sustainability Enabler

Strategic use of automation and AI is helping chemical manufacturers accelerate their sustainability goals. Key areas include:

- Energy Efficiency: Advanced control systems optimize operations in real time, reducing energy waste in high-heat and pressure-intensive processes.
- Raw Material Optimization: Automated dosing systems and feedback loops minimize input overuse, cutting material waste.
- Emission Monitoring: IoT-connected sensors track emissions continuously, helping firms identify leaks early and stay audit-ready.
- Circular Manufacturing: Intelligent automation supports sorting and reprocessing of byproducts, increasing reuse and reducing landfill.
- Green Chemistry Integration: Automated systems support the use of alternative feedstocks and safer chemical reactions by ensuring controlled conditions.

Enhancing Sustainability in Chemical Manufacturing

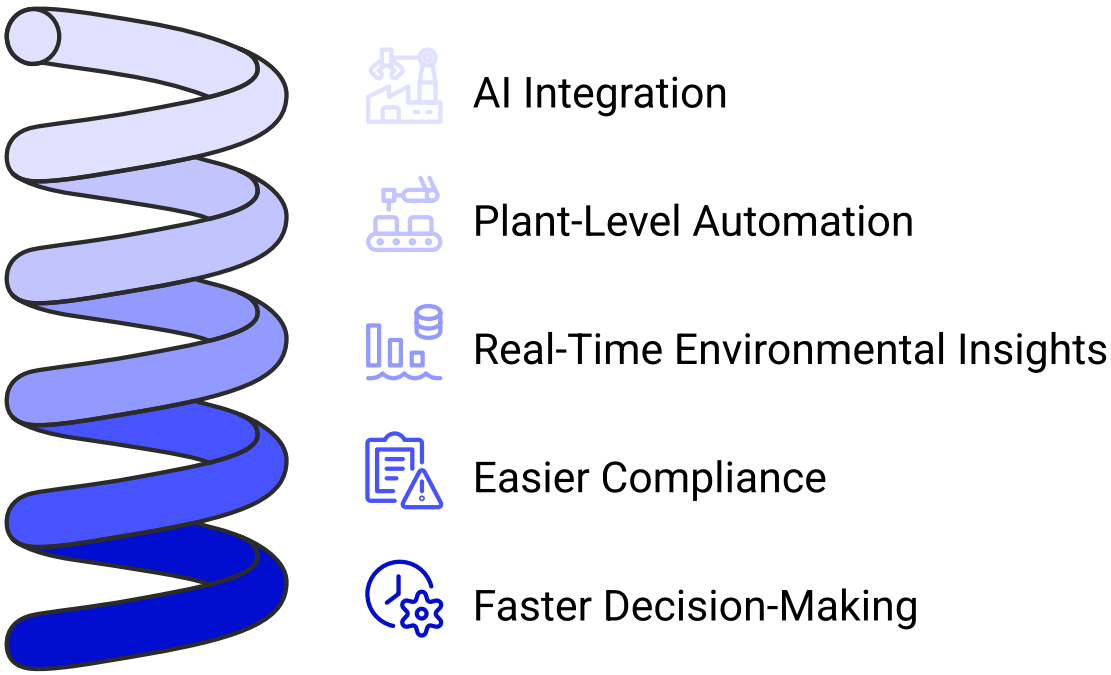


A recent BASF publication highlights how AI can tackle environmental challenges with speed and precision. Methane, responsible for about a third of global warming since the industrial era, often leaks undetected from oil wells, pipelines, and landfills. Traditional tracking methods are slow and imprecise.

Peter Joyce, PhD, from the UK National Centre for Earth Observation, trained an AI model on simulated methane plume data. When applied to real satellite images, it identified 21 plumes across 900 sq. km in under a minute, far outperforming conventional techniques.

This example shows how AI, combined with plant-level automation, provides manufacturers with real-time environmental insights, making compliance easier and decision-making faster.

AI-Driven Environmental Insights in Manufacturing



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Automation for Batch and Continuous Processes

The uses, applications, and strategic benefits of automation and smart manufacturing technologies suit both ends of the chemical manufacturing: whether you're running tightly controlled cycles in batch manufacturing or maintaining continuous flows in large-scale operations. In both models, automation brings precision, repeatability, and agility.

Automation strategies for chemical manufacturing.

Batch Manufacturing

Emphasizes precision and control

Continuous Manufacturing

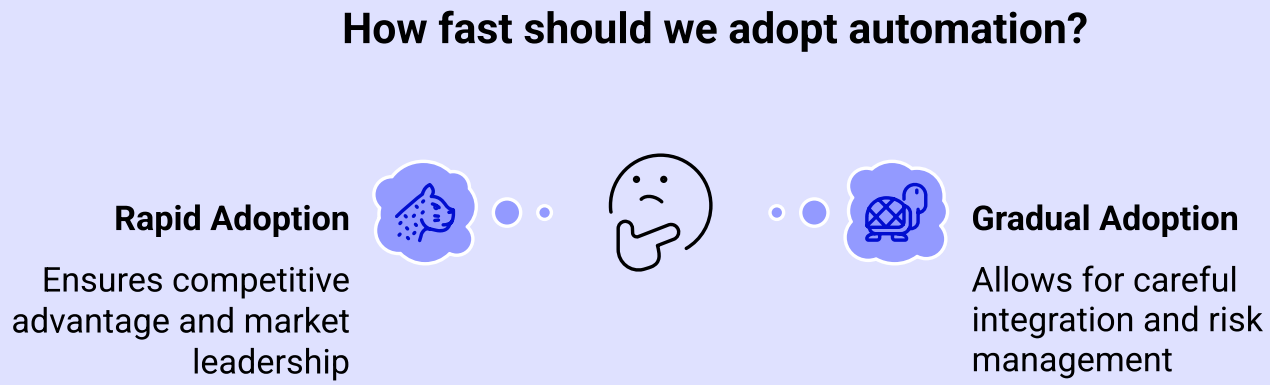
Focuses on efficiency and flow

Batch processes, widely used in specialty chemicals and pharmaceuticals, offer critical flexibility but are often resource-intensive and susceptible to variability. With inflation, overcapacity, and rising sustainability expectations, these inefficiencies carry greater consequences. Automation helps mitigate these challenges by ensuring consistent dosing, precise reaction timing, and adaptive scheduling. For instance, smart sensors combined with recipe-based control systems enable real-time quality corrections, reducing energy waste, cutting rework, and increasing yield. All this can be done while supporting more efficient use of raw materials and lowering the cost per batch.

In continuous manufacturing (often implemented in large chemical and petrochemical plants) efficiency and uptime are paramount. Rising costs and pressure to cut emissions make this even more important. Automation helps by keeping the process stable and reducing waste. It enables early detection of problems, tight control of operations, and quick response to changes. For example, smart systems use real-time data to spot small issues and adjust flow rates without stopping production. This keeps quality steady, saves energy, and cuts downtime. It also helps meet sustainability goals while managing inflation and staying competitive.

Automation and smart systems are the future of chemical manufacturing as they ensure visibility, supports faster decisions, and aligns operations with strategic goals. In these volatile times, automation is the framework for resilient, high-performing chemical manufacturing. As for the leaders in chemical manufacturing,

it's no longer about if they adopt automation strategically, It's about how fast they can do it.



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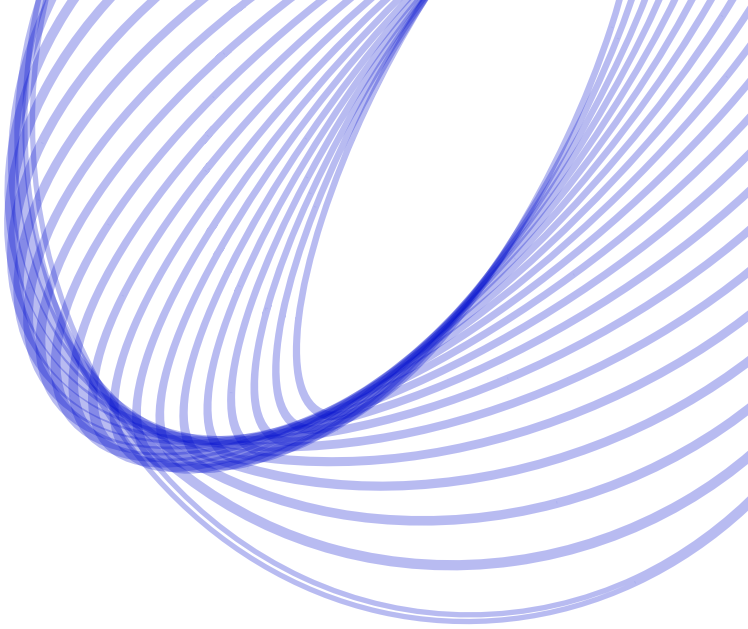

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