MARSH

29th Edition

100 largest losses in the hydrocarbon industry 1974 – 2025

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Foreword

I am delighted to write the foreword for the 29th Edition of the Marsh *100 largest losses* report, an excellent compilation of lessons learned and an invaluable resource that, ideally, would never need updating due to the absence of new incidents. Unfortunately, that is not yet the case.

Learning from past accidents and reflecting on our actions and attitudes is crucial in building safer, more sustainable industrial practices and operations. Safety is at the core of chemical engineering and guides and informs every aspect of our work. While we have made significant progress, much remains to be done. Safety is not only a culture but also an ongoing journey. By analyzing past incidents, we can better anticipate potential risks and take proactive steps to prevent them.

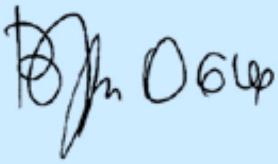
We live in a rapidly changing world. The adoption and deployment of technologies vary widely: in some areas we still work with long-established technologies, while in others the pace of innovation has been remarkable. Digitalization and related technologies are transforming the chemical and process industry. Digital transformation is pervasive and presents tremendous opportunities, but it also brings new challenges. Artificial intelligence, automation and predictive maintenance are now central to monitoring processes, equipment, and safety more effectively. While these innovations are promising, they require us to think carefully about how they can genuinely advance safety culture and practice. We must remain aware of emerging hazards as new technologies and new materials can create unforeseen safety risks. This is why it is imperative that we keep up with proactive safety planning and training.

The Institution of Chemical Engineers (IChemE) remains strongly committed to safety. The IChemE Safety Centre continues its activities, building on the solid foundations laid since its establishment in 2014. The Centre is dedicated to facilitating the exchange of knowledge and experience to elevate standards in process safety. The promotion of the Professional Process Safety Engineer (PPSE) qualification is also central to IChemE's mission to foster safer and more sustainable industrial practice.

Industry must remain committed to hiring and retaining talent with a broad range of experiences, which is fundamental to building strong operational competence. A variety of perspectives encourages different ways of thinking, thereby avoiding a "house style" that goes unchallenged and can result in dangerous oversights. This also ties into our broader collective responsibility to ensure that innovation is responsible and that safety remains fully integrated into our ethical culture and behavior.

In such a challenging and multifaceted environment, the role of industry leaders, operators, and educators in promoting proactive and anticipatory safety is more important than ever. Our approach to safety must be systemic, recognizing that hazards cannot be viewed in isolation. Engineers excel at systems thinking, and this mindset might guide how we lead and advance safety. This includes how we develop, nurture, and update skills; how we apply knowledge; and how we revise our practices. All of these elements are central to engineering a safer and more sustainable future.

Raffaella Ocone OBE FREng FRSE
President, Institution of Chemical Engineers (IChemE)
Professor of Chemical Engineering, Heriot-Watt University



Introduction

Welcome to the 29th edition of the Marsh *100 largest losses in the hydrocarbon industry (100LL)* report. This biennial publication provides insights about 100 largest property damage losses within the hydrocarbon extraction, transportation, and processing sectors from 1974 through 2025.

Jenni Morrison,
Energy & Power, Marsh

Natali Walton Chacin,
Energy & Power, Marsh

In this report, we explore the most significant incidents in the energy industry, drawing valuable insights and lessons from these major events. By analyzing key issues and emerging trends associated with these large losses, we aim to illustrate the industry's progress in enhancing operational practices and strengthening risk management.

This report reflects on the past two years (2023-2025), highlighting significant events and their impact on the industry (page 9). It includes an analysis of the 100 largest losses with valuable insights into the underlying factors driving these major incidents (page 36). The report addresses emerging challenges related to firefighting foam, including risks, evolving regulations, and mitigation strategies (page 21). It also delves into the complexities of the claims process (page 26) and offers an update on Marsh tools used to enhance capabilities for estimating maximum loss (EML) values (page 33). In adition, it highlights the role of strategic business interruption (BI) analysis in preparing for and mitigating potential losses (page 29).

The distribution of losses is presented by date, location, and sector, providing an overview of the industry's historical losses. Additionally, detailed information on each individual loss is provided, and, where appropriate, a link to a US Chemical Safety and Hazard Investigation Board (CSB) video has been included, allowing for a deeper understanding of the incidents.

It is important to note that the data in this report is drawn from Marsh's collection of loss information, and the values are reported in two ways:

- The actual property damage loss as quantified at the time of occurrence and adjusted property damage loss as of December 31, 2025.
- The inflation-adjusted values enable like-for-like comparisons of losses that have occurred years apart, using cost indices.

While this publication focuses on property damage, debris removal, and clean-up costs, the loss figures it presents exclude costs related to business interruption, extra expenses, workforce injuries or fatalities, and liability claims. Furthermore, losses during project construction and marine transportation losses, except those involving marine vessels moored at plant docks, are not included.

The *100 largest losses in the hydrocarbon industry* publication is supported by Marsh's Global Energy & Power Engineering Analytics group and tools developed by Marsh's Data Solutions team. We sincerely thank Everen and Liberty for providing information that has helped us keep this report current and comprehensive.

We encourage you to explore the insights and analysis presented in this report as we reflect on the challenges facing the hydrocarbon industry and work toward a safer, more resilient future.

From losses to lessons: *Advancing risk management in energy*

Amy Barnes,
Global Head of Energy & Power, Marsh

Societies thrive when they have access to reliable and affordable energy; managing risk is key to both.

Our industry stands at the very heart of the global economy. Energy and power are fundamental to virtually every aspect of modern life, powering homes, industries, and infrastructure worldwide. Yet the energy industry is constantly exposed to risk. Risk management is not a peripheral concern; it is deeply embedded in the industry's fabric. Understanding, managing, and mitigating risk is essential — not only to protect communities, assets, and operations but also to ensure the continuity and resilience of the energy supply.

As the leader of Marsh's Energy & Power practice, I am delighted to introduce the 29th edition of our 100 largest losses insights. Our ambition is for this publication to be a vital resource, offering deep insights into the evolving risk landscape of our industry. It highlights Marsh's ongoing commitment to risk engineering excellence and our role in helping clients navigate the complex challenges unique to the energy and power sectors.

Two transformative forces are reshaping the risk environment in our industry: climate risk and the energy transition. Climate change is driving an increase in the frequency and severity of weather-related losses, from hurricanes and floods to wildfires and extreme storms, which continue to challenge traditional risk models. Additionally, evolving regulatory requirements and heightened reputational risks linked to climate issues are creating new exposures that can lead to substantial operational challenges and impact organizational stability.

At the same time, the global shift toward sustainable energy sources introduces potential construction, operational, and technological risks as companies invest in new infrastructure and transition away from legacy operations. These changes can lead to unforeseen equipment failures, project delays, and supply chain disruptions, all of which contribute to loss patterns that differ from historical norms. Therefore, we remain committed to investing in our risk engineering capabilities to see that we maintain the ability to provide insights into emerging drivers of losses, helping clients anticipate and mitigate risks and enhance their resilience.

For nearly 50 years, we have collected, analyzed, and shared data on the most significant losses in the hydrocarbon sector. We combine technical specialization with advanced analytics to identify trends, root causes, and vulnerabilities. This knowledge empowers clients to learn from others, make better-informed decisions, implement more effective risk controls, and aim to reduce the frequency and severity of losses.

In the previous edition, we added 14 new losses. While not all occurred within the preceding two years, their inclusion was necessary to maintain a relevant view of the risk environment. Each loss tells a story of challenges faced, lessons learned, and opportunities for improvement — stories that enrich our collective understanding and drive better risk management across the industry.

This 29th edition adds one new loss. This number belies the reality that the industry continues to experience a high frequency of incidents and near-misses. These events reflect the evolving nature of risk in energy, driven by technological advances, regulatory changes, and shifting operational landscapes. While not all incidents result in the largest losses, they underscore the persistent challenges our industry faces.

The *100 largest losses* report is more than a record of past events — it informs future risk strategies. I want to emphasize that energy's central role in the economy makes effective risk management not just a business necessity but a societal one. Marsh is proud to be a trusted partner, delivering risk engineering excellence that protects what matters most and supports the sustainable growth of the energy and power sectors.

Reflecting on the last two years

Jenni Morrison,
Energy & Power, Marsh

The 2024–2025 period reflected an industry still working through the consequences of multiple disruptions. While operations largely normalized post-pandemic, persistent challenges remain: supply chain constraints, workforce gaps, and inflationary pressures continue to affect project delivery and operational reliability. Energy security concerns, heightened by ongoing geopolitical tensions, have kept commodity prices elevated, sustaining pressure on margins and capital allocation decisions.

Returning to fundamentals

The pattern is familiar: macroeconomic shocks, supply disruptions, and cost pressures create potentially difficult operating conditions. Yet our analysis reveals a more fundamental concern. While external factors shape the context, the most persistent drivers of avoidable losses are generally operational. Many incidents can be traced back to breakdowns in basic practices, including failures in competency, verification, and discipline, rather than novel engineering challenges. The question facing the industry is straightforward: if we are to materially reduce losses in 2026 and beyond, why is reliable performance in critical roles proving difficult to maintain?

Structural shifts and their implications

One trend has been the transfer of assets from major international oil companies (IOCs) to smaller independents. These transactions reflect commercial realities but have operational consequences. Many independent operators work with tighter budgets and more streamlined corporate structures, but these challenges can often be addressed by implementing strong maintenance programs, adopting best practices in operational risk management, and leveraging external expertise to uphold safety and performance standards.

Refining margins, while periodically improved (as reported monthly by Platts Market Center), remain volatile. When margins compress, maintenance and integrity programs are often the first areas to face budget constraints. Proactive risk management helps prevent deferred maintenance from leading to accelerated degradation, higher costs, and increased safety risks.

The workforce challenge

The industry faces a significant workforce issue across key regions, including Asia, Europe, and the US. An aging workforce, coupled with insufficient knowledge transfer and competency development, has created capability gaps that can directly impact operational reliability. Experienced personnel are retiring faster than they can be replaced with adequately trained successors. The result is measurable: fewer people with the depth of knowledge needed to manage complex processes or respond effectively when things go wrong. Without structured intervention, such as rigorous training, competency validation, and knowledge retention programs, this gap will continue to undermine safety and reliability.

External pressures

Inflationary pressures, driven partly by the Russia-Ukraine war and persistent supply chain disruptions, have increased costs for materials, labor, and project execution. These factors delay maintenance and rebuild activities, extending risk exposure and complicating asset integrity management. The effects are tangible: longer lead times, higher costs, and difficult trade-offs between immediate operational needs and the long-term health of assets.

The practice of deferring fabric maintenance has become increasingly common as operators seek to manage these pressures. The evidence suggests this is potentially a problematic strategy: postponed essential maintenance is unlikely to be recoverable within a 10-year timeframe without consequences, such as higher repair costs, extended downtime, and elevated safety risks.

Loss added to the top 100

#10

California, US, February 2025

A hydrocarbon release and subsequent fire occurred at a refinery during maintenance preparation activities, with deficiencies in control of work as a contributing factor.

2024-2025 Notable losses

Marsh engineers have reviewed incidents outside the top 100 that remain significant to insurance markets due to their substantial combined property damage and business interruption claims. Many of these cases are still under investigation to identify their causes, but are expected to offer important insights for energy operators.

These incidents share common threads: equipment failures, process safety breakdowns, and operational discipline issues. Investigations are ongoing, but preliminary findings potentially suggest failures in fundamental controls.

These cases include:

Louisiana, US, March 2024

2024 Fire at a chemical complex caused by a hydrocarbon leak.

Texas, US, September 2024

Gas supply line rupture at methanol plant.

Greece, September 2024

Fire at refinery.

Germany, January 2025

Explosion and fire at a refinery.

Alabama, US, May 2025

Equipment failure resulting in fire.

Texas, US, June 2025

Explosion and fire due to process safety control issues.

Hungary, October 2025

Fire and explosion at refinery on a crude distillation unit.

Regional perspectives

Loss patterns vary significantly across regions due to differences in asset age, operator profiles, regulatory environments, and workforce competency.

Middle East

The Middle East remains a dynamic, rapidly growing hub for refining and petrochemical capacity expansion, driven by strong regional demand and strategic investments in advanced technologies. This growth presents significant opportunities for innovation and modernization across the sector. While rapid development can challenge workforce competency and quality assurance processes, it also encourages the adoption of best practices and targeted training programs to build local expertise and operational excellence. With continued focus on strengthening workforce skills and integrating robust quality management systems, the region is well-positioned to enhance safety, reliability, and long-term asset performance

Europe

Losses in Europe have shown the interaction between stringent environmental regulations and operational risk. The EU Emissions Trading System (EU-ETS) and related climate policies increase operational costs and compliance burdens, which can pressure margins and potentially create incentives for deferred maintenance or operational shortcuts. Fluctuating margins and competitive pressures challenge operators to maintain discipline in constrained financial environments. Workforce competency remains a concern, particularly as the industry navigates both the energy transition and the maintenance of existing asset integrity as highlighted by an incident in the region.

Asia Pacific

The Asia Pacific region continues to experience rapid expansion of refining and petrochemical capacity, driven by both domestic demand and export opportunities. This growth often occurs alongside workforce skill gaps and variable regulatory oversight, which increases vulnerability to operational incidents. The region’s diverse regulatory landscape means that safety culture and risk management maturity vary considerably among countries and operators. Supply chain constraints and resource competition further complicate the execution and maintenance of reliable projects.

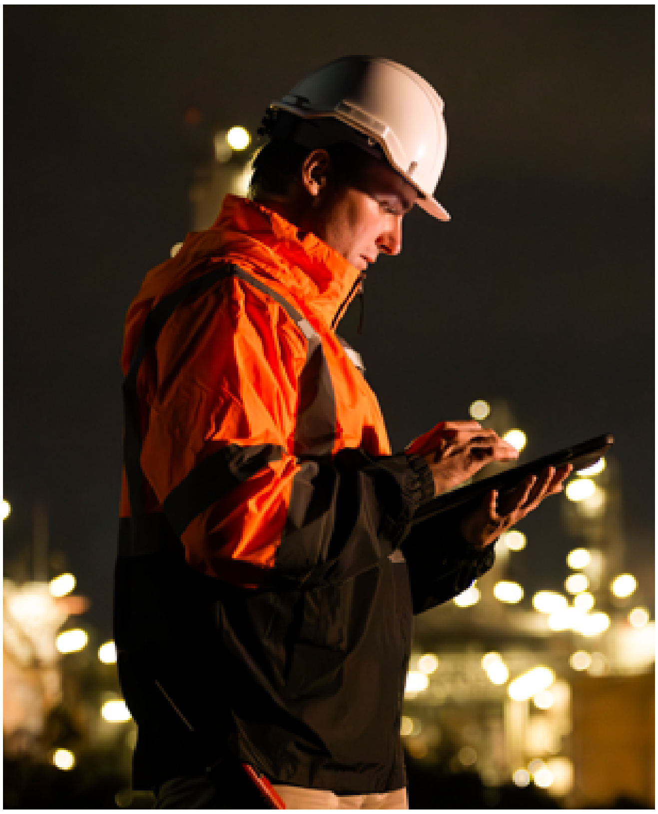
Americas

In October 2025, the US hydrocarbon industry experienced a series of significant fires, explosions, and hazardous material releases that tested the resilience of some of the nation's critical refining and chemical facilities.

During this period, several major incidents highlighted the industry's preparedness and response capabilities:

- On October 3, a major fire and explosion erupted in the Isomax 7 unit of a California refinery, burning for several days and prompting a large-scale emergency response. Although the incident affected local air quality, no injuries were reported, demonstrating the effectiveness of safety protocols.
- An explosion at a Texas refinery on October 6 caused partial structural collapse and resulted in three minor injuries, underscoring ongoing challenges related to process safety management and infrastructure integrity.
- A fire at a chemical processing plant in Texas on October 9 was contained, with all personnel accounted for, demonstrating operational readiness and rapid intervention capabilities.
- On October 11, an ammonia leak at a nitrogen plant in Kansas required emergency response and medical evaluation for exposed individuals, underscoring the hazards of chemical handling and the importance of leak detection systems.

  This frequency of significant incidents within a single month serves as a cautionary reminder for the industry. Despite advances in technology and improvements in safety management, fundamental vulnerabilities persist — particularly in aging infrastructure, workforce competency, and maintenance practices. Such clustering of incidents elevates operational risk, strains emergency response resources, and can undermine public trust and regulatory confidence. It also emphasizes that deferred maintenance and workforce gaps are tangible risks that can culminate in costly and dangerous outcomes.



However, the US hydrocarbon sector continues to demonstrate a commitment to operational discipline and a safety culture that mitigates the human impact of such events. The ability to contain fires without fatalities and limit injuries amid explosions and hazardous releases reflects progress in emergency preparedness and risk management.

Resilience extends beyond incident response; it requires anticipating and preventing risks through disciplined operations, robust safety cultures, and strategic investments. Operators who embrace this mindset will be better positioned to navigate the evolving energy landscape, manage insurance market pressures, and protect both their people and assets.

Insurance market dynamics

Following a period of relatively fewer major losses immediately after the COVID-19 pandemic, the recent uptick in the frequency of incidents within refining has drawn attention from insurance markets. Insurers are scrutinizing the underlying causes of losses, particularly the persistent role of operational competency failures despite technological advances. Global macroeconomic pressures continue to broadly influence risk assessments, but regional variations in regulatory environments, infrastructure maturity, and geopolitical risks create distinct loss patterns and exposures.

Generally, global insurance markets exhibit broad risk appetite, pricing trends, and coverage frameworks that influence regional markets. However, certain regions, due to unique regulatory environments, geopolitical factors, or infrastructure maturity, may increasingly rely on regional market placements, where local insurers can sometimes have a better understanding of specific risks and can offer more tailored terms.

As insurers recalibrate risk models and adjust pricing, operators worldwide are experiencing more varied terms depending on their loss history, risk management practices, and operational profile. The current environment often rewards demonstrated operational discipline with more favorable terms, while operators with adverse trends face more challenging conditions. This market dynamic can encourage operational improvement, but also prove difficult for organizations already managing tight margins and deferred maintenance issues.

Addressing root causes

To mitigate losses in 2026 and beyond, the industry should seek to address fundamental operational weaknesses, which may include:

Workforce competency

Investment in continuous, scenario-based training is essential to maintain current skills and address evolving operational complexities. Knowledge retention initiatives can capture institutional memory before experienced workers exit the industry. Rigorous, regularly applied competency validation processes can equip frontline personnel with the required capabilities. Without sustained focus on these areas, any competency gap is likely to undermine reliable operations.

Operational discipline

A culture that rejects shortcuts and unsafe practices requires more than policy statements. It demands consistent leadership commitment, clear accountability at all levels, and transparent reporting channels that enable hazard identification without reprisal. Robust incident investigation processes that identify root causes and prevent recurrence are fundamental. Recognition of safe practices reinforces expectations, but the foundation is accountability for failures.

Supply chain and cost management

Developing resilient procurement strategies, including diversifying suppliers, maintaining strategic inventories, and enhancing supply chain visibility, can help mitigate some external pressures. Flexible project management that incorporates realistic contingency planning helps accommodate delays and cost fluctuations. Collaboration with suppliers and contractors to align expectations and share risks improves continuity. These approaches reduce, though do not eliminate, vulnerability to external factors that compromise maintenance schedules and project delivery. For a deeper examination of how quantifying business interruption exposures can inform risk management decisions and insurance strategies amid supply chain and market volatility, refer to the dedicated article in this report.

Sustainability integration

Tightening environmental regulations and stakeholder expectations require integration of sustainability considerations into operational risk management. This includes environmental risk assessments in decision-making, the adoption of safer and more sustainable materials and practices — such as transitioning to fluorine-free firefighting foams (discussed elsewhere in this report) — and investment in emissions-reduction technologies. Transparent reporting on sustainability performance is increasingly expected. These requirements add complexity, but are now fundamental aspects of managing operational and regulatory risk.

The hydrocarbon industry faces persistent challenges rooted in both external pressures and internal operational realities. While macroeconomic and geopolitical factors create a challenging operating environment, the most actionable opportunities for loss reduction lie in addressing fundamental weaknesses, including workforce competency, operational discipline, maintenance practices, and supply chain resilience. The recent pattern of incidents underscores the urgency of these issues. Operators who systematically address root causes will be better positioned to manage risks, mitigate losses, and navigate the evolving energy landscape. Those who do not may face not only operational consequences but also face less favorable insurance buying conditions.

Risk quality benchmarking: *Insights from global refining and petrochemical performance*

Irel Viloria,
Energy & Power, Marsh

Refining and petrochemical facilities have historically experienced both frequent and severe major oil and gas losses. The reason is that these operations concentrate high-energy processes, large inventories of hazardous materials, and complex operating environments. One weakness, whether in engineering design, asset integrity, or poor management and execution of operational and competence frameworks, can cascade into catastrophic losses.

Identifying weaknesses before they potentially culminate in a loss is critical. Marsh's *Global Refining and Petrochemical Risk Quality Benchmarking* report first published in 2025 was developed in this context: it examines 389 refining and petrochemical facilities worldwide to understand how the same risk drivers that caused historical disasters are manifesting today, and what they can tell us about future loss potential.

A data-based view of risk maturity

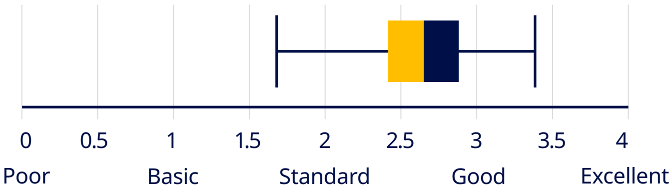
The benchmarking study evaluates each facility across three technical pillars — hardware, management systems, and emergency controls — representing more than 400 individual features. Each element is rated against engineering criteria, then benchmarked against a global peer group to reveal where facilities stand.

Globally, the risk quality for most assets falls within the standard to good range, but only about 5% reach the top quartile. This wide dispersion highlights not just variation in risk performance, but a substantial opportunity for improvement. Even facilities rated "better than standard" — more than half the global population — still show gaps when measured against leading practices.

Across the three pillars, management systems generally achieve the strongest quartile placements, reflecting widespread adoption of formal frameworks. However, Marsh's analysis indicates that approximately 51%

of major losses are linked to management system failures, underscoring a persistent gap between documented processes and consistent execution in practice. Formal processes exist on paper, but consistent application in real-world conditions often remains elusive.

Figure 1. Summary of global petrochemicals and refining risk rating



Source: Marsh

Hardware performance similarly reveals the need for targeted upgrades, particularly in aging facilities where physical infrastructure and engineering safeguards no longer align with current standards.

By contrast, emergency controls emerge as the global weak point. Despite significant compliance-driven investment, real world emergency response capabilities are frequently outdated, inconsistently tested, or insufficiently exercised.

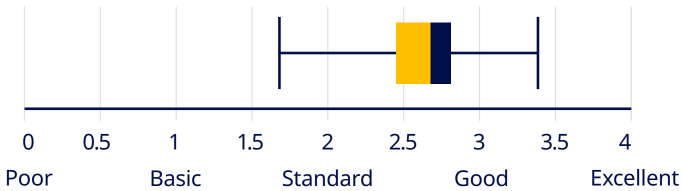
This aligns with the bow tie model of risk management (Figure 11): emergency response sits on the right hand side, influencing how quickly a loss escalates once it begins. The dominant drivers of loss initiation, however, sit on the left, within management systems, inspection effectiveness, and asset integrity. Prevention beats mitigation, and the benchmarking results confirm where the industry's attention should focus more.

Regional performance and navigating transition challenges

Beyond aggregate performance, the benchmarking data reveals stark regional contrasts — and how facilities worldwide are navigating risk during a period of significant industry transition. Energy transition pressures, decarbonization initiatives, digitalization, and organizational change (such as an aging workforce) impacting institutional knowledge, are influencing risk quality in ways that vary across regions:

North America exemplifies the tension between operational maturity, aging infrastructure, energy transition-driven change, and tighter profit margins. Many refineries were built before the 1960s and operate under robust management systems, yet face growing challenges as assets are repurposed, throughput profiles change, and investment decisions are increasingly scrutinized. Inspection effectiveness, asset-integrity governance, and workforce planning have become critical as facilities balance life extension, potential divestment, and selective modernization. Workforce considerations are increasingly centered on knowledge transfer, professional development, and sustaining a stable talent pipeline as experience distribution shifts across the sector.

Figure 2. Summary of North America petrochemicals and refining risk rating

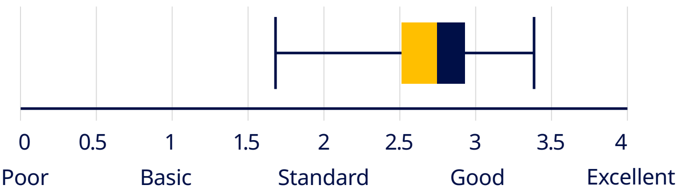


Source: Marsh

Europe benefits from regulatory depth under Seveso III and COMAH frameworks, but its older asset base demands extensive retrofitting at a time when decarbonization targets and sustainability commitments are redirecting capital. Operators are increasingly required to manage energy transition-related risks (such as changes in operating modes, temporary modifications, and evolving workforce models) alongside traditional process safety exposures.

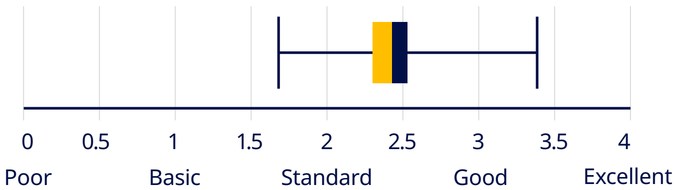
Latin America presents one of the broadest performance spreads. Economic volatility and transition-related uncertainty have, in some cases, deferred investment in aging assets, amplifying inspection and asset integrity risks. Where operators have aligned modernization, digitalization, and risk-based inspection programs with longer-term transition strategies, measurable improvements in risk quality have generally followed.

Figure 3. Summary of Europe petrochemicals and refining risk rating



Source: Marsh

Figure 4. Summary of LATAM petrochemicals and refining risk rating

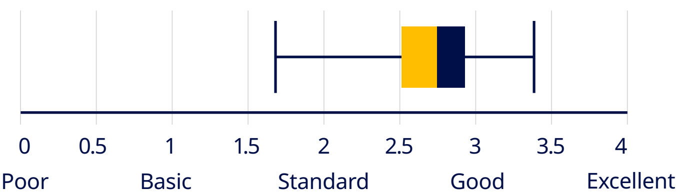


Source: Marsh

The Middle East ranks among the highest performers globally, thanks to modern infrastructure and sustained investment. Large-scale energy diversification programs and new-build projects provide opportunities to embed advanced safety standards from the outset. However, rapid growth, organizational expansion, and reliance on joint ventures place increased emphasis on consistent management system execution and competence assurance during periods of change.

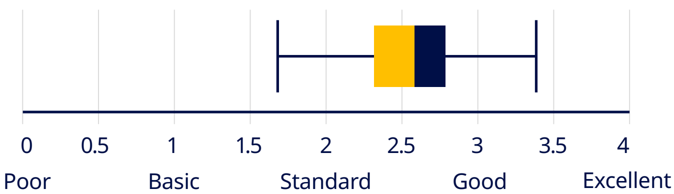
Asia demonstrates the complex reality of rapid industrial growth meeting energy transition ambitions. Industrial hubs show strong performance driven by modern design and technology, while emerging economies face the dual challenge of upgrading legacy assets while accommodating new fuels, alternative feedstocks, and evolving regulatory expectations. Competence development and management of change processes are increasingly critical as operating envelopes shift.

Figure 5. Summary of Middle East petrochemicals and refining risk rating



Source: Marsh

Figure 6. Summary of Asia petrochemicals and refining risk rating



Source: Marsh

The age factor: Understanding how assets degrade over time

Context matters when understanding these loss mechanisms, and few factors matter more than age. The global refining and petrochemical fleet averages approximately 45 years old. North America operates assets averaging 61 years; Europe, 54 years — well beyond their original design life assumptions. By contrast, the Middle East (27 years) and parts of Asia (32 years) benefit from younger infrastructure, though this can introduce different challenges related to rapid growth and organizational maturity.

Operating beyond original design life changes the risk equation. Degradation mechanisms become more complex, corrosion rates less predictable, and original inspection philosophies often prove inadequate for extended service. In this context, failures increasingly stem not from routine maintenance shortfalls but from limitations in inspection coverage, inappropriate inspection intervals, flawed data interpretation, and questionable fitness-for-service decisions.

Benchmarking results align closely with loss statistics and root cause analyses, which consistently show that loss initiation is dominated by left-hand-side bow-tie weaknesses — principally management systems and hardware integrity — rather than emergency response limitations. Management systems may score comparatively well in risk rankings because frameworks and procedures exist, yet the loss record indicates that failures concentrate in how these controls are executed, verified, and sustained over time.

The anatomy of erosion: How small gaps can become catastrophic losses

Across both loss investigations and survey-based risk ratings, a consistent pattern emerges. Major incidents rarely result from isolated technical failures. Instead, they are typically preceded by a gradual erosion of primary safeguards.

In practice, this erosion often manifests through weakened control of work for non-routine activities, incomplete verification of isolations and critical valves, and the routine acceptance of degraded barriers through overrides or bypasses. Periods of organizational change, turnarounds, debottlenecking projects, or transition-driven modifications can further strain these controls, particularly where management of change (MoC) processes are treated as administrative rather than technical safeguards.

Competence and operational discipline remain central to this picture. Benchmarking shows that refresher training for high-risk tasks, realistic scenario-based exercises, and effective contractor integration are unevenly applied, especially at aging facilities experiencing workforce turnover. As experienced personnel retire, reliance on informal knowledge increases, widening the gap between documented intent and actual operating practice.

From a hardware perspective, aging assets increasingly depend on targeted retrofitting of safety-critical equipment to maintain equivalent levels of protection. Where original designs did not anticipate extended service life and are not in line with industry best practices, risk quality improves markedly when operators prioritize upgrades, such as remote-operated isolation valves on critical inventories, modern burner management and combustion safeguard systems, and enhanced sealing arrangements on rotating equipment. These measures do not eliminate degradation, but they can materially strengthen preventive barriers on the left-hand side of the bow tie.

Together, these findings reinforce that loss prevention is driven less by the presence of policies or equipment in isolation, and more by how effectively management systems, competence frameworks, and hardware safeguards are integrated and sustained over time.

Emergency controls remain important — they determine whether a small release becomes a major fire, or a minor incident becomes a catastrophic explosion. But their role sits predominantly on the right-hand side of the bow tie, influencing escalation once primary barriers have already failed. Where emergency response is outdated or insufficiently exercised, severity increases — but the underlying loss drivers remain rooted in management system execution, inspection effectiveness, and hardware integrity.

Implications for operators and the insurance industry

For operating companies, these findings clarify where incremental improvement can yield the greatest impact. Stronger performance is consistently associated with clear competence frameworks, structured refresher training for high-risk and non-routine activities, robust inspection governance, and effective management of change.

For insurers and reinsurers, benchmarking provides an objective basis for comparing risk quality across portfolios, better aligning engineering insight with underwriting decisions, and identifying where preventive investment is likely to deliver the greatest reduction in loss potential. It transforms risk assessment from the realm of subjective judgment to an increasingly data-driven evaluation.

From historical losses to predictive resilience

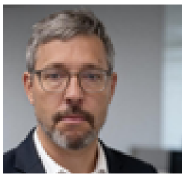
The *Global Refining and Petrochemical Risk Quality Benchmarking* report complements decades of loss analysis captured in the *100 largest losses*. Both reports point to the same conclusion: major incidents rarely arise from single failures. They result from persistent, measurable weaknesses that can be identified, benchmarked, and addressed before a loss occurs.

As the industry navigates the energy transition, the data suggests that the greatest risk lies not in new technologies themselves, but in how effectively organizations manage competence, inspection, and operational discipline during periods of change.

The weaknesses are visible. The tools to measure them are available. The path to improvement is clear. What remains is the collective resolve to act decisively to avoid a loss.

Firefighting foams in energy and power losses: *Balancing safety, environmental impact, and liability risks*

Peter Clayton,
Energy & Power, Marsh



Francois Carletto,
Energy & Power, Marsh

Large-scale fires in the energy and power sector can result in significant losses, including physical damage to infrastructure, business disruptions, and environmental and reputational harm.

Firefighting foams are widely used to extinguish fires and prevent their spread. However, the use of certain foams, particularly aqueous film-forming foams (AFFF) containing per- and polyfluoroalkyl substances (PFAS), has raised important environmental, health, and safety concerns globally.

Risks of PFAS-containing firefighting foams

AFFF foams play an important role in combating hydrocarbon fires, which are common in drilling, refining, transportation, or power generation operations. While highly effective, these foams typically contain PFAS — often called "forever chemicals" due to their persistence in the environment. PFAS contamination of soil, groundwater, and surface water near energy facilities has become a growing global concern.

In response, regulators worldwide are increasingly restricting or phasing out PFAS-based foams, and many foam manufacturers are stopping production of these foams in favor of fluorine-free foams. For example, the EU has restricted the use of PFAS in firefighting foams under the REACH Regulation, which took effect in October 2025. Energy and power companies must therefore align their commercial and regulatory frameworks with evolving requirements, striking a balance between fire safety needs and environmental and liability considerations.

Regulatory trends and safer alternatives

Regulations governing the use, sale, transportation and manufacture of PFAS vary globally, but generally trend toward tighter restrictions and phase-outs. As such, energy and power companies should proactively consider appropriate replacements to reduce their reliance on PFAS-containing foams.

Steps may include:

- Investing in alternative firefighting technologies, such as fluorine-free foams, which have proven to be effective in firefighting.
- Improving spill prevention and response procedures.
- Implementing stricter waste management practices to limit environmental releases of PFAS.

Challenges remain, including ensuring that PFAS-free foams are compatible with existing firefighting systems and that personnel receive adequate training on their use.

Learning from past large losses

The Buncefield oil depot fire, 2005

The Buncefield incident in the UK illustrates the scale and consequences of firefighting foam use.

After a massive explosion, fires burned for several days given the depot's large stocks of refined products, including gasoline, aviation turbine fuel, diesel, and gas oil. Approximately 250,000 liters of firefighting foam were deployed, much of it PFAS-based. The environmental fallout was significant, with lasting health and ecological effects reported. Retrospective analysis queried whether applying foam was the optimal response, given that the fire was uncontrollable and might have been better left to burn out naturally to minimize environmental damage.

While much smaller in scale, a 2024 fire at an oil depot in Europe involved the use of about 1,000 liters of PFAS-free foam, demonstrating the feasibility of more environmentally friendly alternatives without compromising fire suppression effectiveness or safety.

Balancing necessity and impact

Despite advances, the reality remains that large energy losses often require substantial quantities of firefighting foam. To minimize environmental impacts while maintaining safety, companies should focus on:

- **Improved training:** Ensuring emergency response teams are proficient in foam deployment. FFF are less resistant to disruption than AFFF, so firefighting tactics differ substantially — for instance, requiring using lower jet velocities and less direct, gentler application to maintain an effective foam blanket.
- **Environmental containment:** Implementing systems to capture foam runoff and prevent soil and water contamination.
- **Regular risk assessments:** Engaging risk engineers to evaluate site-specific hazards and develop tailored fire response plans that minimize foam use where possible. Additionally, companies should consider implementing routine PFAS monitoring in the environment surrounding the plant to proactively manage and mitigate potential future liability risks.

Industry collaboration and knowledge sharing are also vital to continuously improve fire response and develop best practices.

Proactive investment in fire safety preparation and risk management

Investing in fire safety — through risk identification, prevention strategies, regulatory compliance, and emergency training — can be cost-effective compared to the potential losses and liability from a major fire event. A risk management program should also address the practical challenges of transitioning to newer fire suppression methods, including fluorine-free foams.

Marsh's energy risk engineers are equipped to help you develop tailored fire safety plans, maintenance programs, and employee training to support this transition.

The insurance industry can further facilitate such progress by supporting insurers in understanding and embracing new techniques and by removing disincentives for operators to make necessary shifts.

PFAS regulations

- Since 2019, several countries have imposed restrictions on PFAS usage
- From 2030, European regulations will prohibit PFAS use in firefighting foam
- Globally, PFAS-contamination levels are monitored and strictly controlled
- Insurers are increasingly looking to implement specific exclusions related to PFAS exposure

Transitioning from AFFF to FFF

- Conduct through verification and updates of relevant systems
- Inspect and upgrade storage facilities
- Establish a clear, compliant elimination process
- Perform environmental assessments before and after the transition to establish baseline conditions

Toward a safer and more sustainable future

Firefighting foam remains indispensable for managing large-scale fires in the energy and power sector. However, the environmental and health impacts associated with traditional PFAS-containing foams necessitate a careful reevaluation of their use. Historical losses, such as the Buncefield incident, provide critical insights into the scale of foam application and its potential consequences, guiding the industry toward more sustainable practices.

Transitioning to PFAS-free firefighting foams, combined with improved training, risk management, and containment strategies, marks significant progress in reducing environmental harm. The ongoing challenge is to maintain a balance — promoting safety and operational continuity while protecting the environment.

By learning from past incidents, embracing innovation, and fostering collaboration, the energy sector can continue to enhance its firefighting practices, mitigate liability risks, and contribute to a safer and more sustainable future.

LASTFIRE

LASTFIRE (Large Atmospheric Storage Tank Fires) is a consortium of international oil companies that develops and promotes best practices for managing the risks of fires in storage tanks. Its fire hazard management practice has conducted numerous end-user driven tests using PFAS-free foams across a variety of application techniques and fuels, including crude oil, refined hydrocarbons, petrochemicals, and water-soluble products.

LASTFIRE has concluded that, to date, there is no evidence that the minimum application rates recommended in recognized standards, such as NFPA 11, are ineffective when applied correctly for PFA-free foams. In fact, these rates have remained consistent since before the introduction of PFAS-containing foams.

The transition to PFAS-free foams has provided a valuable opportunity to deepen understanding and optimize application techniques and foam bubble properties.

Naphtha tank leak, Europe, 2024

A major naphtha spill and fire at a tank farm underscored the importance of preparation, command, and inter-agency cooperation in industrial fire response.

The local fire service managed a prolonged 12-day operation to control the incident, which began with a significant naphtha leak posing high risks due to the substance's flammable nature.

Throughout the response, only fluorine-free foam was used to suppress the fire. Challenging conditions — including high winds, heat, and continuous liquid flow — frequently disrupted the foam blanket, requiring large volumes of foam concentrate to maintain coverage. The fire service initially used its database to locate local foam reserves, while additional foam was sourced from facilities in neighboring countries. In total, about 1,000 m^3 (1,000 liters) of foam concentrate were procured, with 800 m^3 deployed during the response. Following the incident, a strategic decision was made to maintain a stockpile of fluorine-free foam concentrate for potential future incidents.

The response demonstrated the feasibility of more environmentally friendly firefighting foams without compromising fire suppression effectiveness or safety.

From loss to resolution: *The high stakes of claims in the energy sector*

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When a loss strikes an energy facility, the difference between a swift recovery and a prolonged struggle often depends on preparations, precision, and the right supporting team in your corner.

These factors are crucial for minimizing both operational disruptions and economic impacts. While property damage is the most visible consequence of such incidents, business interruption losses frequently surpass physical damage in both scale and complexity. Marsh's *100 largest losses in the hydrocarbon industry 1974 – 2025* report catalogs the major property damage events in the industry; however, many incidents above and below this threshold incur business interruption costs that far exceed the reported property damage losses. This reality underscores the critical importance of claims strategies that address the full scope of potential impacts.

Figure 7. General claims process

Source: Marsh

The anatomy of a successful claims recovery

Insurance claims in the energy sector typically unfold along two parallel, yet interconnected, paths:

1. Strategic claims advocacy

Successful recovery often depends on effective claims advocacy, which involves coordinating the entire claims process, developing coverage strategies, and managing relationships with insurers and key stakeholders. Given the critical nature of energy infrastructure and the high costs associated with operational downtime, this role goes beyond simple project management. It requires a thorough understanding of specialized insurance policies and practices in the sector, enabling advocates to assist in securing early confirmation of coverage, negotiating interim payments that help maintain cash flow during the recovery period, and resolving potential coverage disputes. The objective is to actively support recovery while minimizing delays that could prolong the return to normal operations.

2. Technical claims preparation

Claims in the energy sector can be compromised by limitations on understanding of the complex technical realities of a loss. Insurers require comprehensive claim documentation, ranging from detailed damage assessments and root cause analyses to reinstatement plans and well-supported cost schedules. For large-scale incidents, this often means assembling a large volume of records, including invoices and purchase orders, and developing clear, compelling presentations that tell the full story of the loss. Claims engineering specialists play a key role in translating technical data into more digestible formats, helping to smooth the path to coverage confirmation.

Equally important are forensic accountants, particularly when addressing business interruption claims. They help to bridge the divide between standard accounting practices and insurance policy definitions of compensable loss. Together, these specialists help to show the full scope and impact of losses in a sector where downtime and disruption carry significant operational and financial impacts.

Recovery in action: Two defining cases

The following cases illustrate how complex energy-sector claims can be successfully navigated through a powerful blend of technical knowledge, strategic advocacy, and careful financial analysis. Both examples reveal unique challenges and tailored approaches that have driven effective recoveries, underscoring the value of early engagement and specialized knowledge in managing the claims process toward a favorable outcome.

Turning catastrophe into swift resolution: The US$900 million settlement

When an explosion and fire destroyed a US gas fractionation facility, the recovery challenge was immense. The company's strategy involved constructing an entirely new facility at a different location, complicating both the property damage and business interruption calculations.

Recognizing that a traditional claims process for such a loss could take three to four years — the same amount of time needed for reconstruction — proactive claims management was essential. This included coordinating multiple insurer site visits, pursuing early confirmation of coverage, negotiating interim payment schedules to support cash flow, and maintaining ongoing communication among stakeholders. These efforts resulted in a settlement exceeding US$900 million reached within six months of the incident itself, a fraction of the typical timeframe for losses of this magnitude.

Overturning denial through technical precision: From US$0 to US$4.5 million

During a routine inspection, cracks were discovered in a 32-inch isolation valve, posing a risk to the asset and its operational continuity. The insurers initially denied the claim.

Through persistent advocacy, Marsh's claims engineers and advocates worked with the company's technical team to overcome the insurers' initial denial and substantiate the extent of the property damage and business interruption losses incurred, resulting in a final settlement of US$4.5 million. Such a recovery would likely have been unattainable without specialized technical and advocacy expertise.

Early engagement, stronger recovery

Early engagement can make a significant difference. The most successful claims outcomes begin before disaster strikes, with integrated risk management frameworks where claims specialists, risk engineers, and placement strategists collaborate to identify exposures and transfer risk.

As highlighted in the *100 largest losses in the hydrocarbon industry 1974-2025* report, energy losses pose significant challenges that necessitate effective risk mitigation strategies. Key lessons highlight the critical importance of proactive risk identification, continuous monitoring, and the mobilization of specialized capabilities.

Claims will continue to be a reality in the energy sector, making it essential to have the right team in place to support a swift return to operations, manage the frequency and impact of claims, and help control overall risk costs. An effective team will engage with and manage interactions with all stakeholders, including loss adjusters, forensic accountants, and specialists appointed by insurers.

Strategic BI analysis: *Prepare for potential losses*

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In today's interconnected and volatile energy and power landscape, unexpected interruptions can cascade through supply chains, causing operational disruptions and substantial financial losses. For operators in this sector, business interruption (BI) is far more than a theoretical concern; it is a real and pressing reality.

Data compiled by Marsh indicates a proportional increase in the business interruption (BI) component of claims relative to property damage (PD) losses, and therefore BI portions of a loss should be viewed by organizations as a leading driver of the total loss figure. Industry analysis shows that the BI to PD ratio is exceeding the historical average of 3 to 1, with some claims even reaching a BI to PD ratio of 10 to 1.

BI losses are impacted by the current period of market volatility stemming from geopolitical events and increasing supply chain complexity. Additional factors contributing to generally increasing BI exposures include:

- **Rising material costs**
- **Material shortages**
- **Challenges related to contractor solvency**
- **Heightened scrutiny from public authorities alongside evolving regulatory requirements.**

Additionally, prolonged physical reinstatement periods of damaged property can delay the settlement of PD claims while also lengthening the outage duration and consequently the associated financial loss.

Organizations that adopt a proactive, pre-loss approach to understanding their BI exposures can see benefits to that approach in the event of a claim. By identifying and addressing risks ahead of time, operators are better equipped to manage unexpected disruptions. This forward-looking strategy not only helps in developing effective business continuity measures to reduce losses but also supports securing risk transfer solutions. Providing insurers with a clear understanding of the BI exposures can help to facilitate a smoother claims process. Without BI analysis, exposures can remain uncertain, leading to longer claim settlement times as stakeholders work to fully assess the extent of the loss.

Business interruption exposures and coverage

Decisions about coverage, sums insured, and indemnity periods hinge on a detailed understanding of operational complexities. Operators should thoroughly assess their risk exposures and financial vulnerabilities related to interruptions.

BI insurance is not one-size-fits-all, especially in the energy and power sector. The rapid growth of renewable power installations, interdependencies within multi-site facilities, and diverse contractual arrangements across complex value chains and property portfolios require a flexible, often tailored approach to BI insurance coverage. For example:

- Traditional and renewable power facilities face a wide range of contractual arrangements shaped by local regulatory requirements and variables, including generation hierarchies (such as baseload versus peak shaving), power purchase agreements, and grid usage.
- In offshore oil and gas production, traditional BI coverage typically assumes a static production profile, applying daily recovery limits based on average output. However, for operations in ramp-up or with substantial drilling programs underway, it is critical that coverage reflects the evolving production profile; otherwise, BI recovery may fall short of expectations in the event of loss.

Operators should seek to align their BI coverage with the business's operational activities, commercial frameworks, and financial profiles. BI values should be declared in accordance with the policy's specified calculation basis, which may differ from the standardized accounting metrics used for budgeting or forecasting. Stress-testing credible scenarios can help to identify unknown exposures and anticipate the coverage response. Of equal importance is having systems and personnel capable of preparing the needed loss data.

When operators and their insurers have a clear, shared understanding of the business's operations and commercial context, the claims process can be more streamlined. Insurers are increasingly scrutinizing the quality and transparency of BI submissions. Evidence-based submissions help to show the extent of potential losses and can enable a smoother settlement process.

Case studies: Pre-loss BI analysis can support faster, fairer claims outcomes

Fire at a petrochemical operator

A leading petrochemical operator experienced a major fire at a polyolefin unit. The site's production profile had a high degree of integration, operational complexity, and multi-asset interdependence. Pre-loss BI analysis enabled stakeholders to estimate the potential BI exposure and identify mitigation strategies to reduce loss. As the incident unfolded, the operator was able to re-optimize operations and implement these mitigations effectively. These proactive steps provided insurers with greater confidence that the operator was managing the interruption comprehensively, facilitating a more efficient claims process.

Outage at an ammonia plant

A major fertilizer producer faced an outage at an ammonia plant — an event that had been modeled during a pre-loss BI review. The review had identified key exposure drivers and viable mitigations, which closely aligned with the operator's actual response. Consequently, the BI impact closely aligned with the pre-loss estimates (adjusted for market fluctuations), allowing the insurer to address the claim promptly. This combination of a proactive BI assessment and disciplined loss management transformed what could have been a complex claim into a well-understood, evidence-based recovery.

Vapor cloud explosion at a refinery

A major refinery experienced a vapor cloud explosion (VCE) on its residue fluid catalytic cracking (RFCC) unit, a scenario often identified as the estimated maximum loss (EML) for refineries equipped with this technology. This incident underscored that "worst-case" events do occur, despite a common misconception that such EML-type scenarios are highly unlikely. The event validated the importance of rigorous EML modeling and BI exposure quantification, highlighting the need for preparedness against credible events with the most severe operational and financial consequences.

How BI losses shape insurance solutions and the role of upfront analysis

Historically, losses have revealed significant mismatches between declared BI values and actual BI loss, leading insurers to seek to rely on volatility clauses capping recoveries based on declared values. Such limiting provisions can have a material impact on the claims process.

In today's complex and dynamic business environment, declaring and maintaining current BI values is arguably more challenging than ever. The highly-integrated energy sector can see BI values shift markedly and without warning through sudden changes in feedstock pricing, tariffs, and product spreads. This volatility makes regular BI exposure reviews key to seeing that the insurance coverage will provide the desired protection amid actual realities.

Proactive management of BI values through regular assessment and adjustment can support more accurate insurance coverage and foster stronger relationships between insureds and insurers, facilitating smoother claims processes when interruptions occur.

For example, a 2025 fire at a substation serving Heathrow Airport caused widespread power outages, grounding flights and disrupting essential services, local communities, and supply chains. The incident highlighted the interconnectedness of modern energy infrastructure and underscored the importance of thorough BI assessments that consider utility and supply chain disruptions. This loss event sparked interest in the insurance market for substation redundancy, leading to increased scrutiny of this area of operations.

Financial foresight driven by BI preparedness

The future of BI resilience requires shifting from a reactive mindset to strategic, forward-looking approaches. Energy and power operators can build resilience by:

- **Assessing BI exposures regularly,** considering operational data such as feedstock availability, production yields, and any contractual obligations. This promotes the declaration of BI values that reflect current operational realities.
- **Integrating supply chain and finance functions** to align operational data with financial and insurance planning to support both insurance declarations and improved claims recovery.
- **Modeling loss scenarios** to understand potential exposures and test mitigation strategies.
- **Fostering a culture of BI preparedness** across the organization, ensuring all stakeholders understand the importance of proactive BI management.

Real-world case studies show that pre-loss business interruption analysis is far from theoretical; it delivers tangible benefits in both claims outcomes and operational resilience. At the same time, shifting insurance market dynamics highlight the importance of evidence-based BI declarations to securing effective coverage.

Beyond the blast: *Safeguarding energy infrastructure*

Chris Price-Kuehne,
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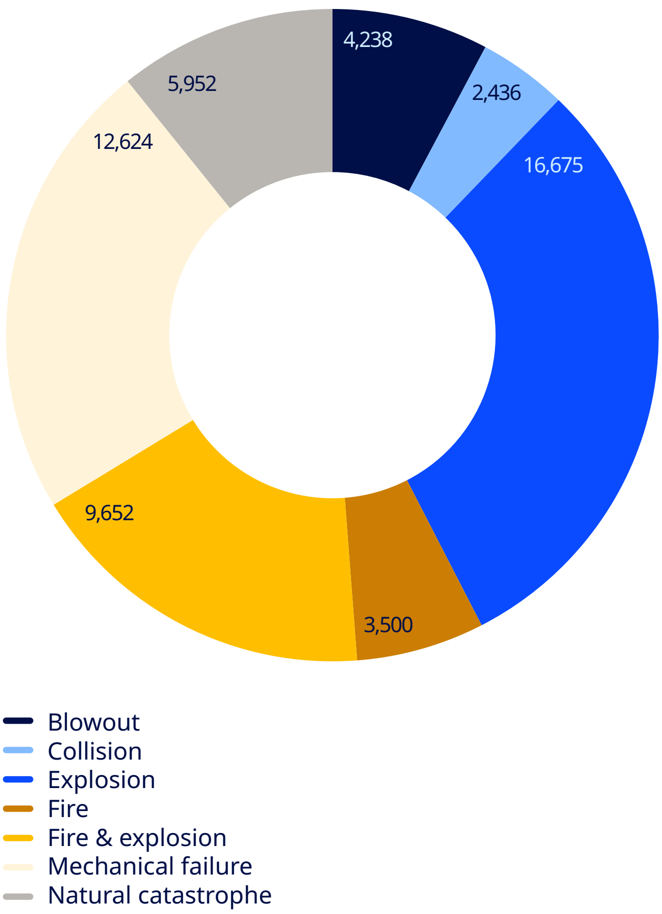
Fillipe Dobbin Caruso,
Energy & Power, Marsh

Explosions remain among the most catastrophic and costly incidents affecting the energy sector. The *100 largest losses in the hydrocarbon industry 1974 – 2025* report underscores that vapor cloud explosions consistently rank among the most severe events, causing extensive property damage. Beyond infrastructure destruction, these incidents can endanger lives, disrupt operations, and reveal vulnerabilities in existing risk assessment frameworks.

The challenge extends beyond isolated incidents. The risk landscape is currently evolving at an unprecedented rate, rendering some traditional risk assessment methodologies inadequate for today's environment. In sectors where catastrophic events can result in billions of dollars in losses (Figure 8), the gap between legacy risk assessment techniques and modern reality has the potential to become untenable. Embracing innovation in risk management

Figure 8. Distribution of value by event type (US$ million)



Source: Marsh

The limits of yesterday's tools

Historically, many providers of loss estimate assessments in the energy insurance sector have relied on trinitrotoluene (TNT)-based models. While commonly used for simplicity, these models may fail to account for the complex combination of factors that impact the severity of vapor cloud explosions: chemical reactivity, congestion patterns, and confinement effects.

In essence, TNT-based models generally treat every explosion scenario with the same broad brushstrokes, and having only a single handle to adjust for explosion severity can leave critical gaps in the understanding of the risk. This can result in misjudged exposures and poor prediction of losses.

The challenges are becoming more complex. Modern industrial operations are increasingly intricate, while new technologies and alternative fuels have introduced risk profiles that legacy models were not designed to evaluate. Organizations now face an important choice: enhance their risk assessment capabilities or risk making decisions without a clear understanding of property loss exposures.

Precision through innovation

New, sophisticated simulation models, powerful data analytics, and integrated software platforms are enabling risk professionals to move beyond generic assumptions and to capture specific scenario dynamics with remarkable accuracy.

Consider the assessment of explosion risks. Marsh has partnered with BakerRisk to develop the Marsh BLAST (powered by BakerRisk) software – a cutting-edge loss assessment tool used to estimate losses at refineries, petrochemical plants, LNG facilities and other energy facilities worldwide. Unlike legacy assessment techniques, the BLAST platform uses contemporary modeling to simulate a range of loss events, taking into account the specific configuration of every site to deliver greater precision. Importantly, the BLAST software has been calibrated using data held by Marsh on losses featured in this report to validate property loss value predictions.

The global energy transition presents a particularly complex challenge for risk managers. While traditional hydrocarbon facilities continue to grow in scale and intricacy, requiring vigilance and increasingly sophisticated risk assessment techniques, the accelerated move towards hydrogen and other low-carbon technologies, such as sustainable aviation fuels and biofuels, is introducing new risk profiles.

Legacy risk models often fall short in addressing novel fuels, as the specific physical arrangements of production facilities and the particular chemical properties of the materials involved require purpose-built risk assessment techniques. In response, innovative risk tools are evolving to incorporate these distinct characteristics into their simulations, delivering improved accuracy and more actionable risk assessments amid a transforming energy landscape.

For example, working in collaboration with BakerRisk, Marsh's Risk Engineering team is driving an evolution of the BLAST software. For traditional hydrocarbon operations, we have incorporated years of Marsh's real-world data and BakerRisk's scientific research to enhance existing models in the BLAST software. This includes addressing the handling of damage factors for multiple, simultaneous explosions, updating the assessment of physical properties for liquid inventories, and revising the methodology for calculating vapor cloud drift distances. For emerging fuels, Marsh and BakerRisk have jointly developed specialized loss assessment models that capture the unique physical and chemical risks associated with next-generation energy sources including hydrogen.

Integration and accessibility: Making innovation practical

Technical sophistication means little if tools remain inaccessible. Modern risk management platforms recognize this, prioritizing intuitive interfaces, streamlined data workflows, and seamless integration with broader risk management systems. This greater accessibility enables risk engineers and insurance insurers to share information more effectively and respond more rapidly as portfolios grow increasingly complex.

Furthermore, as industries evolve and novel risks emerge, organizations should deploy tools that not only respond to present challenges but also anticipate future uncertainties. The cost of complacency may well be unquantified loss exposures, pricing uncertainties, and diminished capacity to support the innovation that drives progress.

By embracing advanced modelling technologies and continuously refining analytical capabilities, risk managers can transform uncertainties into more manageable variables. Marsh loss assessment modeling, using the Marsh BLAST (powered by BakerRisk) software, embodies this approach, blending deep technical capabilities with cutting-edge technology to provide actionable insights that support better informed decision-making.

Marsh's commitment to evolving risk engineering solutions reflects an understanding that tomorrow's challenges demand innovative answers. A key question is how quickly organizations will adapt to this reality before the next catastrophe reveals the cost of hesitation.

A catastrophic loss may strike without warning. Our preparedness should not be left to chance.

100 largest losses: *Learning from root cause analysis patterns*

Natali Walton Chacin,
Energy & Power, Marsh

For over half a century, Marsh's *100 largest losses in the hydrocarbon industry* report has served as a vital resource for understanding the scale and consequences of major incidents. Each edition reveals where and how losses occur — but understanding "why" they happen is equally critical.

Root cause analysis (RCA) enables us to look beyond immediate circumstances to uncover the underlying drivers of incidents. In this edition, we have applied an RCA structured lens to approximately 80 of the largest ever historical losses. While comprehensive RCA details are not available for every event, the data provides sufficient insight to identify recurring patterns and extract meaningful lessons. RCA transcends immediate failures; it exposes systemic issues rooted in organizational culture, **barrier** effectiveness, and leadership decisions.

What emerges is both familiar and urgent: the same failure modes — mechanical, organizational, and those driven by **natural catastrophes** — recur across decades. Equally revealing is the critical role of barriers, the controls and safeguards designed to prevent incidents or limit their escalation. When these safeguards fail, whether in physical **hardware, emergency controls,** or routine **systems of work,** they often determine whether an event remains contained or escalates into a major loss.

This article examines the most frequent **immediate causes** and barrier failures for major losses, highlights trends across **upstream, downstream, and midstream** losses, and reflects on what these patterns mean for risk leaders today. The objective is not simply to explain the past, but to prompt a discussion on how organizations can further embed consistency, relevance, and resilience in loss prevention.

The data story

Immediate causes

Understanding the immediate cause — the initial factor that triggers a loss event and sets the failure chain in motion — is a critical first step in incident analysis. This is documented at a high level, even when subsequent investigations reveal additional technical information and complexity.

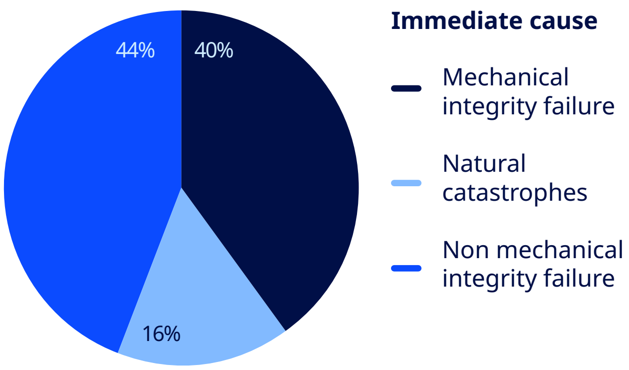
Immediate causes fall into four primary categories:

- **Mechanical integrity failures**
- **Non-mechanical integrity failures**
- **Natural catastrophes**
- **Reservoir unintended flow or loss of well control**

Downstream and midstream: Immediate causes

Downstream and midstream incidents in the 100 largest losses (refining, petrochemicals, gas processing, and terminals/distribution), fall into three primary immediate cause categories (Figure 9).

Figure 9. Immediate causes of downstream and midstream incidents



Source: Marsh

Figure 9 shows that the largest contributors to major losses are mechanical and non-mechanical integrity failures. While these categories describe the manner in which failures occur, in practice, both categories are predominantly driven by underlying weaknesses in asset integrity and management systems. Mechanical integrity failures rarely arise from a single, isolated cause. Instead, they typically arise when equipment degradation, **inspection** effectiveness, **maintenance** quality, or original design assumptions fail to keep pace with aging facilities or evolving operating conditions.

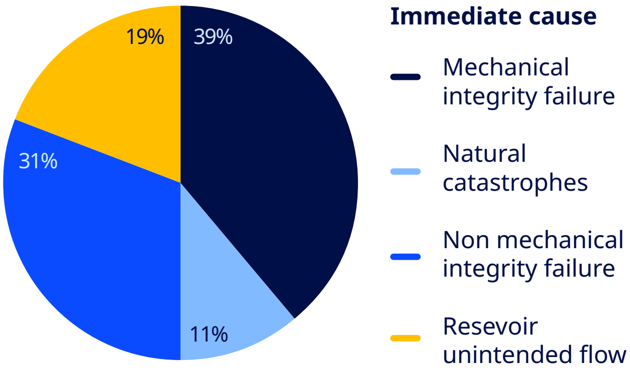
On the other hand, non-mechanical integrity failures are often associated with operational drift beyond the intended parameters, frequently due to the gradual erosion of procedural controls, safeguards, or change management processes, as well as a loss of organizational capability and competence.

> The distribution highlights that downstream and midstream facilities are mainly vulnerable to breakdowns in integrity and management systems rather than rare technical anomalies or external events. In this context, major losses tend to reflect the cumulative effect of degraded controls and normalized risk, rather than isolated points of failure.

Upstream: Immediate causes

Upstream incidents in the 100 largest losses (offshore platforms, floating production storage and offloading units (FPSOs), drilling, and production facilities), fall into four primary immediate cause categories (Figure 10).

Figure 10. Immediate causes of upstream incidents



Source: Marsh

Figure 10 shows that upstream facilities exhibit a broader range of risk drivers than downstream and midstream facilities. While mechanical and non-mechanical integrity failures predominate, nearly one-fifth of upstream losses stem from loss of well control — a hazard unique to upstream operations and closely tied to well control barriers and pressure containment systems. Natural catastrophes also feature prominently, reflecting the vulnerability of offshore and remote assets to extreme weather and environmental conditions.

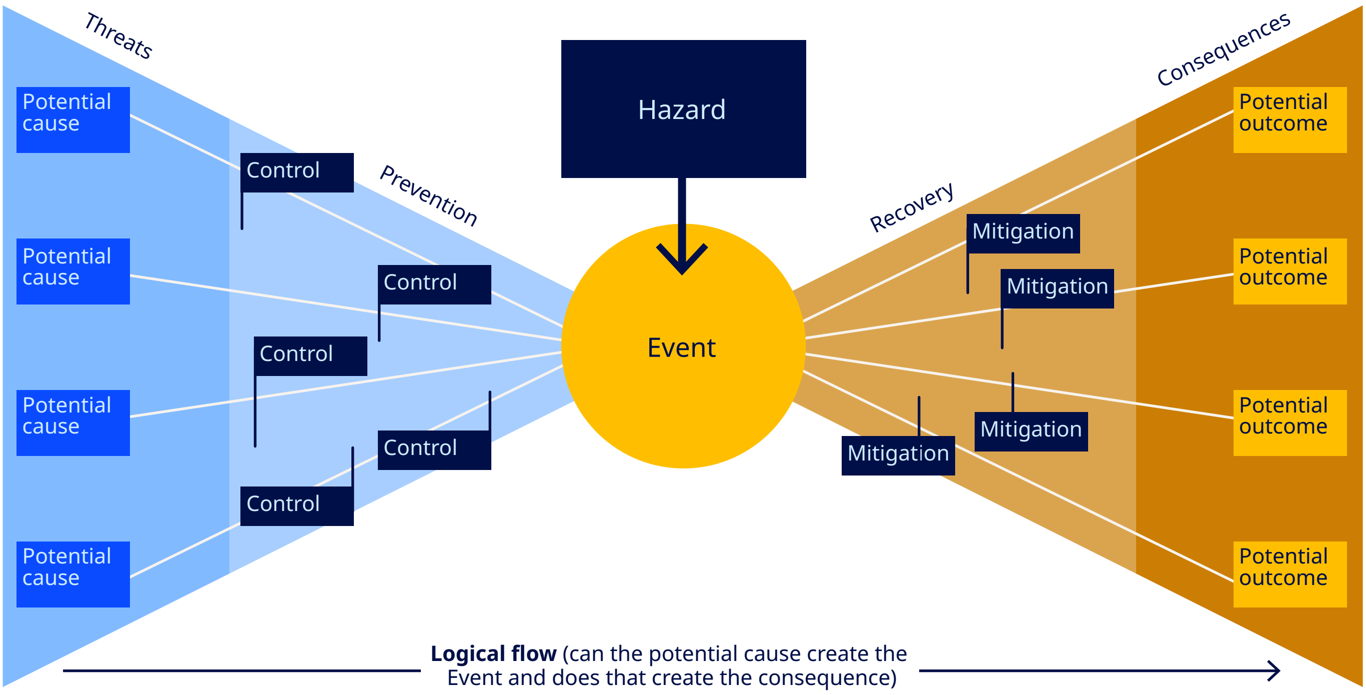
Barrier analysis

In loss prevention, a barrier represents any measure intended to prevent an incident or mitigate its consequences. Within Marsh's **risk ranking** framework, barriers are categorized into three groups:

- Hardware
- Management systems ("software")
- Emergency controls

Our risk ranking assigns relative weightings when assessing risk exposure during surveys. For example, management systems have a 55% weighting, hardware has a 30% weighting, and emergency controls have a 15% weighting. This weighting structure mirrors bow-tie methodology (Figure 11), where preventive barriers (primarily management systems and hardware) control threats, while reactive barriers (emergency controls) mitigate consequences. In the Marsh weightings given above, although the right hand side emergency controls are important, the primary focus is the left hand side — keeping the oil in the pipes in the first place.

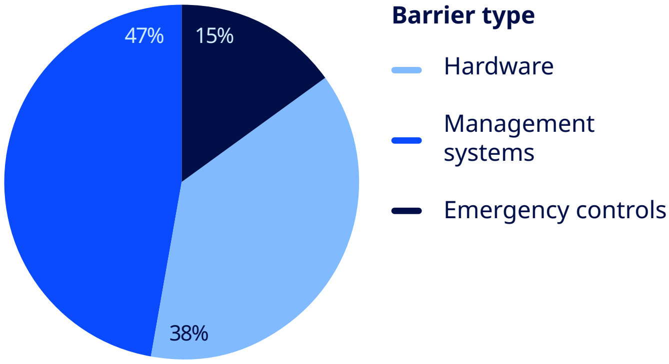
Figure 11. Bow-tie diagram



Understanding barrier failure occurrence

"Occurrence" quantifies how frequently failed barriers are attributed to each of the three categories. Since a single loss event may involve multiple failed barriers, one incident can generate several data points, providing richer insight into how protective layers break down.

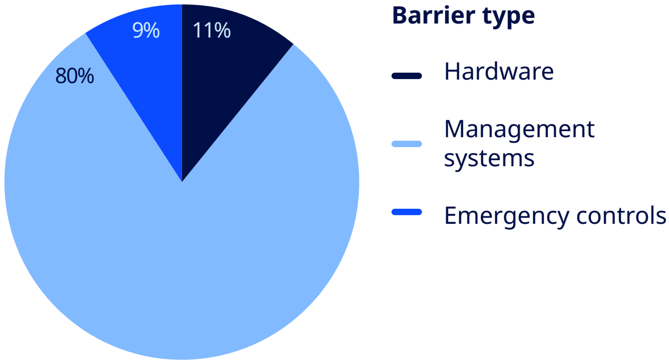
Figure 12. Downstream and midstream barrier failures



Source: Marsh

Figure 12 shows that management system failures are the leading contributors to major losses. While this is a cause for concern, it presents an opportunity: management systems, processes, and behaviors are among the most practical and cost-effective areas for improvement, compared to large-scale hardware upgrades. This distribution highlights that process safety management, which encompass both technical and operational aspects, and procedural adherence figure prominently in the failure landscape. At the same time, emergency controls, positioned on the reactive side of Figure 11, remain critical in limiting escalation.

Figure 13. Upstream barrier failures



Source: Marsh

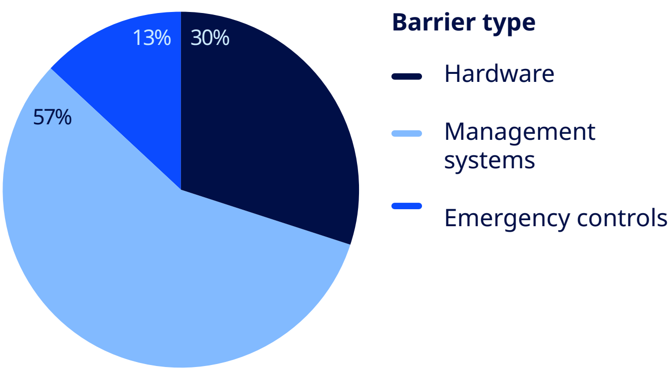
In upstream contexts, organizational and procedural barriers in drilling and production operations are the primary drivers of failure occurrence, with management system deficiencies accounting for a substantial 80% of these issues, as shown in Figure 13. This reinforces that loss potential is less frequently caused by hardware breakdown alone and more often a consequence of how risks are governed, controlled, and managed over time.

> Encouragingly, there has been demonstrable progress in the adoption of process safety barrier modeling to systematically identify degraded or impaired safeguards. However, progress has not yet consistently translated into significantly more effective risk reduction.

The management and execution of mitigation strategies remain uneven, with gaps between the identification of barrier weaknesses and their timely, disciplined application in operational settings.

These inconsistencies continue to leave upstream assets vulnerable, highlighting that the true challenge lies not only in recognizing barrier failures, but in reliably closing them to promote sustained risk control.

Figure 14. Combined barrier failures (upstream, downstream, and midstream)



Source: Marsh

Emergency controls are often challenging to assess post-incident; without detailed investigation reports, it can be difficult to distinguish between emergency controls that fail and situations where the event's magnitude overwhelmed the response. As a result, their contribution to incidents may be underrepresented in the data, even though they frequently influence final severity.

On a positive note, the software-based elements of emergency controls — including procedures, training, emergency drills, emergency plans, and response coordination — are areas where meaningful improvements can be made relatively quickly and cost-effectively, without the need for large-scale hardware upgrades. Strengthening these elements offers a practical opportunity to improve loss outcomes by limiting escalation when primary barriers fail.

Figure 14 shows that barrier failures in management systems (encompassing procedures, training, and **operational discipline**) constitute the single largest contributor to major losses, aligning with historic lessons from Piper Alpha, Deepwater Horizon, Texas City, and similar watershed events.

From risk ranking to risk improvement recommendations

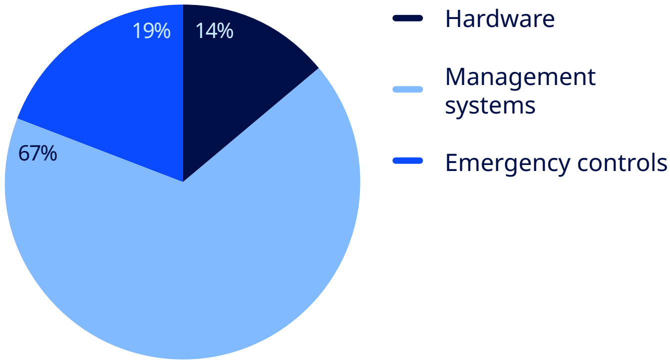
Risk ranking captures a snapshot of what risk engineers observe during site surveys, documenting the relative strengths and weaknesses of different barriers and providing an evidence-based view of risk exposure. Naturally, any identified weakness should inform **risk improvement recommendations.**

However, not every weakness can be readily addressed. Hardware-related issues, such as plant layout or aging infrastructure, may score poorly yet prove cost-prohibitive or physically impractical to remediate. Conversely, management systems and emergency controls offer more accessible avenues for improvement: processes can be revised, training enhanced, and procedures strengthened.

Asset age significantly influences this dynamic. As facilities age, maintaining mechanical integrity becomes more challenging, testing the effectiveness of existing management systems. While asset integrity programs typically exist, their execution fluctuates with shifting corporate priorities and resource availability, creating "peaks in themes" – periods of intense focus following major incidents (such as post-2017 refining loss campaigns on **control of work** and **process isolations**), followed by gradual drift as personnel change and organizational attention shifts.

Even within emergency controls, many risk improvement recommendations trace back to management systems, such as emergency planning, drill effectiveness, and competency development. Hardware-focused risk improvement recommendations (enhanced gas detection, double pump seals, upgraded **firewater systems**) exist but remain the exception.

Figure 15. Downstream, midstream, and upstream risk improvement recommendations primary risk ranking area classification



Source: Marsh

Figure 15 presents over 5,000 risk improvement recommendations raised by our risk engineers worldwide over the past five years.

> This helps to explain why risk improvement recommendations consistently emphasize management systems over hardware — not as a distortion of risk, but as a reflection of what is realistically changeable and actionable, overlaid with the natural attention cycles that emerge as the industry learns from experience.

A broader industry perspective

The 100 largest losses analysis confirms that barrier failures underlying the largest events are predominantly management systems ("software") failures — weaknesses in procedures, inspection protocols, maintenance execution, workforce competence, and operational discipline.

Across combined upstream, downstream, and midstream operations, management systems account for approximately 57% of recurring barrier issues, followed by hardware (~30%) and emergency controls (~13%). While emergency controls significantly influence event severity, they typically affect consequences rather than the root cause.

This distribution closely aligns with Marsh's risk framework weightings and is reinforced by analysis of more than 5,000 global risk improvement recommendations from our risk engineering surveys conducted over the past five years, in which nearly 70% target management systems.

Three independent perspectives — historic loss analysis, risk ranking assessments, and current risk improvement recommendations — converge on the same conclusion: many of the drivers of major losses are well understood, yet their control remains inconsistent in practice. The persistent occurrence of management system failures, however, highlights an execution gap where leadership focus and operational discipline should intensify. This challenge is further complicated by underlying industry and geopolitical trends that can magnify these issues, including aging assets, margin pressures, mergers and acquisitions, and capacity expansion efforts. At the same time, the workforce itself is evolving. As experienced personnel retire or move out of operational roles, and as the industry competes for talent amid changing career expectations and ways of working, critical know-how increasingly risks remaining tacit rather than embedded. Ultimately, the challenge is not knowing what to do, but ensuring that knowledge is shared, retained, verified, and consistently applied over time.

Barrier topics and common themes

While barrier type analysis identifies which category of protection failed, barrier topics pinpoint the specific issues within those barriers. Marsh's classification system builds on these barrier topics by grouping related issues into **common themes,** enabling the identification of emerging patterns through ongoing loss data reviews and risk engineering insights. This approach highlights recurring weaknesses and uncovers new areas of focus across the industry.

The following analysis focuses on recurring barrier topics in the 100 largest losses, separating findings into downstream, midstream, and upstream categories. While each sector faces distinct operational challenges, the underlying common themes reveal a striking consistency in where safeguards most frequently break down.

Downstream and midstream operations: Recurring themes

The most frequently recurring barrier topics (Figure 16) in downstream and midstream operations include:

- Inspection
- Engineering standards
- Systems of work
- Emergency plans

Secondary contributors include:

- Site layout and location/climate
- Recruitment and training (operations)
- **Ergonomics and operability**
- **Control of ignition**

Additional factors, such as corporate/asset loss control policy, housekeeping, process layout, gas detection, process control, maintenance, **fixed fire protection,** process isolation, depressuring and dumping, **firewater systems,** fireproofing, and control rooms, also appear but with lower frequency.

Common themes (Figure 17), such as hazard identification, **inspection philosophy, corrosion management,** hazard awareness, and operational discipline, closely mirror these topics, reinforcing that core challenges center on inspection effectiveness, design integrity, and procedural compliance.

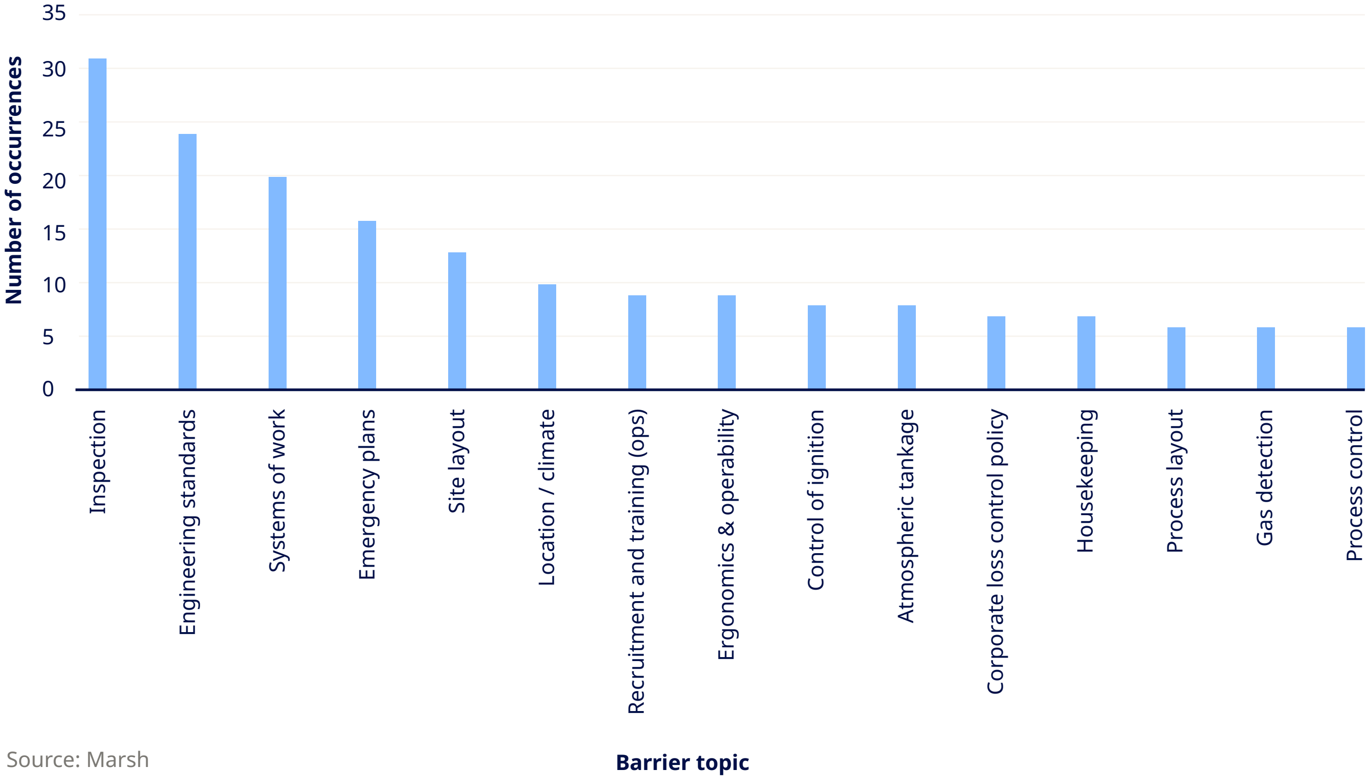
Emerging themes such as **alarm management, critical valve management,** deadleg management, and control of work deficiencies reflect current industry concerns, including **critical valve management** (highlighted by recent LNG incidents) and alarm reliability.

These findings align with other studies, including the 2016 Lloyd's Market Association's loss analysis, which also identified inspection programs, materials of construction and quality assurance, operations practices and procedures, control of work, and **management of change** as major contributors to large downstream and midstream events.

Overall, the data shows persistent weakness in barriers dependent on procedural consistency and operational experience. *Inspection* and *maintenance* form the foundation of asset integrity, but their success depends on disciplined execution, clear accountability, and continuous verification.

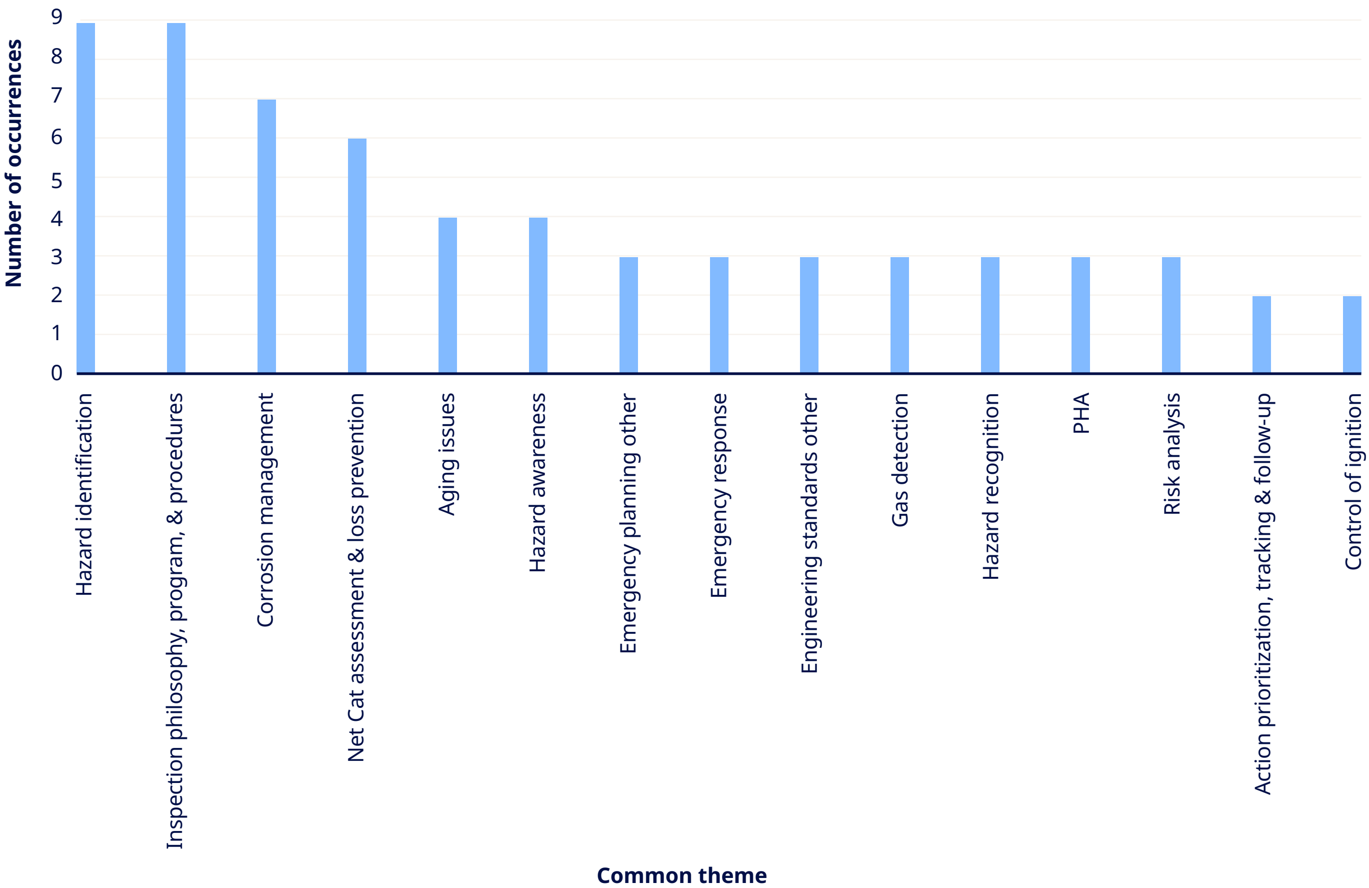
Meanwhile, a shrinking pool of experienced personnel and challenges attracting new talent make structured competency development and knowledge retention programs increasingly critical.

Figure 16. Top 15 downstream and midstream barrier topic occurrences



Source: Marsh

Figure 17. Top 15 downstream and midstream common theme occurrences



Source: Marsh

Upstream operations: Recurring themes

For upstream operations, the most frequently recurring barrier topics (Figure 18) are:

- Systems of work (operations)
- Recruitment and training (operations)
- Engineering and technical standards
- Inspection

Secondary contributors include **ergonomics and operability,** drilling and well servicing, **process safety management,** emergency plans, maintenance of instruments and control, construction standards, marine and aviation operations, **asset layout,** depressuring and flare systems, and process isolation (Figure 18).

Common themes, highlighted in Figure 19, that complement these topics and appear repeatedly include:

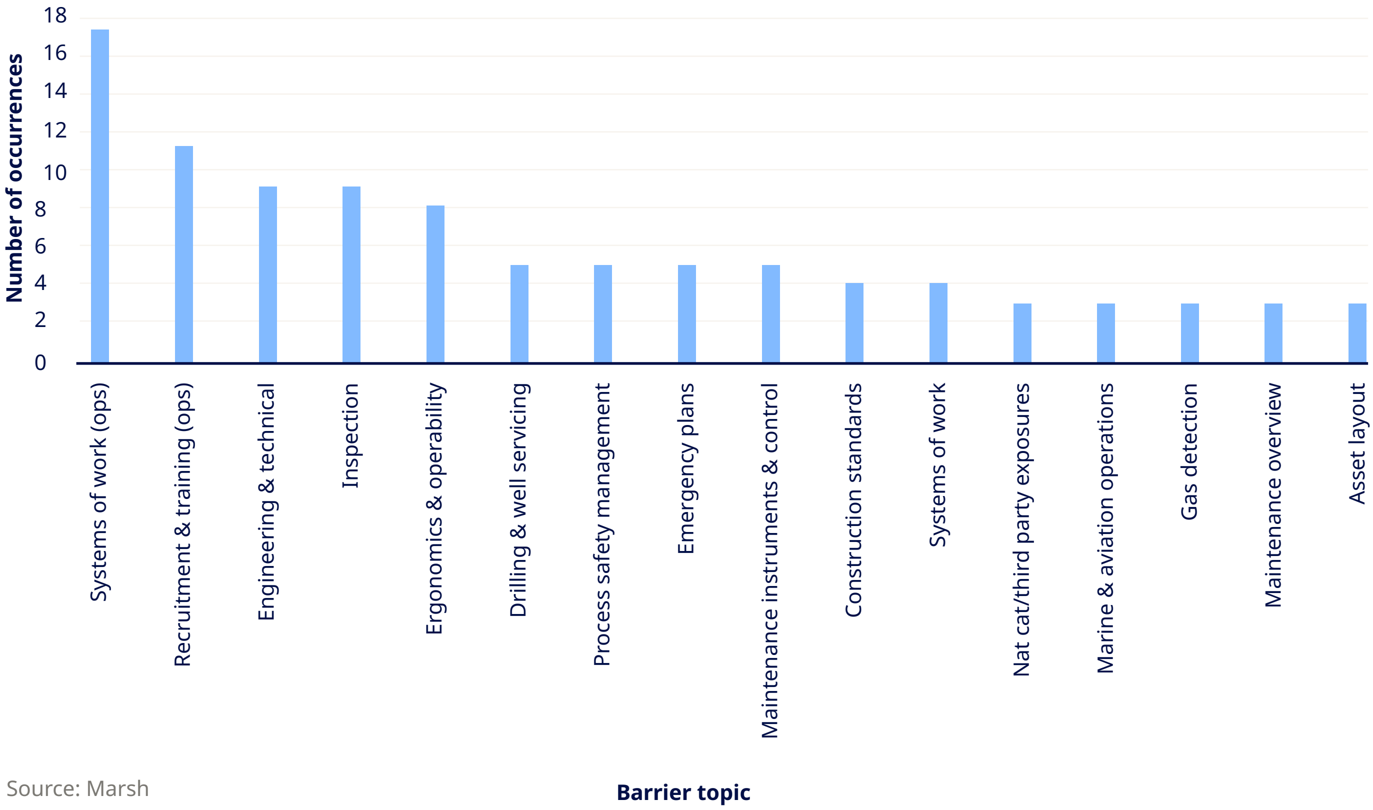
- Process safety management
- Corrosion management
- **HAZOP** and other **PHA** techniques
- Management of change
- Inspection philosophy

Other recurring issues include permit-to-work, control of work, critical valve management, and design standards.

The overlap between topics and themes reinforces a clear message: mechanical integrity and procedural compliance remain the defining pillars of upstream risk management, but are often undermined by inconsistent inspection, documentation, and operational follow-through. This is particularly evident in aging assets and mature basins, where extended equipment lifecycles, change in production profile over lifetime, and increased contractor reliance heighten the importance of robust management of change, corrosion control, and clear accountability.

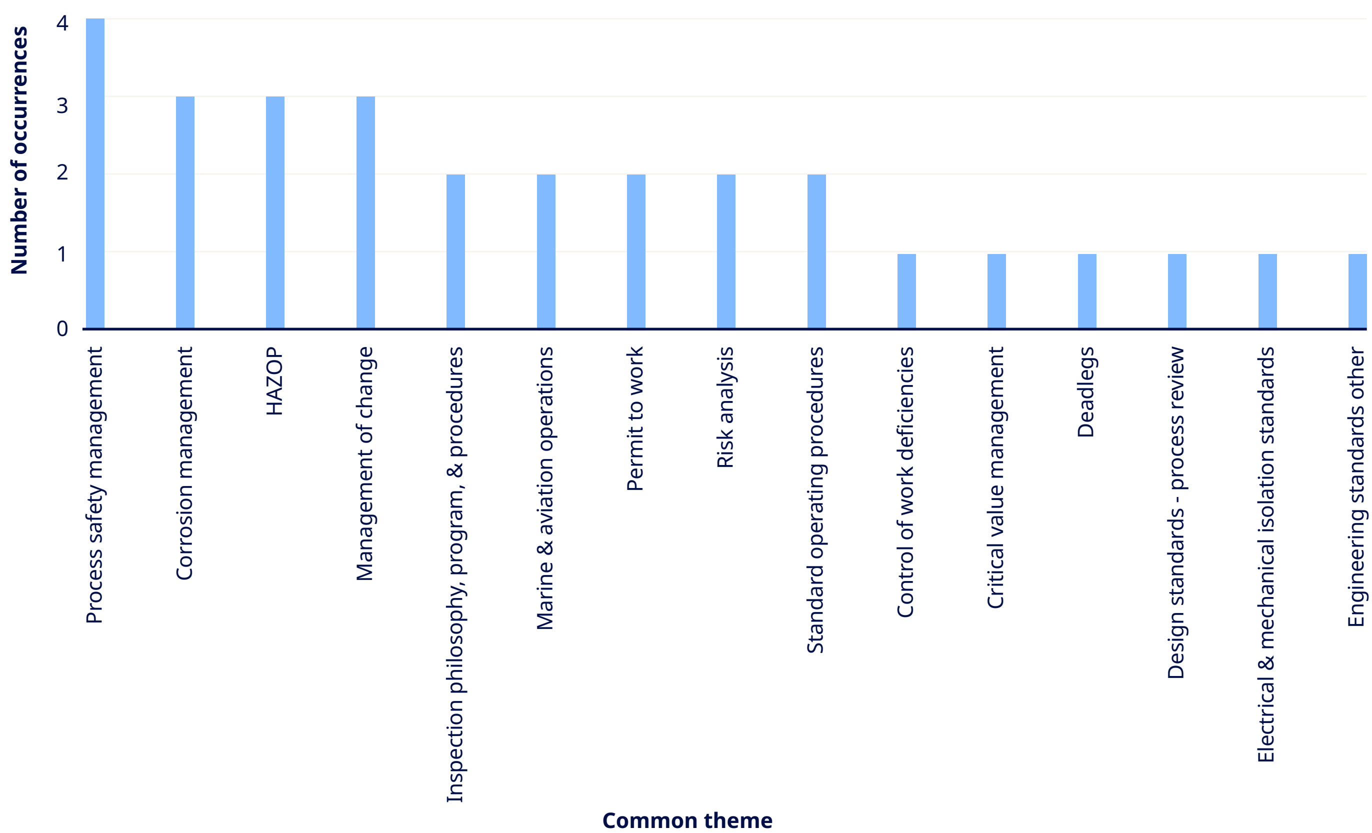
> The upstream landscape sees challenges related to asset degradation and late-life integrity, loss of primary containment, well integrity and control, external and environmental factors (such as vessel collisions and natural catastrophe (Nat Cat) weather events), and management system controls (including safety management systems and maintenance management systems). Equally critical, yet often assumed rather than assured, is the reliability of emergency control escalation. Active fire protection systems, including fire pumps and active fire protection systems, are frequently treated as a last line of defense expected to function flawlessly, despite their dependence on asset condition, utilities, human intervention, and effective maintenance. Overconfidence in these systems risks masking latent vulnerabilities that only become evident during major loss events.

Figure 18. Top 15 upstream barrier topic occurrences



Source: Marsh

Figure 19. Top 15 upstream common theme occurrences



Source: Marsh

Downstream, midstream, and upstream: A unified message

Across upstream, downstream, and midstream operations, the 100 largest losses reveal a shared root-cause profile. The profile generates a consolidated list of questions for operators' day-to-day practice, provided here as representative examples rather than an exhaustive checklist:

Inspection

- Are all potential corrosion mechanisms tracked or only those which have historically occurred? This includes external corrosion, corrosion under insulation (CUI), and touchpoint corrosion.
- Are deadlegs documented on drawings, and are they physically verified, revalidated, and inspected at frequencies aligned with their risk profiles?
- Are corrosion loops fully defined, owned, and regularly refreshed — or have they drifted out of alignment with current operations and fluid characteristics?
- Is your inspection program driven by an up-to-date understanding of corrosion mechanisms, or by fixed intervals inherited from legacy strategies?
- When pipework fails, do you systematically analyze where and why? Is the failure data used to reshape inspection priorities, or does the learning stop at repair?
- Have temporary repairs remained temporary risk controls, or have they evolved into unchallenged, long-term integrity exposures?

Systems of work

- Do permits issued reflect the risk tolerance which is set by site leadership, or have they become administrative documents that rely on individual judgment to compensate for complexity and time pressure?
- Are all changes — technical, operational, organizational, and temporary — consistently captured, assessed, and closed out through MoC, or are some changes progressing outside the system as "business as usual"?
- Are isolations designed, verified, and managed to remain effective under abnormal conditions, or do they depend on perfect execution and memory in a dynamic operating environment?
- Does shift handover reliably transfer risk-critical information — including degraded barriers, overrides, and abnormal conditions — or is vital context being lost between crews?
- When permits, MoC, isolations, and handover interact during complex or non-routine work, is their combined effectiveness tested or assumed?
- When permits, MoC, isolations, and shift handover are most challenged (during non-routine, degraded, or time-pressured operations), do they still function as independent risk controls, or do they rely on individual vigilance to prevent escalation?

Maintenance execution

- Is the maintenance philosophy explicitly risk-based and aligned with degradation mechanisms, or has it evolved into a schedule-driven exercise shaped by legacy practices and cost pressure?
- Is the ratio of preventive maintenance to corrective maintenance aligned with industry expectations?
- Do maintenance and failure data inform decision-making, or are trends, weak signals, and repeat failures recorded without a strategy?
- Is safety critical equipment such as instrument systems and fire water systems tested under conditions that reflect real demand and degraded scenarios, or only under idealized test conditions?
- Is your fabric maintenance strategy driven by risk and degradation mechanisms, or by short-term cost optimization and backlog pressure, especially in the upstream environment?
- Does maintenance execution — from philosophy to data interpretation to safety-critical testing — confirm that barriers will function under stress, or does it primarily demonstrate procedural completion under normal conditions?
- Is your fabric maintenance strategy driven by risk and degradation mechanisms, or by short-term cost optimization and backlog pressure, especially in the upstream environment?
- Does maintenance execution — from philosophy to data interpretation to safety-critical testing — confirm that barriers will function under stress, or does it primarily demonstrate procedural completion under normal conditions?

Training and competence

- Is critical operational knowledge embedded in systems and procedures, or concentrated in a small number of experienced individuals? As experienced personnel retire or rotate out, is critical operational knowledge being systematically captured and embedded in systems or lost with the departure of individuals? What happens to operational risk when experienced people retire, rotate, or are unavailable?
- Does training routinely challenge personnel with realistic “what-if” and degraded-barrier scenarios, or is competence primarily assessed against normal operating conditions?
- Are training programs designed to build judgment and hazard recognition, or primarily to demonstrate compliance?
- Can competence be demonstrated as being maintained over time, not just achieved at a single assessment point?
- At what intervals are personnel competencies formally reassessed, and are there explicit triggers — such as major incidents or process safety near misses (PSNMs) — that require a re-evaluation?

Common themes such as process safety management, corrosion control, management of change, and inspection philosophy appear repeatedly. Primary vulnerabilities, therefore, lie in mechanical integrity and human or organizational barriers rather than in design or technology gaps. The unifying challenge is the same: bridging the gap between established safety knowledge and its consistent, day-to-day application.

Data perspective: Learning from history

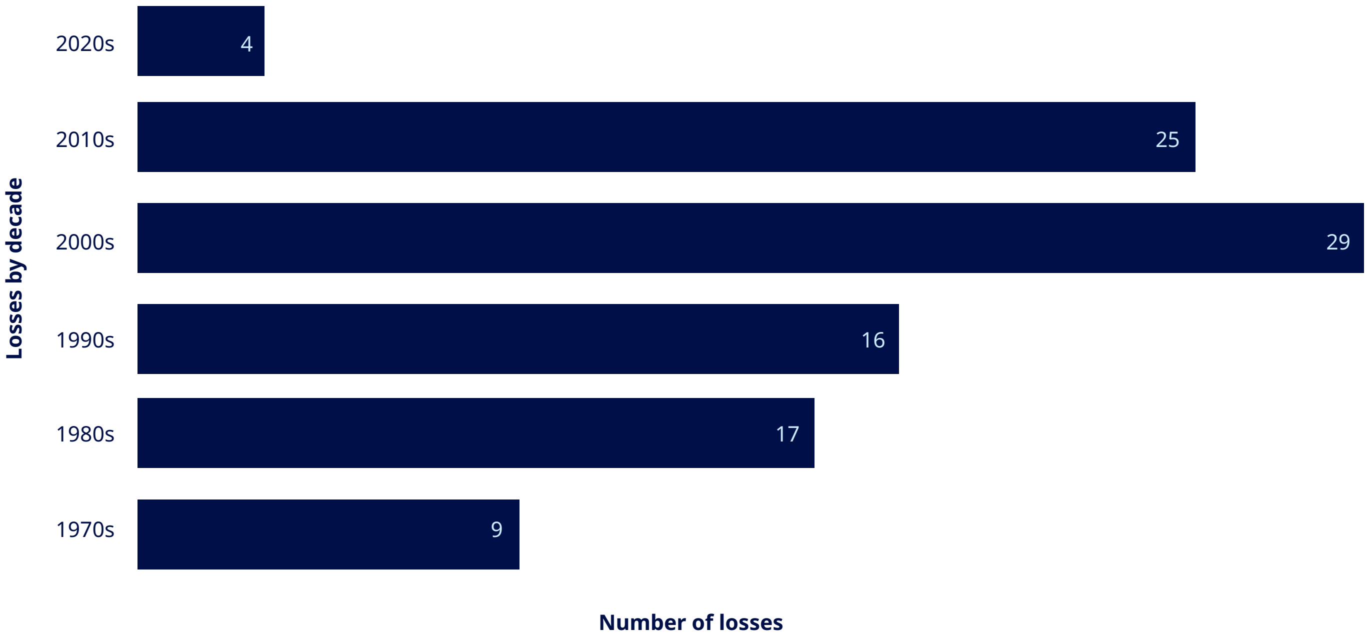
The 100 largest losses span nearly five decades, with most incidents occurring in the 2000s and 2010s, and relatively few thus far in the 2020s (Figure 20). Many events involved older facilities and legacy operations, where asset age played a significant role.

However, recent incidents over the past five years demonstrate that the same systemic weaknesses persist despite modernization and digitalization. Failures in maintenance, control of work, and training continue to feature prominently.

Barrier and theme occurrence analyses for the past five years reveal strong continuity with historical patterns (Figure 21). On the barrier side, systems of work, ergonomics and operability, inspection, recruitment, and training remain the most frequent contributors, followed by engineering standards, contractors, maintenance oversight, emergency plans, and process isolations. Common themes in Figure 22 include hazard identification, standard operating procedures, equipment and piping design, inspection philosophy, management of change, **permit-to-work.**

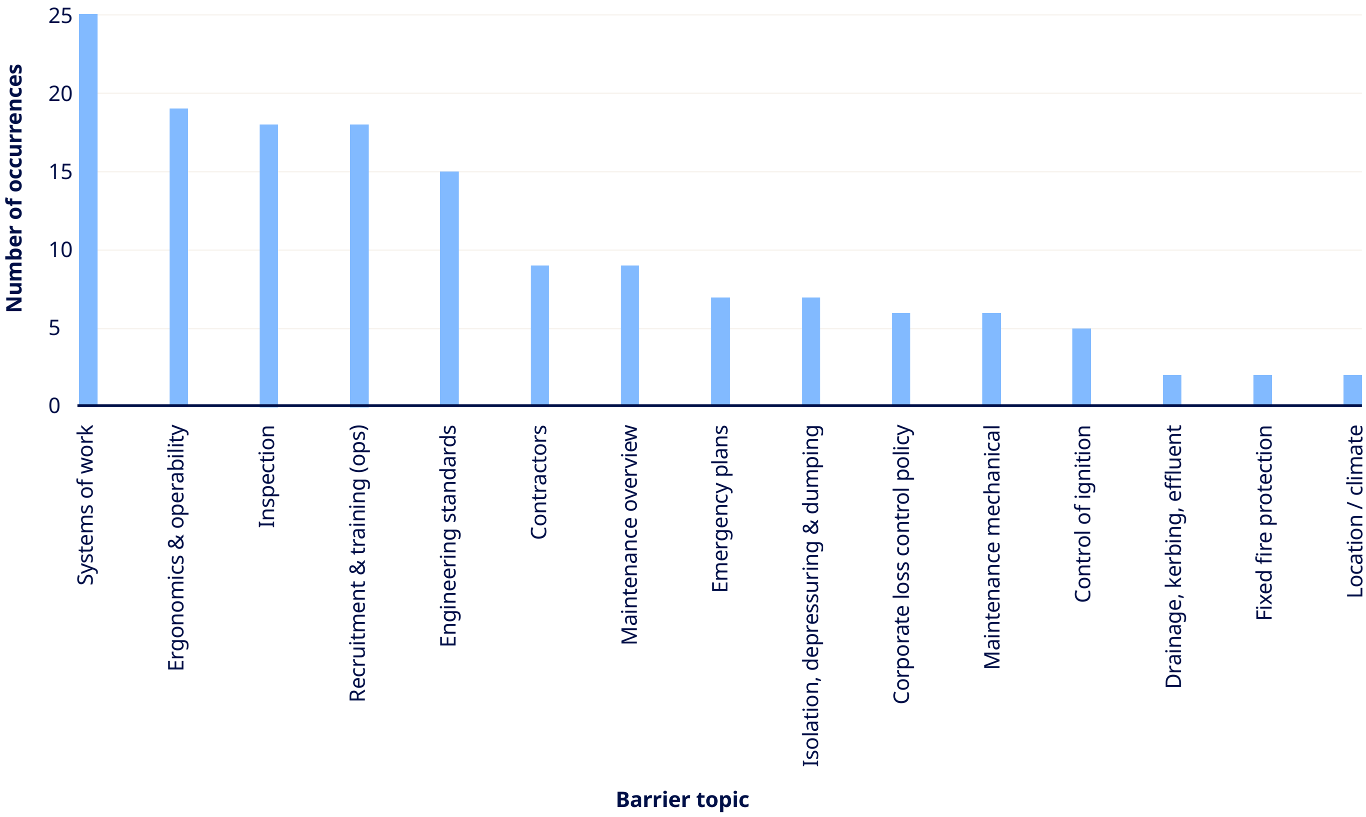
Additional focus areas, such as control of work deficiencies, human factors, and learning from previous incidents, reflect growing attention to behavioral and cultural aspects of safety. However, their occurrence indicates that improvements have not consistently translated into reduced numbers of incidents.

Figure 20. 100 largest losses in the hydrocarbon industry by decade



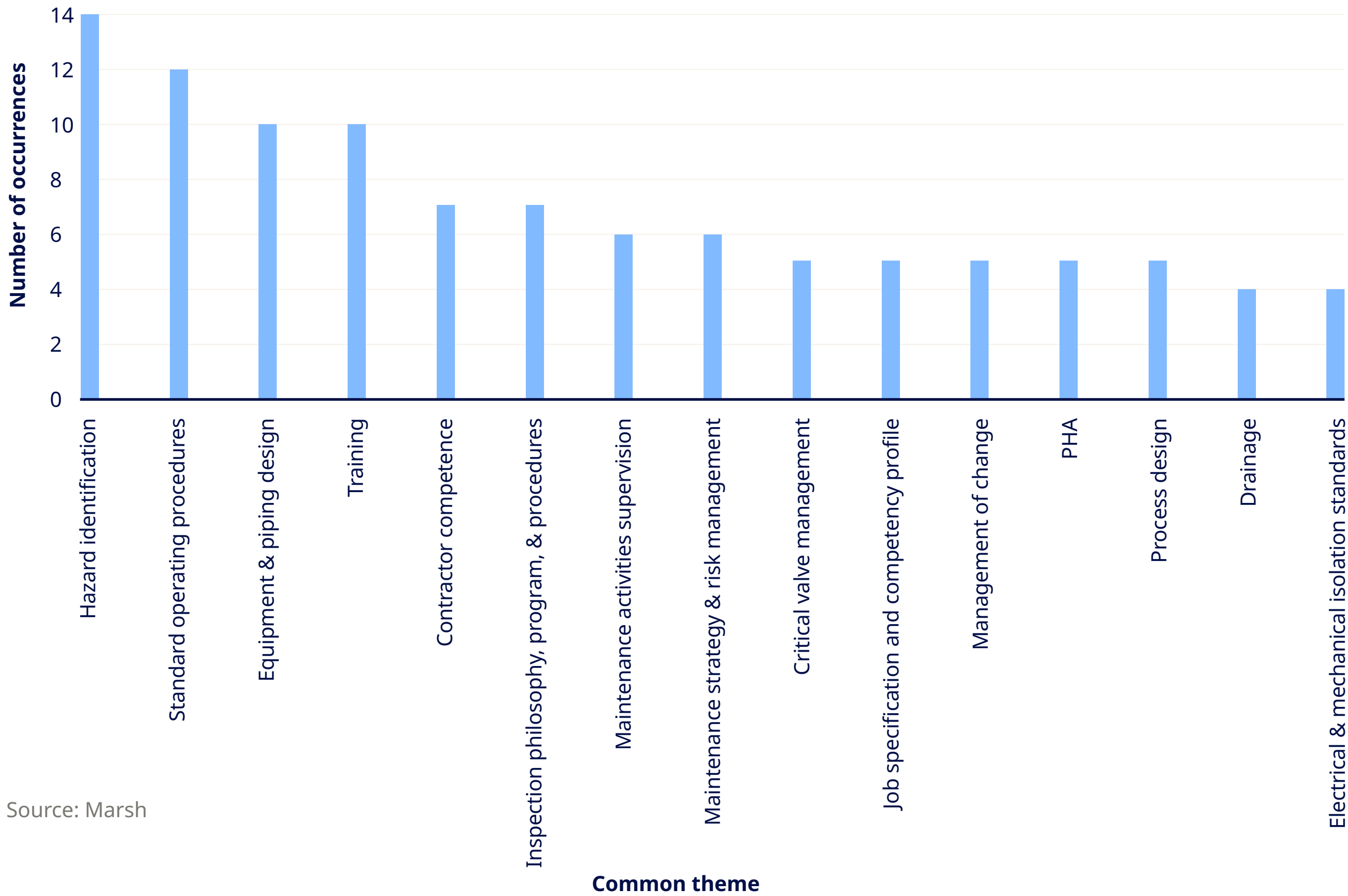
Source: Marsh

Figure 21. Top 15 hydrocarbon losses 2020-2025 barrier topic occurrences



Source: Marsh

Figure 22. Top 15 hydrocarbon losses 2020-2025 common theme occurrences

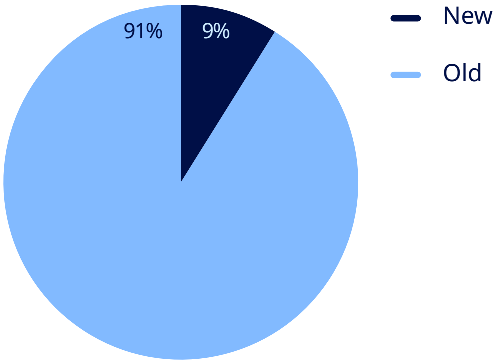


Source: Marsh

Are we learning? Old versus new causes

This review indicates that 91% of identified causes relate to long-established and well-recognized failure modes, with only 9% associated with new or emerging contributors (Figure 23). These "old" causes reflect issues documented in industry guidance, standards, and incident investigations, including well-known systemic weaknesses: inspection and maintenance management, process safety culture, and control of work. Despite recognition, these issues have not been consistently and effectively mitigated.

Figure 23. 100 largest losses old versus new causes



Source: Marsh

Loss investigations frequently identify gaps in follow-up, inadequate verification of safety-critical tasks, and a gradual normalization of deviation from routine activities. Control of work is one of the most persistent vulnerabilities, with recurring failures in permit-to-work implementation, supervision of non-routine activities, and communication between shifts and contractors common precursors to high-consequence events.

Several refinery and LNG incidents have exhibited similar patterns: noncompliance with procedures, poor alarm management, and operator fatigue. Operational excellence is therefore not only a technical objective, but a behavioral and leadership intention, grounded in accountability and verification at every organizational level.

Emerging topics — alarm reliability, critical valve management , digital permit-to-work systems — are gaining relevance, but remain overshadowed by recurring fundamental issues. The core constraints are generally execution, verification, and accountability, not knowledge.

Closing reflections

Leadership and the workforce: Turning awareness into action

Analysis of the 100 largest losses highlights a persistent and uncomfortable reality: the causes of major incidents are mostly well understood, yet they continue to recur across operators of all sizes, including large multinational organizations with mature management systems. This demonstrates that access to knowledge alone does not guarantee effective risk control. Even where strong standards and corporate engineering frameworks exist, lessons are not always embedded consistently across assets, sustained over time, or translated into field-level practice. This is particularly true within aging facilities and complex, geographically dispersed portfolios.

At the same time, industry learning remains fragmented. The most comprehensive insights into loss causation often sit within insurance and risk engineering functions, informed by cross-portfolio visibility that individual operators rarely possess. While knowledge is shared through surveys, renewals, and post-loss engagement, it is generally not systematically embedded across the wider industry. As a result, familiar failure patterns continue to re-emerge independently across companies and regions.

The persistence of management system failures across upstream, midstream, and downstream operations, therefore, reflects a structural challenge. Barriers often fail not because they are unknown, but because learning is unevenly shared, controls are inconsistently executed, and verification weakens under operational pressure. The leadership challenge is not to generate new lessons, but to see that existing knowledge — wherever it resides — is actively shared, translated into practice, and reinforced through sustained accountability.

Industry leadership

For leaders, the challenge is often not whether policies, standards, and processes exist — most organizations can demonstrate that they do. The real test is whether these controls are alive: continuously informed by experience, shaped by learning from losses, and reinforced in daily decision-making. In practice, this means that leadership — particularly operations leadership — should consider:

Operations leadership

- Actively reinforcing the fundamentals — control of work, process isolations, inspection, and management of change — not assuming they will hold without continual leadership attention.
- Promoting consistent applications of controls across every site, shift, and operating condition, and not varying standards depending on people, timing, or pressures.
- Visibly defending barrier integrity, and not letting short-term trade-offs become normalized, especially when controls are inconvenient or competing priorities emerge.
- Establishing verification systems that regularly check, test, and challenge critical activities, confirming that work is executed as intended, not just documented as complete.

Site leadership

- Deliberately investing in capability, through training, mentoring, and on-the-job experience, to build operational awareness and sound judgment, particularly as experienced personnel retire or rotate out.
- Embedding chronic unease in the organization's safety culture, enabling leaders and teams to question success, identify weak signals, and act before incidents occur.
- Being deeply thoughtful about the use of administrative rather than engineering controls for the highest risk situations

The most resilient organizations are those that routinely and honestly challenge themselves with a simple question: Would our barriers perform today — on this shift, with this crew, under degraded or abnormal conditions — and how do we know?

Workforce

For the workforce, the message is equally clear: the fundamentals still prevent major losses and save lives. Permits, isolations, inspections, maintenance quality, and effective communication are not administrative requirements — they are engineered defenses, shaped by hard-learned lessons from past incidents.

A strong safety culture is built on a chronic sense of unease; a willingness to pause, question, and challenge whether controls remain effective in real operating conditions. This means routinely asking "what if?" questions in day-to-day work, such as:

- Is this job safe or simply authorized?
- What if a key assumption in this permit, isolation, or plan is wrong?
- When I'm uncertain whether a given situation will exceed my site's risk tolerance, am I escalating that upwards or absorbing it to keep work moving?
- Am I relying on familiarity or actively reassessing the hazard today?
- What risk decision is embedded in this handover, temporary repair, deferral, or test result?
- If this control failed now, would the consequence be contained, or would it escalate?

Every task, every shift, and every decision subtly shapes the organization's risk profile. Major losses rarely stem from a single dramatic failure; they emerge from a series of small compromises, unanswered questions, and accepted uncertainties left unchallenged over time. A chronic sense of unease is not pessimism; it is professional vigilance, and it remains one of the most effective barriers against major incidents.

The enduring lesson

The 100 largest losses highlight a consistent and enduring message: sustained safety performance largely depends on consistency, not novelty. New technologies, digital tools, and advanced analytics can support risk management, but they cannot replace effective implementation, maintained capability, and regular verification that critical controls continue to perform as intended.

The industry's challenge is usually therefore not the identification of new lessons, but the consistent application of established good practice. This applies across asset portfolios, over extended operating life, and as organizations and workforces change. Major losses rarely result from unknown risks; more often, they develop when known weaknesses persist, early indicators are not acted upon in a timely manner, or corrective actions are deferred in the presence of competing priorities.

> In this context, future major losses are more likely to arise from gaps between what is recognized and what is consistently implemented, rather than from a lack of information or technical guidance.

Glossary

100 largest losses
Marsh's long-running report that tracks the largest property damage losses in the hydrocarbon industry.

Hydrocarbon industry
Industry involved in the exploration, production, processing, storage, and distribution of oil, gas, and related products.

Root cause analysis (RCA)
A structured method used to identify the underlying causes of an incident, beyond the initial failure.

Barrier/barriers
Any measure designed to prevent an incident from occurring or to limit its escalation and consequences.

Immediate cause
The first observable event or condition that directly triggers an incident.

Mechanical integrity failures
Failures where equipment no longer performs its intended function due to degradation, damage, or defect.

Non-mechanical integrity failures
Failures caused by operating outside safe limits or procedures rather than by inherent equipment defects.

Natural catastrophes (Nat Cat)
Severe natural events such as earthquakes, hurricanes, floods, or storms that can cause major damage.

Reservoir unintended flow
Uncontrolled movement of formation fluids outside intended flow paths due to loss of containment or barrier failure.

Loss of well control
Formation fluids flow into the wellbore and cannot be controlled by standard well control methods, potentially requiring intervention.

Upstream
The sector of the hydrocarbon industry focused on exploration, drilling, and production activities involving wells and facilities where hydrocarbons are extracted.

Midstream
The sector of the hydrocarbon industry focused on the transportation and storage of hydrocarbons between production and processing or refining.

Downstream
The sector of the hydrocarbon industry focused on refining, petrochemicals, gas processing, product storage, distribution and marketing.

Hardware
The category that describes the relevant physical aspects of the risk.

Management systems
The category that describes the relevant management and procedural aspects of the risk. (e.g., procedures, training, maintenance systems).

Emergency controls
The category that describes the fire, explosion, or other emergency mitigating or aggravating features of the risk. (e.g., firefighting, evacuation, emergency plans).

Systems of work
The structured framework for planning, authorizing, executing, and monitoring work, including procedures, supervision, competence, and formal controls (e.g., permit-to-work, isolations, and management of change), so activities are carried out safely and risks remain controlled.

Inspection
Activities to examine equipment or systems to verify their condition and continued fitness for service.

Maintenance
Planned or reactive work to preserve or restore equipment performance and integrity.

Risk ranking
A structured method of assessing and scoring risk based on the quality of barriers and potential consequences.

Occurrence
The frequency with which a particular type of failure, cause, or barrier issue appears.

Barrier type
A high-level category of barriers, typically including hardware, management systems, or emergency controls.

Barrier topic
Specific subject within a barrier type (e.g., inspection, training, site layout, emergency plans).

Common theme
Grouped, recurring issues or focus areas identified across multiple incidents, reflecting shared weaknesses in systems, processes, or behaviors. These themes often highlight industry-wide risk drivers or emerging hot topics, including those influenced by new or evolving regulations, standards, technologies, or operating practices (e.g., corrosion management and alarm management).

Process safety management (PSM)
A structured framework for managing hazards that could cause major releases, fires, or explosions, combining engineering, procedures, and management controls to prevent catastrophic process incidents.

Permit to work
Formal authorization process that controls higher-risk work, ensuring hazards are identified, and controls are in place.

Control of work
The system for planning, authorizing, coordinating, and controlling hazardous or non-routine work, including permits, isolations, communication, and supervision, to keep risk controlled throughout the task.

Management of change (MoC)
Formal process for assessing and controlling risks when changes are made to equipment, procedures, organization, or conditions.

Corrosion management
Planned approach to monitor, prevent, and mitigate corrosion throughout the lifecycle of assets.

Inspection philosophy
Overall strategy and principles guiding how inspections are prioritized, planned, and executed.

Ergonomics and operability
Design and layout of equipment and interfaces to support safe, efficient, and error-resistant human operation.

Control of ignition
Measures to prevent or manage ignition sources that could ignite flammable materials.

Firewater systems
Piping, pumps, and hydrants that are used to deliver water for firefighting.

Fixed fire protection
Installed fire protection systems such as sprinklers, deluge, foam, or gas suppression.

Asset layout
Physical arrangement of equipment, units, and buildings on a site.

HAZOP
A hazard and operability study is a structured technique for identifying process hazards and operability issues by systematically examining deviations from design intent using guidewords, and assessing their causes, consequences, and safeguards.

Process hazard analysis (PHA)
Formal method for identifying and assessing process hazards and safeguards.

Process isolation (PI)
The measures used to physically and procedurally separate equipment from hazardous energy or materials, promoting safe conditions for work through defined isolation standards, verification, and control under permit-to-work systems.

Operational discipline
Consistent, rigorous adherence to procedures and good practice in day-to-day operations.

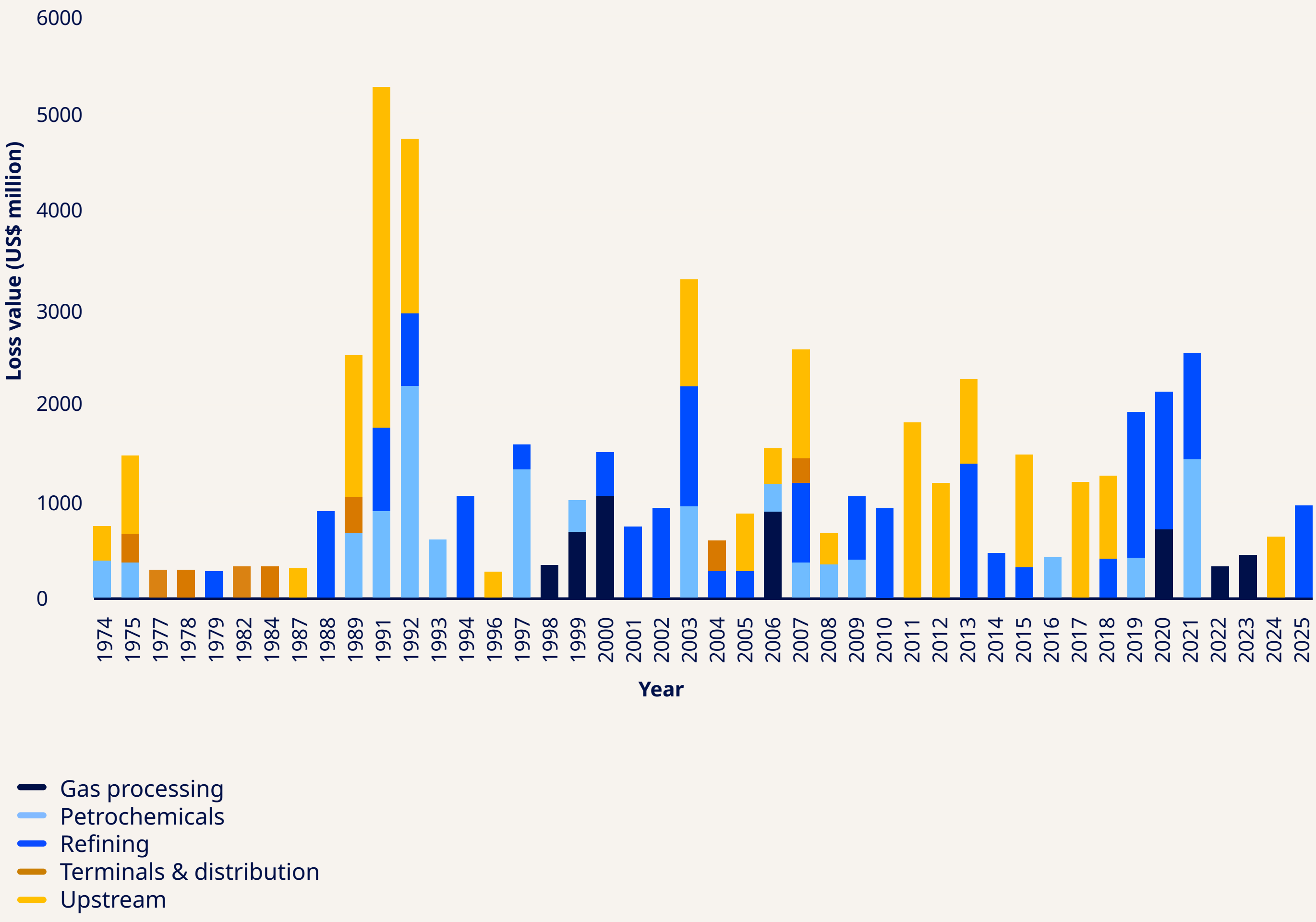
Alarm management
The design, rationalization, operation, monitoring, and maintenance of alarms so operators receive clear, prioritized, actionable warnings that help keep the plant within a safe operating envelope.

Critical valve management
The assurance process for safety-critical valves to ensure correct specification, position control, testing, leak tightness, maintenance, and performance so they will operate when needed to prevent or mitigate a major accident.

Risk improvement recommendations
Actions suggested by risk engineers or auditors to reduce risk by improving barriers or controls.

100 largest losses graphical data

Figure 24. 100 largest losses by year and sector



Source: Marsh

Details of the 100 largest losses

Figure 25. Value of incidents by sector (US$ million)

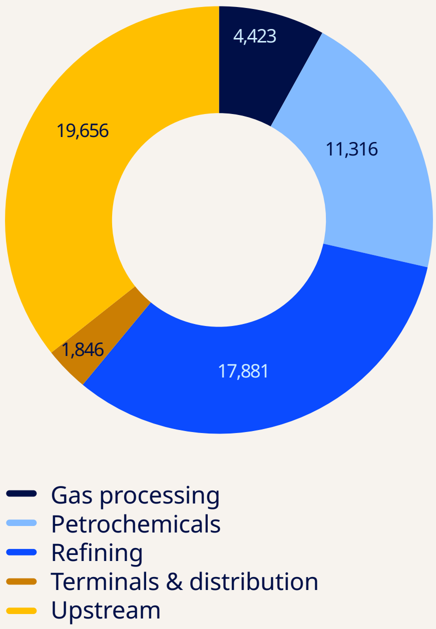


Figure 26. Number of incidents by sector

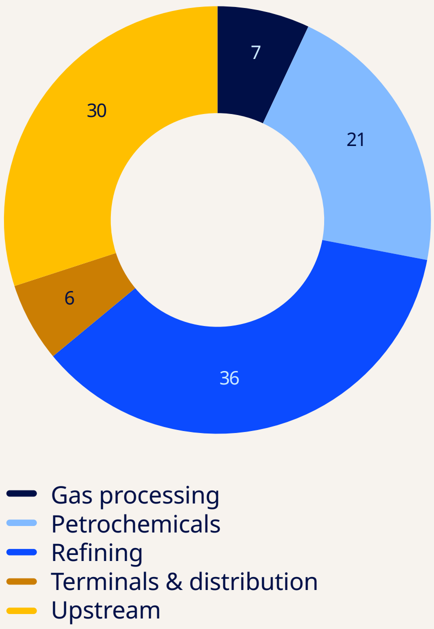


Figure 27. Distribution of value by region (US$ million)

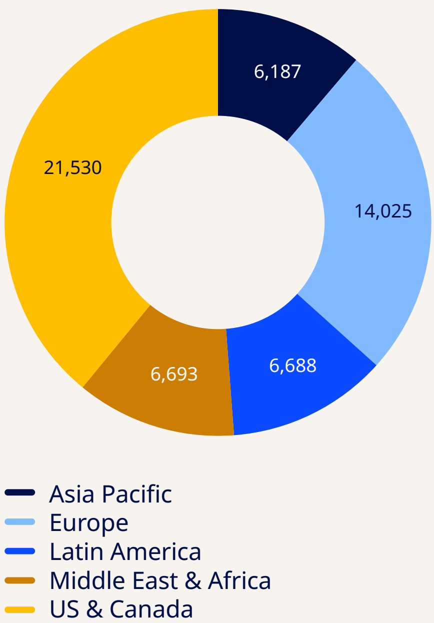


Figure 28. Distribution of value by region (number)

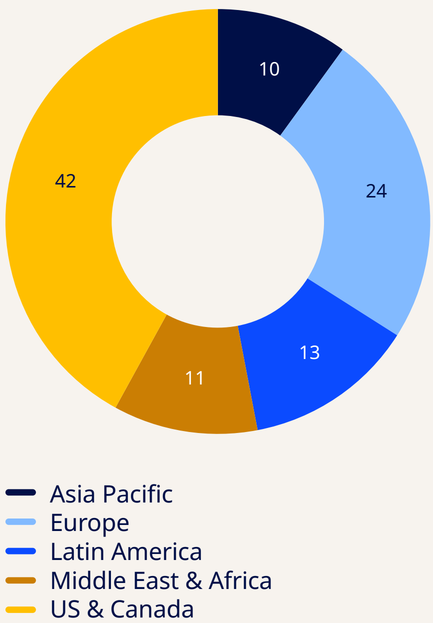
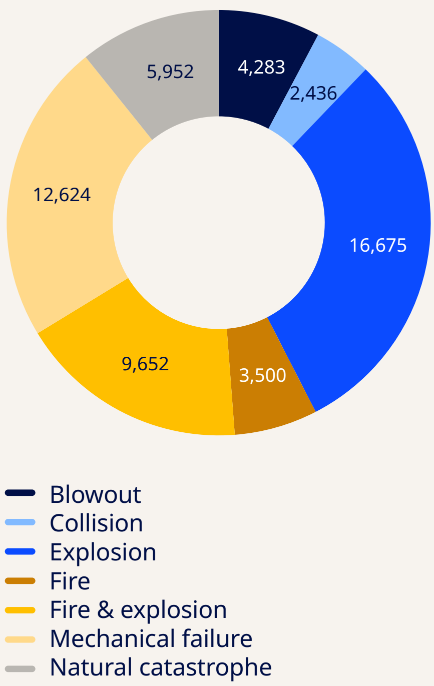
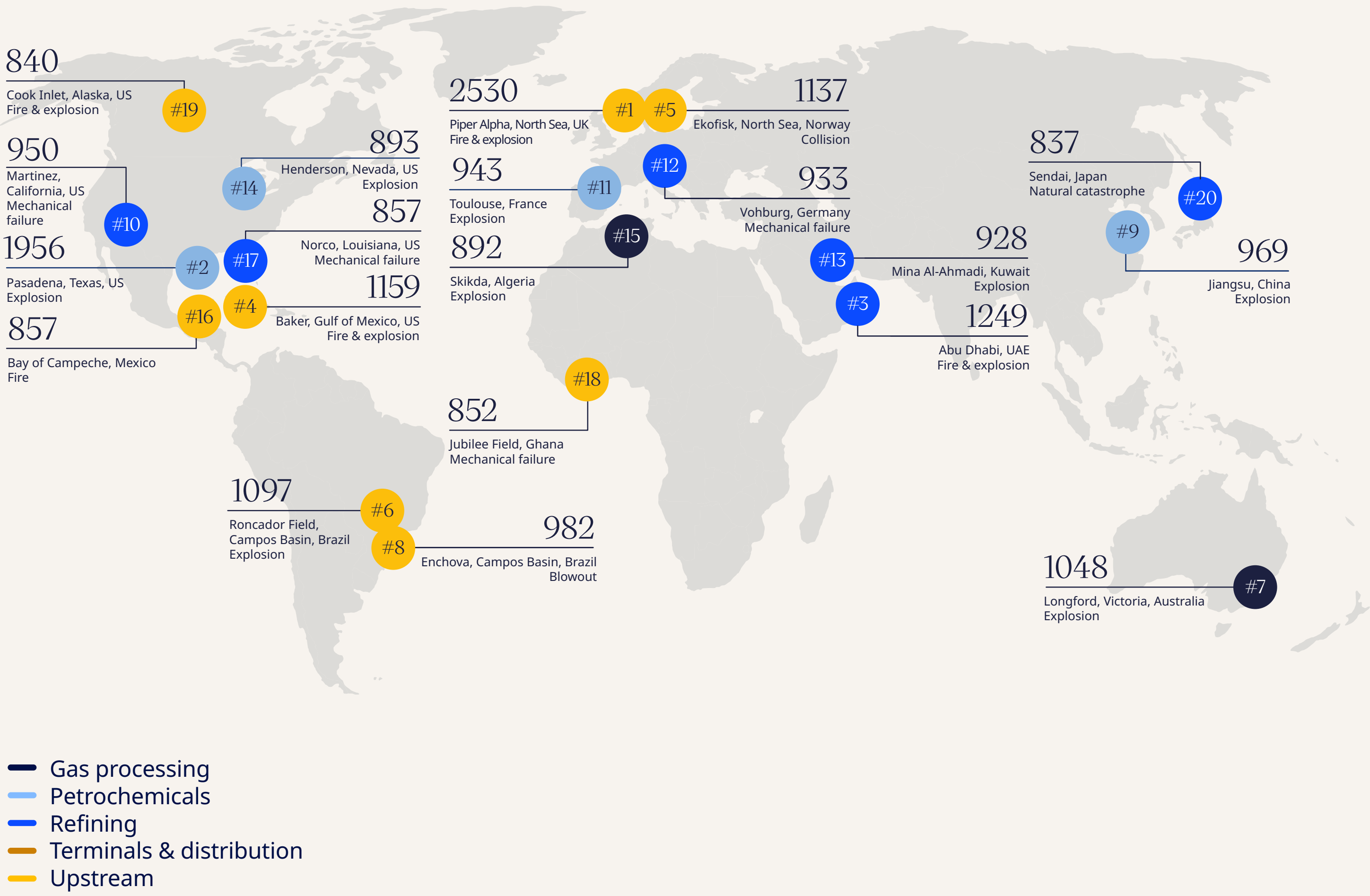


Figure 29. Distribution of value by event type (US$ million)



Details of the 100 largest losses

Figure 30. 20 largest losses

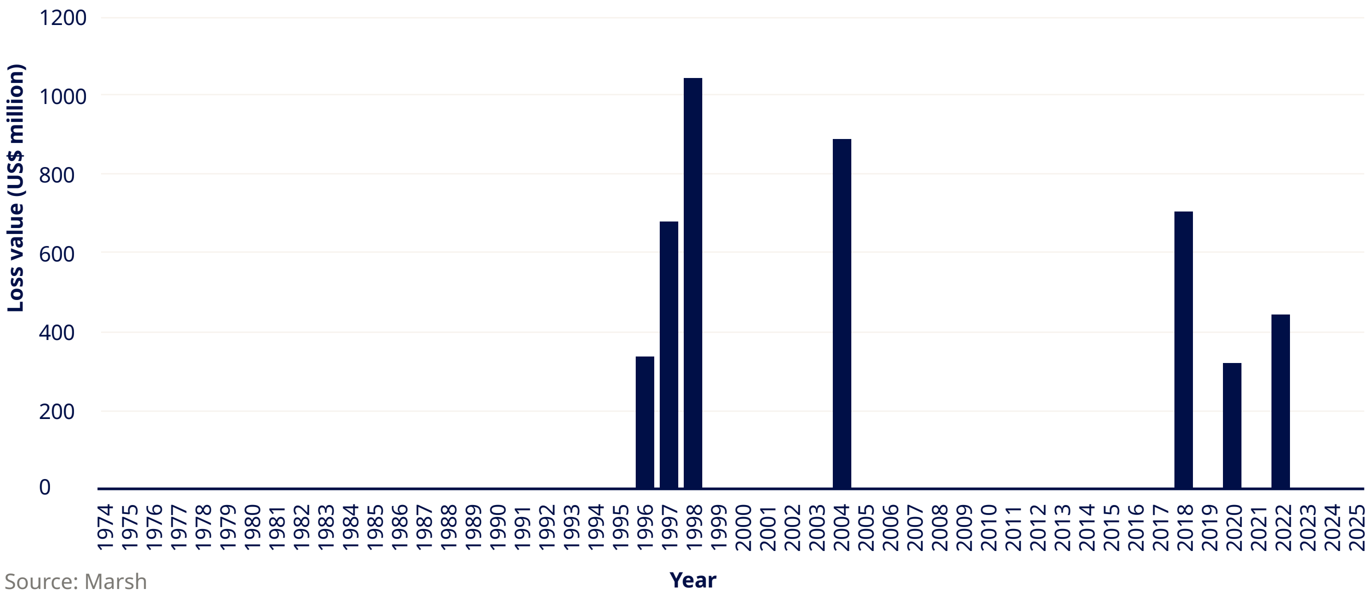


100 largest losses by sector *Gas processing*

In the past two years, no gas processing losses have qualified for inclusion in this report. Although each of the last three editions recorded one new gas processing loss, this edition marks a departure with no qualifying incidents reported. Historically, seven property damage losses related to gas processing rank among the 100 largest losses, underscoring the ongoing significance and risk within this sector.

Gas processing facilities are inherently complex, involving high-pressure separations, corrosive and high-temperature operations, sophisticated heat integration, and layered automation systems. This complexity increases the likelihood of equipment failures, control system issues, and cascading impacts across mechanical, electrical, and process control areas. The high value of assets and the hazardous nature of the materials handled further elevate the risk profile. Consequently, even minor deficiencies in design, maintenance, or operational oversight can result in significant incidents. This highlights the essential need for comprehensive risk management, effective safety barriers, and continuous monitoring to safeguard personnel and infrastructure in gas processing operations.

Figure 31. Gas processing losses



Source: Marsh

Gas processing		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#7 **Explosion**	**Longford, Victoria, Australia** 25 September, 1998 Gas supplies to Victoria State in Australia were disrupted due to an explosion and fire at a gas processing plant. This incident's cause was traced back to a heat exchanger rupture, triggered by the abrupt shutdown of hot oil pumps, leading to a process upset. The cessation of hot oil supply caused chilling in certain vessels due to cold oil exposure. Upon re-introducing hot oil to the heat exchanger, it ruptured from a brittle fracture. An initial release of approximately 22,000 pounds of hydrocarbon vapor resulted in an explosion, with an estimated 26,000 pounds burning as a jet fire that lasted for about two and a half days. This incident underscored a combination of factors, including ineffective management procedures, staffing oversights, communication problems, inadequate hazard assessment, and training shortfalls, which contributed to a significant plant disruption and the loss of lives.	443	**1,048**
#15 **Explosion**	**Skikda, Algeria** 19 January, 2004 An explosion at an LNG plant resulted in 27 fatalities, 72 injuries, and seven individuals reported as missing. The explosion led to the destruction of three out of six liquefaction trains, damage to a nearby power plant, and the shutdown of a 335,000 bbl/d refinery. Some neighboring industrial facilities were also affected. Initially attributed to a faulty boiler, investigations revealed a large hydrocarbon release from a cold-box exchanger that ignited upon entering the boiler. LNG Complex Trains 6, 5, and 10 were restarted in May and September 2004. However, Trains 20, 30, and 40 were destroyed in the incident, representing 50% of the LNG complex's capacity.	470	**892**

Gas processing		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#24 **Natural catastrophe**	**Komo, Papua New Guinea** 26 February, 2018 A magnitude 7.5 earthquake struck with multiple aftershocks over the following weeks. The event caused significant building and infrastructure damage, and over 100 people from the local communities were killed. The damage affected the local airport at Komo, a gas conditioning plant — which was safely shut down with some damage but no loss of containment — and the associated pipeline system, where there was no loss of containment but a need to remediate the pipeline "right of way" along most of its onshore length. (Note: The value quoted here is believed to be the reserve across all elements of the loss, including the gas plant and the associated pipeline.	583	**706**
#25 **Fire and explosion**	**Bintulu, Sarawak, Malaysia** 25 December, 1997 An explosion and subsequent fire transpired at a gas-to-liquids (GTL) plant, with the fire eventually coming under control the following day. This plant was one of only two commercially viable GTL facilities globally, capable of producing 12,500 bbl/d of middle distillates and waxes from natural gas feedstocks. The explosion took place in the air separation unit (ASU), which provided oxygen for the synthesis gas feedstock production. Investigations pinpointed an initial combustion event in the ASU as the most likely cause. This event is believed to have initiated the explosive burning of aluminum heat exchanger elements in the presence of liquid oxygen, resulting in their explosive rupture. The incident caused twelve injuries, none of which were serious, and the plant remained shut down for several months to facilitate repairs.	285	**681**

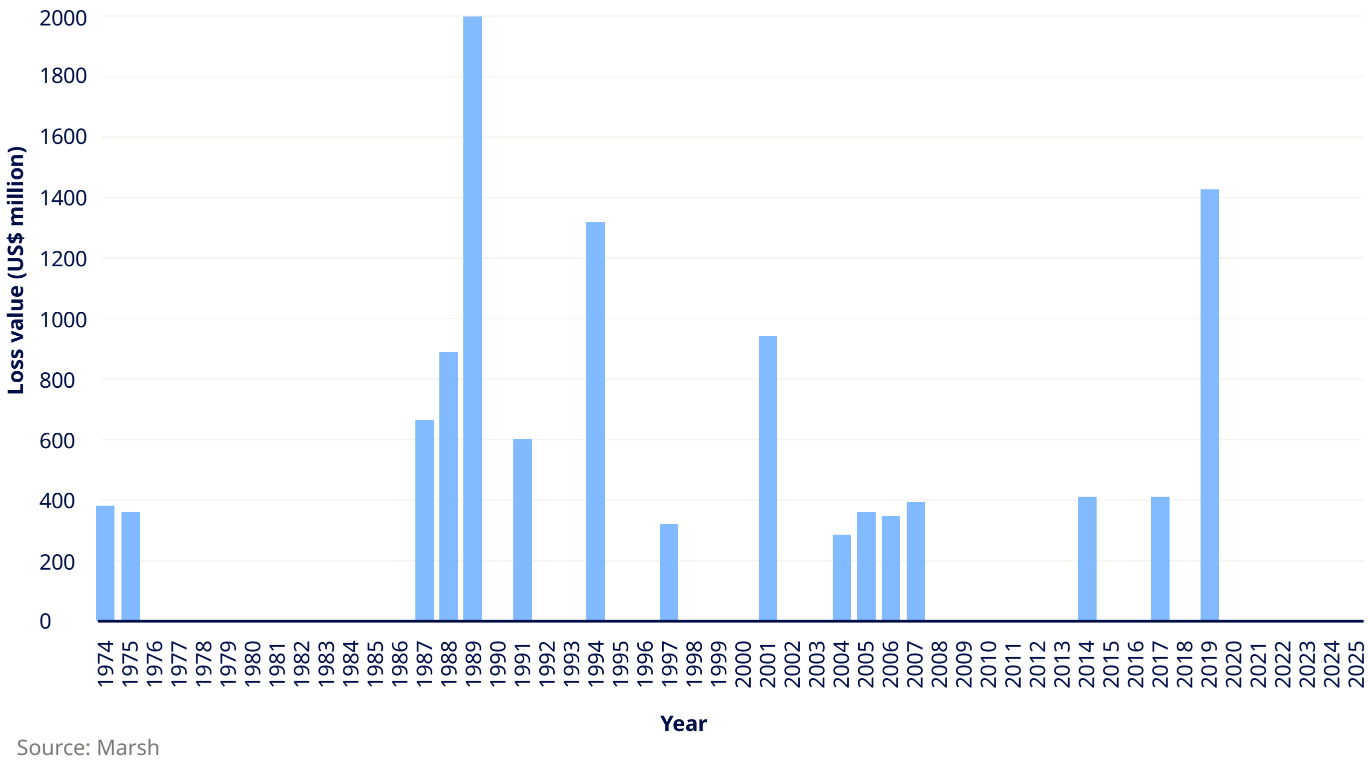
Gas processing		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#49 **Fire**	**Medford, Oklahoma, US** 9 July, 2022 A fire erupted at a Natural Gas Liquids (NGL) fractionation facility, resulting in substantial damage to the plant and a significant loss of production. Temporary evacuation of local residents was taken as a precautionary measure. The root cause of this fire at the facility is currently under investigation.	425	**442**
#69 **Explosion**	**Cactus, Reforma, Chiapas, Mexico** 26 July, 1996 A sequence of explosions rocked a gas processing complex, stemming from a vapor cloud explosion in Cryogenic Unit No.2, followed by two more blasts in Cryogenic Unit No.1. The latter suffered significant damage, including the destruction of control rooms and extensive harm to LPG product pumps. The incident originated during maintenance work on one of the pumps in Cryogenic Unit No.1, where a seal leak was addressed. However, an ensuing LPG product leak led to a vapor cloud that ignited and triggered the initial explosion, ultimately resulting in extensive damage and disrupting a substantial portion of Mexico's gas processing capacity. Firefighters managed to quell the fires after around three hours.	137	**335**
#79 **Fire**	**Hammerfest, Norway** 28 September, 2020 During a scheduled restart at the facility, a fire transpired within the filter housing of gas turbine generator 4. An investigation determined that the primary cause was "autoignition in the filters in the turbine's air inlets," resulting from the use of the anti-icing heat exchanger in the air inlet beyond its intended scope, leading to elevated temperatures and igniting the fire. No injuries were reported, and the facility has since recommenced operations.	300	**318**

100 largest losses by sector *Petrochemicals*

There have been no new petrochemical incidents added to the dataset in the last two years. However, there have been several notable petrochemical losses that remain under review, highlighting that despite not appearing in the top 100, the sector remains vulnerable to ongoing risks and challenges.

Petrochemical losses can be exceptionally large due to several factors. The concentration of high-value equipment and machinery within these facilities, and the large volumes of highly flammable or hazardous materials, means that any damage or failure can result in significant property damage losses. Additionally, the interconnectedness of petrochemical supply chains means that disruptions in one facility can create a ripple effect throughout the industry, impacting production, distribution, and pricing on a global scale.

Figure 32. Petrochemicals losses



Source: Marsh

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#2 **Explosion**	**Pasadena, Texas, US** 23 October, 1989 An inadvertent release of ethylene and isobutane transpired from a high-density polyethylene (HDPE) unit within a chemical complex. Approximately 60 seconds later, the released gases ignited, generating an explosion of considerable force. The explosion led to the destruction of two HDPE units, which encompassed eight particle-form, loop reactor trains. Additionally, it caused boiling liquid expanding vapor explosions in nearby pressurized storage tanks. While other process units at the chemical complex suffered minimal damage and resumed standard operations within a few weeks. The initial gas release occurred through an eight-inch diameter ball valve on a settling leg of one loop reactor, following lapses in maintenance procedures.	675	**1,956**
#9 **Explosion**	**Chenjiagang Chemical Industry Park, Jiangsu, China** 21 March, 2019 An extensive explosion took place at a chemical plant situated in an industrial park, with a focus on fertilizer and pesticide production. The blast inflicted significant damage to surrounding factories and offices. Windows up to 6km away were shattered, and another chemical factory's roof, located approximately 3km from the explosion, collapsed. The explosion registered as a 2.2 magnitude seismic shock, necessitating the deployment of over 900 firefighters to control ensuing fires. The incident's direct cause, according to the Chinese Ministry of Emergency Management, was the long-term illicit storage of nitrated waste in the on-site solid waste warehouse. It is understood that nearly 80 people were killed and over 600 people injured as a result of the incident.	800	**969**

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#11 **Explosion**	**Toulouse, France** 21 September, 2001 An explosion occurred at a fertilizer plant located just outside Toulouse, France. This facility stored around 300 tons of off-specification ammonium nitrate crystals. The explosion's force was significant, registering as a 3.4 magnitude earthquake on the Richter Scale, causing extensive damage not only to the plant but also to surrounding areas. This event resulted in the loss of 30 lives and left approximately 3,000 individuals with various degrees of injuries. The incident highlighted the importance of proper handling and storage procedures for hazardous materials to prevent such disasters.	430	**943**
#14 **Explosion**	**Henderson, Nevada, US** 4 May, 1988 An explosion occurred at a plant producing ammonium perchlorate (AP) for rocket fuel. This incident resulted in the flattening of the local industrial park, creating a crater 125 meters wide and damaging walls up to 15 miles away. Two fatalities were reported. The cause is believed to be a fire in a batch dryer. The initial explosion had a force equivalent to 108 tons of TNT, with a subsequent explosion four minutes later equivalent to 235 tons of TNT. Roughly half the buildings in the nearby town of Henderson were destroyed. Additionally, the explosion ruptured a natural gas pipeline under the plant, which burned for a week.	300	**893**

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#27 Explosion	**Pampa, Texas, US** 14 November, 1987 An explosion transpired within an air line connected to a reactor during the startup procedure. This reactor was designated for the liquid-phase oxidation of butane. The explosion had repercussions as it ruptured the external section of the air line, allowing the reactor's contents to vaporize and form a hazardous cloud. Approximately 25 to 30 seconds following the initial release, the vapor cloud ignited. This explosion resulted in substantial property damage within the immediate vicinity and had a considerable impact on the entire site, with reports of broken windows up to seven miles away. The primary factor believed to contribute to this incident was inadequate purging of the reactor during a prior shutdown	215	**665**
#38 Explosion	**Port Neal, Iowa, US** 13 December, 1994 An explosion in the ammonium nitrate process area led to the total destruction of the seven-story main process building and the creation of a 30-foot diameter crater. During the explosion, metal fragments punctured one of the plant's two 15,000-ton refrigerated ammonia storage tanks, releasing approximately 5,700 tons of ammonia. This event necessitated the evacuation of around 2,500 people in the vicinity. Additionally, metal fragments struck a nitric acid tank, causing the release of approximately 100 tons of nitric acid. The force of the explosion also ripped metal siding from nearby buildings, damaged three third-party electric generating stations, shattered windows in buildings located 16 miles away in Sioux City, and had a noticeable impact over 30 miles away.	203	**521**

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#42 **Explosion**	**Belpre, Ohio, US** 27 May,1994	182	**467**

An abnormal chemical reaction unfolded during the batch production of a thermoplastic rubber product, resulting in a violent explosion. This event led to the complete destruction of the reactor, process controls, associated equipment, control room, and the facility dedicated to this production unit.

The ensuing fire subsequently extended to affect a section of the tank farm, causing extensive damage to five atmospheric storage tanks. The crisis escalated as the first of four 1,000,000-US-gallon and one 500,000-US-gallon styrene storage tanks erupted around midday. In response, firefighting teams employed a combination of cooling water and foam hose streams to prevent the fire from spreading to other nearby storage tanks, notably two containing highly flammable butadiene. The fire was ultimately brought under control after approximately nine hours.

#46 **Explosion**	**Port Neches, Texas, US** 27 November, 2019	380	**460**

Approximately 6,000 gallons (about 30,000 pounds) of liquid butadiene were released after a pipe rupture in the final fractionation section of the 1,3-butadiene production unit. This release subsequently vaporized and ignited, leading to multiple fires and explosions at the facility, causing three injuries. The U.S. Chemical Safety and Hazard Investigation Board (CSB) determined that the inadequate management of “popcorn polymer” in a “dead leg” of piping caused the incident. Popcorn polymer, a sticky substance, accumulated within the dead leg, ultimately building enough pressure to rupture the piping and release flammable butadiene that quickly ignited. The investigation revealed failure to properly manage this hazard, resulting in safety recommendations and regulatory changes.

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#51 Fire and explosion	**Pori, Finland** 30 January, 2017 A fire broke out at a titanium dioxide manufacturing facility, leading to substantial damage to the plant and a halt in pigment production. The incident is believed to have originated in the electrostatic precipitator and rapidly spread to the pipe network and manufacturing halls.	325	**413**
#52 Explosion	**North Brabant, Netherlands** 3 June, 2014 An explosion occurred at the Styrene Monomer Production complex (MSPO-2) during the start-up phase after routine maintenance. The initial explosion happened in reactor MSPO-2, throwing shrapnel widely and leading to a more powerful explosion in reactor MSPO-1 during a shift changeover. Subsequently, a fire broke out. The flash vessels experienced ductile overloads due to excessive internal pressure generated by an uncontrolled catalytic reaction.	302	**412**
#54 Explosion	**Niigata, Japan** 20 March, 2007 An accident occurred at a methylcellulose manufacturing facility, involving an initial explosion and subsequent fire that was successfully extinguished after approximately seven hours. Tragically, seventeen individuals working on-site sustained injuries - three classified as critical, five as serious, and nine with minor injuries. Additionally, one off-site minor injury was reported. This incident was likely ignited by static electricity, culminating in a powder dust explosion. As a result, all methylcellulose operations were halted for a two-month period before gradually resuming.	240	**395**

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#55 **Explosion**	**Flixborough, UK** 1 June, 1974 A large vapor cloud explosion caused extensive damage to a chemical facility. This incident resulted in the loss of 28 workers' lives and left 36 others with injuries. The outcome could have been even more devastating if the event had occurred on a regular workday, as the main office block remained unoccupied due to it being the weekend. Offsite, 53 individuals reported injuries, and properties in the vicinity experienced varying degrees of damage. Before the incident, a reactor had been removed, and a bypass assembly was installed to maintain production. On June 1, this 20-inch bypass system ruptured, possibly triggered by a nearby fire on an eight-inch pipe. This rupture led to the release of 30 tons of hot cyclohexane, forming a flammable cloud that found an ignition source. The control room suffered significant damage, resulting in 18 fatalities due to shattered windows and a collapsing roof. Subsequent fires continued to burn for over three days.	58	**381**
#59 **Mechanical failure**	**Antwerp, Belgium** 2 October, 1975 An explosion and fire resulted in significant damage at a low-density polyethylene plant. The incident occurred due to a high-pressure ethylene leak, caused by the fatigue failure of a vent connection on the compressor's suction side. The event led to six fatalities and 13 injuries.	60	**361**

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#60 **Explosion**	**Munchmuster, Germany** 10 December, 2005 A hexane release led to the ignition of a vapor cloud when it encountered an electric motor, resulting in an explosion. The incident caused damage to a process unit and resulted in 20 injuries. One firefighter was killed, and another was seriously injured while fighting the blaze.	200	**361**
#66 **Explosion**	**Port Arthur, Texas, US** 29 April, 2006 A shelter-in-place directive was issued when a fire broke out following an explosion in the propylene refrigeration section of an ethylene unit. The fire, which burned for three days, forced the facility's shutdown for six months but caused no deaths or serious injuries.	200	**345**
#70 **Natural catastrophe**	**Cedar Bayou, Texas, US** 20 October, 1994 Severe Texas floods along the San Jacinto River, resulted in the shutdown of a major industrial site. The complex comprised facilities for producing 650,000 tons per year of ethylene, 200,000 tons per year of LLDPE, and 280,000 tons per year of LDPE, in addition to general utilities. These widespread floods not only impacted the site but also disrupted downstream clients who depended on these utilities. The floodwaters breached protective dikes surrounding the main substation, leading to inundation of control rooms and offices, causing extensive operational disruptions.	130	**334**

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#71 **Fire and explosion**	**Sterlington, Louisiana, US** 1 May, 1991 An incident unfolded as workers were preparing to inspect a compressor in the Nitroparaffin unit. They discovered a small fire and promptly activated the plant's fire alarm system. In approximately 30 seconds, a substantial explosion occurred, followed by a series of smaller explosions. The initial blast's impact extended as far as eight miles away and resulted in the complete destruction of an area within the plant roughly the size of a city block. Fires ignited in the aftermath and persisted for over seven hours. While the incident didn't harm the two on-site ammonia units, the entire plant was prudently shut down temporarily.	120	**332**
#75 **Mechanical failure**	**Deer Park, Texas, US** 22 June, 1997 A petrochemical plant was rocked by a substantial explosion and a subsequent large fire. The impact of this explosion reverberated over a 10-mile radius, while the ensuing blaze raged for roughly ten hours. The incident caused significant damage to the plant, with several workers sustaining minor injuries. The surrounding area and property were also affected, leading to temporary road closures. To prevent exposure to potentially harmful substances, residents were advised to remain indoors. The event was traced back to the cracked gas compressor system within the Olefins unit. It was initiated by the structural failure of a 36-inch pneumatically-assisted, non-return valve on a high-pressure light hydrocarbon gas line. The escaping gas formed a vapor cloud, which eventually encountered a source of ignition, culminating in an unconfined vapor cloud explosion.	135	**323**

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#86 **Explosion**	**Illiopolis, Illinois, US** 23 April, 2004 An explosion at a plastics plant producing 200 million barrels per year of specialty-grade PVC occurred. The explosion, which could be felt from eight kilometers away, took place in a reactor where vinyl chloride and vinyl acetate were being mixed. Up to 75% of the plant was destroyed in the incident, resulting in two serious injuries and the loss of five lives.	150	**285**
#90 **Mechanical failure**	**Pajaritos, Coatzacoalcos, Mexico** 11 March, 1991 A gas leak involving the pipe rack that runs to the terminal in the petrochemical complex led to an initial explosion near the complex's chemical plant. This caused additional damage to the pipe rack and resulted in a major gas leak. A powerful second explosion occurred, which could be felt more than 15 miles from the complex. This explosion and the subsequent fire completely destroyed the chemical plant, caused significant damage to the pipe rack, and also resulted in moderate damage to other complex buildings and adjacent third-party facilities. The fire was extinguished after approximately three hours. Due to the incident, the chemical plant at this complex was completely shut down for seven months to allow for the reconstruction of the plant and pipe rack.	97	**268**

Petrochemicals		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#99 **Mechanical failure**	**Antwerp, Belgium** 7 March, 1989	79	**230**

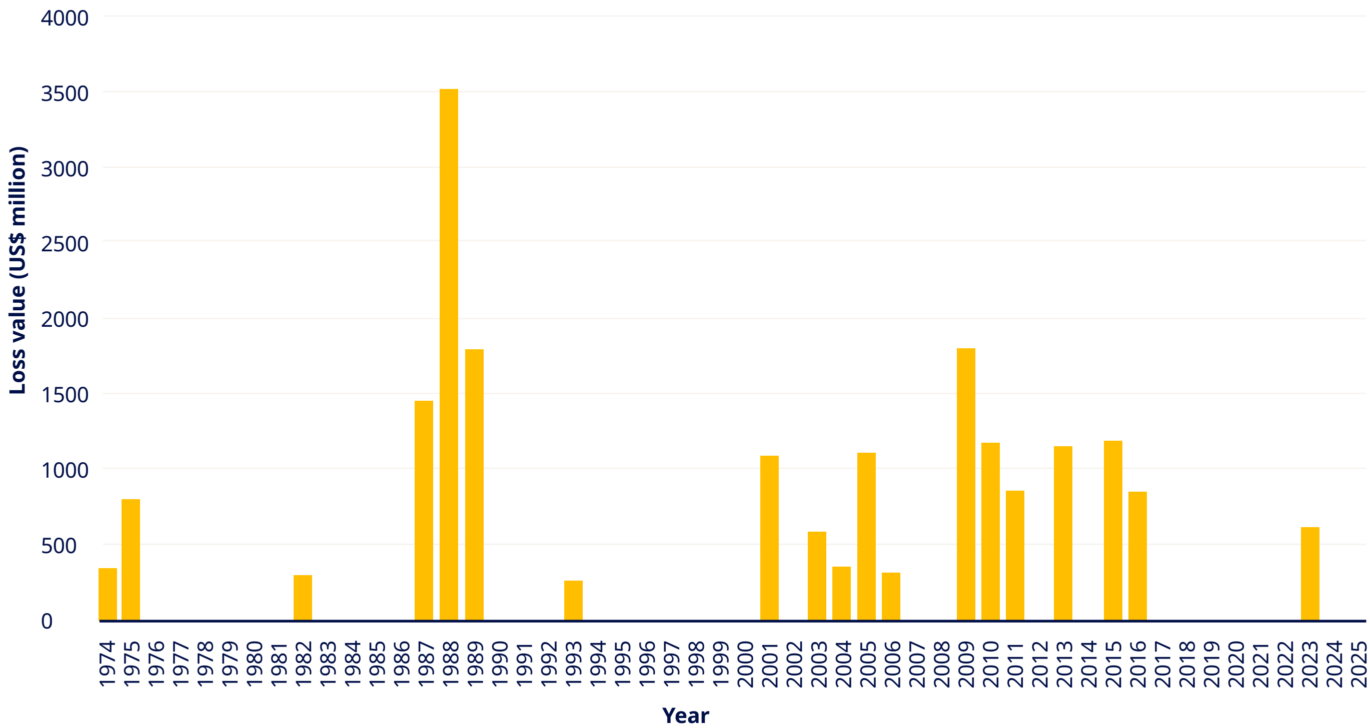
A hairline crack developed in a welded seam of piping connected to the level indicator system on the Aldehyde column at a gas processing plant. This crack, caused by low-cycle fatigue, led to a minor ethylene oxide leak near the level indicator. Over time, the escaping ethylene oxide reacted to form polyethylene glycols (PEG) within the mineral wool insulation surrounding the piping. During repair work on the level indicator, the metal sheathing of the insulation was removed, exposing the PEG-soaked insulation to air. This exposure triggered auto-oxidation of the PEG, igniting the insulation material. The piping heated to a level that caused auto-decomposition of the ethylene oxide inside, which then propagated into the Aldehyde column, resulting in a catastrophic explosion. The blast completely destroyed the distillation section of the plant. The ensuing large fire and flying debris caused extensive damage across multiple process areas. As a consequence, the plant was shut down for a minimum of 24 months.

100 largest losses by sector *Upstream*

While the upstream sector recorded the second-highest number of incidents among all sectors in the 100 largest losses dataset, its economic value is the highest.

This is largely due to the significant asset values involved, including offshore platforms, onshore facilities, and extensive equipment, as well as the large volumes of hydrocarbons handled. The combination of high exposure and the potential for severe events such as blowouts, explosions, and fires contributes to the substantial financial impact of upstream losses. Notably, no new upstream losses were added to this report from the last two years.

Figure 33. Upstream losses



Source: Marsh

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#1 **Fire and explosion**	**Piper Alpha, North Sea, UK** 6 July, 1988 A release and ignition of gas condensate occurred within the platform's gas compression module due to the inadvertent pressurization of a piping section, where a pressure-relief valve had been removed for maintenance. This event initiated a chain of fires and explosions, resulting in substantial facility damage. The accident's severity was compounded by ruptured pipelines, which released oil and gas, and the subsequent disabling of most emergency systems. The gas compression module's proximity to the control room rendered it nonfunctional. The manual operation of firewater pumps, due to divers in the water before the incident, complicated response efforts. Out of 226 individuals on the platform during the accident, only 61 survived, partly due to the quarters' location above the initial release site.	850	**2,530**
#4 **Fire and explosion**	**Baker, Gulf of Mexico, US** 19 March, 1989 During the installation of a pig trap on an 18-inch export gas pipeline, a cold cut into the pipe resulted in the release and ignition of hydrocarbons. This incident triggered a destructive explosion and fire that not only engulfed the main structure but also led to further explosions due to ruptured nearby pipelines exposed to intense heat. Tragically, the accident led to the complete destruction of the platform and the loss of seven lives. It took two years to replace the platform.	400	**1,159**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#5 Collision	**Ekofisk, North Sea, Norway** 4 June, 2009	750	**1,137**

A vessel, conducting well intervention, lost power, subsequently colliding with an unmanned platform in a 230,000 bbl/d complex. The collision caused severe damage to both the vessel and the platform. This damage included harm to the platform's structure, linking access bridge, and well equipment. Approximately 23,000 bbl/d of oil production was reported as affected. The force of the collision resulted in the bow of the vessel compressing by about two meters. Additionally, the platform was partially displaced, resulting in several support legs loosened from the main load-bearing structure. Moreover, one of the platform's water injection risers was significantly bent, and several wellheads were displaced, with additional collision-related damage identified.

#6 Explosion	**Roncador Field, Campos Basin, Brazil** 15 March, 2001	500	**1,097**

Explosions resulting from a gas release affected the world's largest offshore production facility. These explosions led to the displacement of a support pillar on the semi-submersible platform, permitting seawater to enter the vessel. Workers initiated measures, including injecting nitrogen and compressed air, along with efforts to pump out nearly 3,000 tons of seawater in an attempt to maintain the rig's buoyancy. However, these efforts were unsuccessful. Ultimately, on March 20, the rig sank to the sea floor, resulting in the loss of eleven workers.

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#8 **Blowout**	**Enchova, Campos Basin, Brazil** 24 April, 1988 During a well conversion from oil to gas production on an offshore platform, a high-pressure gas pocket forced the drill pipe out, leading to a well blowout. The blowout preventer failed to shut in the well, resulting in ignited escaping gas. The fire raged for 31 days, destroying most of the platform's topside structure. Consequently, the facility was deemed a total loss. In an effort to expedite the resumption of production, the production module underwent a redesign within 45 days. Full production recovery was achieved 18 months after the incident. This accident showcases the importance of robust well control measures and disaster recovery planning in offshore drilling operations.	330	**982**
#16 **Fire**	**Bay of Campeche, Mexico** 1 April, 2015 In the Gulf of Mexico, a fire erupted within a complex of six offshore platforms situated in 30 meters of water. The blaze originated on the lower decks of the production platform, leading to severe damage to that platform and causing radiation and fire damage to an adjacent compression platform. Bridge links and pipelines were lost, and other bridge links sustained radiation damage. A government-mandated root-cause investigation attributed the initial failure to corrosion within a small-bore pipeline. This incident underscores the critical importance of proactive infrastructure maintenance and corrosion prevention measures in offshore environments to avert potentially catastrophic accidents.	640	**857**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#18 **Mechanical failure**	**Jubilee Field, Ghana** 11 February, 2016 The primary turret bearing on a floating production storage and offloading vessel experienced a seizure and eventual failure, causing the vessel to lose its weathervaning capability. To resume production, a modified operating approach was adopted, necessitating the use of tugs to maintain a consistent heading. Later, the vessel underwent a conversion to establish a permanent spread moored configuration. This reconfiguration secured the vessel's heading and integrated a deep-water offloading buoy to facilitate its operations.	650	**852**
#19 **Fire and explosion**	**Cook Inlet, Alaska, US** 20 December, 1987 During cementing operations for the 13 3/8" casing at a depth of 2,265 feet in Well No. M-26 on the northwest leg of the Steelhead Platform, a surge in formation pressure led to a well blowout. This catastrophic event resulted in the expulsion of substantial amounts of fluid, gas, and subsoil debris into the atmosphere. Sparks generated during the ejection of sand and rocks from the well led to its ignition. The platform sustained extensive damage as a result of this incident.	273	**840**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#21 **Blowout**	**Macondo, Gulf of Mexico, US** 20 April, 2010 In Mississippi Canyon Block 252, about 50 miles off Louisiana's coast, a deepwater semi-submersible drilling rig experienced a major explosion and fire due to well integrity failure. Eleven lives were lost, with 17 crew members suffering severe injuries from a total of 126. Within 36 hours, the rig sank in approximately 5,000 ft of water. The exploration well had reached a total depth of 18,360 ft and was undergoing cementing operations for temporary abandonment when the well control incident occurred. A buckled drill pipe within the blowout preventer (BOP) hindered the blind shear ram from cutting the pipe and sealing the well. Hydrocarbons continued to flow through the damaged BOP for 87 days, ending with a successful static kill. This event necessitated an unprecedented subsea and surface spill control response, ultimately ending after five months with the successful interception of a relief well, resulting in the release of approximately five million barrels of hydrocarbons into the environment.	560	**830**
#22 **Mechanical failure**	**Caspian Sea, Kazakhstan** 24 September, 2013 A newly operational offshore pipeline in Kazakhstan was found to have a gas leak. The affected section was repaired, but more leaks soon appeared in both the gas and oil pipelines. The root cause was identified as localized hardness in the pipes, which led to sulphide stress cracking. To resolve the issue, both pipelines were replaced.	596	**829**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#26 **Collision**	**Mumbai High North Field, India** 27 July, 2005 A significant incident led to the complete destruction of an oil platform, resulting in the loss of twenty-two lives. A multi-purpose support vessel, while evacuating a worker to a medical center, collided with the platform's riser, causing a major explosion. The vessel itself was engulfed in flames and eventually sank. The crews of two nearby platforms were saved when connecting bridges collapsed. The platform housed 150 individuals who transferred to a nearby water injection platform. An additional 348 individuals were safely evacuated from the oil platform, despite challenging weather conditions. A cantilever jack-up rig, linked by a bridge to the process platform, was also engulfed in the fire. This emergency evacuation sadly resulted in the loss of one employee's life. In a separate but related incident, six divers were trapped in a saturation chamber on the vessel and were successfully rescued after 36 hours.	370	**668**
#29 **Natural catastrophe**	**Gryphon, North Sea, UK** 4 February, 2011 Severe North Sea storm conditions caused four of a floating production storage and offloading (FPSO) vessel's 10 anchor chains to fail, displacing the FPSO. The vessel faced 53 knot winds and nine-meter waves. The incident damaged the complex piping system connecting the seabed wells to the FPSO. In response, all wells were promptly shut down. Subsequent assessments revealed no oil loss. Seventy-four non-essential crew members were evacuated to nearby platforms, while 43 essential crew remained on board with two sustaining minor injuries. The facility had an estimated average oil production of 18,400 bbl/d prior to the event.	450	**638**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#30 **Blowout**	**Treasure Saga, North Sea, Norway** 20 January, 1989 During drilling, a semi-submersible rig experienced a gas kick at 15,527 feet while attempting to clear cement from the drill pipe. This led to a well blowout. It took 11 months to regain control of the well by injecting heavy mud through a relief well. An additional four months were needed to complete the cleanup and the final abandonment of the blowout well.	220	**638**
#32 **Fire and explosion**	**Cantarell Field, Gulf of Mexico, US** 7 July, 2023 At the Nohoch-A production platform, a fire caused extensive damage and a production loss of approximately 100,000 barrels per day. The fire was extinguished the following day, with the platform fully restoring production after several days. During the incident, eight workers sustained injuries. Two individuals lost their lives, and one remains missing. An ongoing investigation is underway to determine the cause of the fire.	600	**625**
#33 **Blowout**	**Bourbon Field, Gulf of Mexico, US** 4 November, 1987 Sustained casing head pressure leaked from the production casing into the outer casing strings, leading to the failure of one of the casing strings. This event triggered an underground blowout, which resulted in significant damage to the platform and a gas plume around the platform. To restore stability to the seabed, the well was successfully killed.	200	**618**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#35 **Mechanical failure**	**Siri Field, North Sea, Norway** 14 March, 2003 During an inspection of the Siri platform in the North Sea, cracks were discovered in the sponson cantilever extension connected to the primary oil storage tank. To enable an internal examination, access openings were created in the sponson walls, with miniature remotely operated vehicles (ROVs) deployed for the inspection. A total of 39 internal cracks were identified. The primary issue was attributed to the insufficient design of the support structure for the caisson.	291	**591**
#41 **Blowout**	**Fateh L3, Dubai, UAE** 1 July, 1975 The Fateh Field L-3 development well, having reached a depth of 4,180 feet, faced an unexpected "kick" during drilling operations. As attempts to control the kick failed, the rig was evacuated due to gas breakthrough around the 20-inch casing shoe, with gas seeping beneath the platform. Eight days following the initial blowout, the accumulated gas ignited. Over the subsequent two weeks, both the drilling rig and platform catastrophically submerged beneath the ocean's surface.	79	**476**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#47 **Natural catastrophe**	**Thunder Horse, Gulf of Mexico, US** 10 July, 2005 Hurricane Dennis swept through the platform's vicinity, leading to partial submersion. This incident was attributed to the incorrect installation of a seawater valve in a ballast tank, causing an overflow of water in the tanks. Fortunately, the platform had been evacuated, and no oil, fuel, or hazardous substances were released. However, this setback resulted in a three-year production delay for the project. To address the issue, the company retrieved and reconstructed all the sea-bed production equipment after identifying metallurgical failures in various components of the field sub-sea systems during subsequent testing.	250	**452**
#56 **Blowout**	**Montara, Timor Sea, Australia** 21 August, 2009 Oil, condensate, and hydrogen sulfide were released from a wellhead on a platform undergoing maintenance in the Timor Sea. As a safety measure, 69 workers on the jack-up rig were evacuated. The incident was triggered when a plug obstructing one of the project's 1,200-meter-deep wells came free, leading to oil and gas spilling. The next day, a spill measuring 12 kilometers in length and 30 meters in width was reported. Subsequent efforts were made to seal the well over the following two months, with an estimated daily leak rate of 400 barrels of oil and gas. On November 1, it was reported that drillers had successfully intercepted the well and commenced the injection of heavy mud to seal it. However, while attempting to plug a deeper leak, a fire broke out on the drilling platform. The fire was eventually extinguished two days later. Approximately 4,140 tons of oil were estimated to have been lost in this incident, impacting both the platform and the drilling rig.	250	**379**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#62 **Blowout**	**Temsah, Egypt** 10 August, 2004 A fire erupted during drilling operations at an offshore gas production platform due to a well-control incident. The fire, initially contained, eventually extended to a nearby jack-up drilling rig owned by a major drilling contractor, causing significant damage and resulting in the rig's collapse. All 79 individuals on the drilling rig were safely evacuated, while the production platform, accommodating 150 personnel, had been evacuated earlier. Regrettably, the drilling rig sank and couldn't be salvaged. The platform sustained irreparable damage, leading to its ordered decommissioning by the authorities.	190	**361**
#63 **Mechanical failure**	**Frigg Field, North Sea, Norway** 15 March, 1974 A series of underwater visual inspections revealed cracks in the concrete external diaphragm walls of a platform. Upon investigation, it was established that the stresses endured by these diaphragms throughout their construction, towing, and platform installation phases were sufficient to initiate the cracks. These cracks couldn't be attributed to a single isolated incident but were rather a result of cumulative stress factors over time.	54	**355**
#65 **Mechanical failure**	**Caribbean Sea, Venezuela** 13 May, 2010 A natural gas drilling rig submerged in the Caribbean Sea. All 95 workers were safely evacuated, and no reported leakage transpired. The sinking was a result of a sudden inflow of water into one of the submarine rafts supporting the platform legs. Automatic sub-sea safety valves sealed the wells, preventing any oil leakage.	235	**348**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#68 Explosion	**Camarupim Field, Brazil** 3 November, 2015 An explosion occurred on a floating production storage and offloading (FPSO) vessel off the coast of Brazil, leading to nine fatalities and multiple injuries. This incident took place while the vessel was anchored in the Atlantic Ocean, approximately 120km off the coast of Espirito Santos, Brazil. The FPSO, originally a very large crude oil tanker converted for the production of up to 10 million cubic meters of natural gas, experienced a condensate leak during a fluid transfer operation, releasing a flammable vapor cloud into the engine room. This cloud ignited, causing an explosion in the machinery space. Although the FPSO took on water, the explosion did not breach the vessel's hull. Most of the fatalities were among the emergency response team.	250	**335**
#72 Collision	**Auk Field, North Sea, UK** 1 August, 1975 A supply vessel collided with a jacket on the Auk field, causing severe damage to the platform. Three braces were lost, and a fourth was severely bent. The impact also caused damage to the platform's topside facilities. The supply vessel that collided with the Auk field platform was the MV "Stad Sea". The "Stad Sea" was a semi-submersible drilling rig that was being used as a supply vessel at the time of the incident.	55	**329**

Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#74 **Mechanical failure**	**Atlantic Ocean, near Angola** 1 July, 2013 A jack-up drilling rig experienced a sudden sinking event as the seabed unexpectedly collapsed beneath one of its three support legs. This incident occurred during the rig's positioning for drilling operations in roughly 40 meters of water. At the time of the incident, the rig accommodated 103 workers. The abrupt tilt led to the rig taking on water and subsequently capsizing. One crew member went missing in the process, and six others sustained minor injuries..	235	**328**
#78 **Mechanical failure**	**North Sea, Norway** 5 November, 2006 Offshore gas alarms on the floating production unit were activated. Subsequent investigation confirmed a leak from one of the production risers. Further examination revealed that five additional risers were impacted by similar issues. Subsequent corrective measures were implemented to address the situation.	185	**319**
#82 **Mechanical failure**	**North Atlantic Ocean, near Newfoundland, Canada** 15 February, 1982 The semi-submersible rig known as the "Ocean Ranger" vanished from radar screens amidst a powerful storm. The rig was designed to operate in harsh weather conditions, but the storm was one of the worst in decades. The storm generated waves of up to 37 feet and winds of up to 90 knots. The Ocean Ranger was battered by the waves and wind for several hours, and eventually capsized and sank. Eventually, the rig was discovered submerged upside down in 300 feet of water. All 84 crew members on board died.	92	**304**

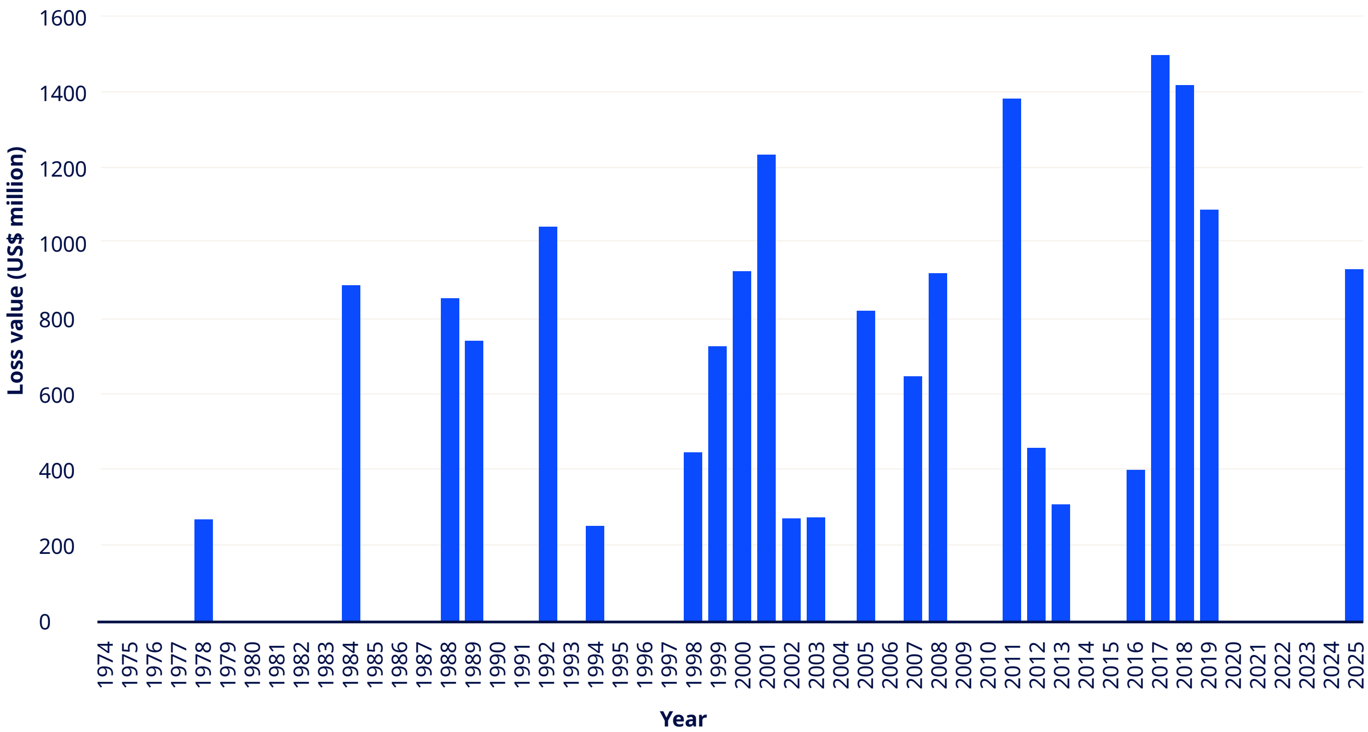
Upstream		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#84 **Natural catastrophe**	**South China Sea, Philippines** 15 September, 2009 During the passage of Typhoon Koppu, the typhoon reached maximum intensity with estimated wind speeds of approximately 140 km/hr (about 75 knots) near its center. Notably, the FPSO Nanhai Fa Xian was positioned roughly 60 miles from the storm's center. In this adverse weather, four out of the eight mooring lines failed, particularly in proximity to the Buoy Turret Mooring (BTM) system. Consequently, the BMT/FPSO was anchored in place by the remaining four mooring lines, although it had shifted approximately 600m to 700m north of its original location. Extensive damage to the Mooring System, Risers, Pipeline End Manifolds (PLEMS), as well as varying degrees of damage to piping and power cables near the PLEMS, has been identified.	191	**289**
#91 **Mechanical failure**	**Lama, Lake Maracaibo, Venezuela** 25 March, 1993 An apparent failure of a propane intercooler liquid level control during unsupervised maintenance led to an explosion and fire. The control room on the main platform was destroyed, and adjacent platforms were affected by the blast wave. The incident resulted in eleven fatalities.	100	**264**
#100 **Mechanical failure**	**Gulf of Mexico, Mexico** 12 April, 2011 Six hundred thirty-eight workers were safely evacuated from a flotel located approximately 80 km offshore Campeche, Mexico, after the structure began to lean to one side due to water entering a pontoon. No injuries were reported during the evacuation. The incident resulted in the flotel being declared a total loss.	160	**227**

100 largest losses by sector *Refining*

Refining accounts for the highest number of losses among all sectors in the 100 largest losses dataset, with a total of 36 incidents. This includes a newly added loss that occurred in California, US, in February 2025. The frequency of losses in refining reflects the complexity and scale of refinery operations, where numerous interconnected processes and high-value equipment present multiple risk points.

Additionally there have been several notable losses from the last two years: a fire at a chemical complex in Louisiana, US (March 2024), a gas supply line rupture at a methanol plant in Texas, US (2024), a fire at a refinery in Greece (September 2024), an explosion and fire at a refinery in Germany (January 2025), an equipment failure resulting in fire in Alabama, US (May 2025), and an explosion and fire due to process safety control issues in Texas, US (June 2025).

Figure 34. Refining losses



Source: Marsh

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#3 **Fire and explosion**	**Abu Dhabi, UAE** 11 January, 2017 During a maintenance operation, the accidental release of hot, light hydrocarbons led to a significant fire outbreak. The incident transpired within a newly commissioned residual fluid catalytic cracking (RFCC) unit, part of a major expansion effort that doubled the refinery's overall capacity. The severity of the fire prompted the temporary closure of the expanded refinery area, necessitating extensive rebuilding work to restore normal operations.	1,000	**1,249**
#10 **Mechanical failure**	**Martinez, California, US** 1 February, 2025 A hydrocarbon release followed by a fire took place at a refinery during maintenance preparation activities on a hydroprocessing unit. The release followed the opening of a flange on an active piping system, resulting in a leak that ignited shortly thereafter. The fire extended to adjacent processing areas, including associated gas plant equipment, and required a prolonged emergency response lasting several days. Six workers were medically evaluated and released without hospitalization. Operations at the affected units were suspended while damage assessments and investigations were undertaken. An independent investigation identified deficiencies in operational monitoring and contractor oversight, together with procedural and regulatory control gaps, as contributing factors. Recommendations were issued to strengthen safety controls and oversight of work activities.	950	**950**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#12 **Mechanical failure**	**Vohburg, Germany** 1 September, 2018 A hydrocarbon release happened in a reactor vessel on a naphtha hydrotreater unit operating at approximately 25 bar and 140 degrees Celsius. This release of hot naphtha and hydrogen formed a vapor cloud that ignited, resulting in an explosion and fire. The explosion triggered additional releases from other parts of the plant, including a nearby diesel hydrotreater, which intensified the fire. Eight on-site employees suffered injuries, but no fatalities were reported. Residents of a nearby town were evacuated as a precaution, and hundreds of firefighters were deployed to control the fire. Extensive damage occurred in several refinery process units, office and maintenance buildings, and even caused window breakage in a village approximately 3 kilometers away. The initial release of hydrocarbon was attributed to a 1.5-meter crack near the welded vessel support in the reactor vessel, although detailed investigation findings have not been widely disclosed.	770	**933**
#13 **Explosion**	**Mina Al-Ahmadi, Kuwait** 25 June, 2000 An explosion happened when employees were trying to isolate a leak in a condensate line connecting an off-site NGL plant and the refinery gas plant. This event led to the damage of three crude units and the destruction of two reformers. It took around nine hours to extinguish the subsequent fire, which resulted in five fatalities and 50 injuries. The investigation revealed a deficiency in the inspection and maintenance of the condensate line, which was not under the ownership of the refinery. The lack of a clear understanding regarding the line's ownership is believed to have caused delays in isolating it.	412	**928**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#17 **Mechanical failure**	**Norco, Louisiana, US** 5 May, 1988 In a routine 90,000 bbl/d fluid catalytic cracking (FCC) unit operation, an eight-inch diameter carbon steel elbow, positioned 50 feet above ground in the depropanizer column overhead piping system, suffered a catastrophic failure due to internal corrosion. Approximately 20,000lb of C3 hydrocarbons were released, creating a substantial vapor cloud within the 30 seconds before ignition. The depropanizer column and accumulator depressurized through the breach. The vapor cloud most likely ignited from the FCC charge heater. The initial explosion obliterated the FCC control building, toppling the 26-foot diameter main fractionator and causing widespread damage across the 215,000 bbl/d refinery. Off-site damage resulted in around 5,200 property claims. The FCC unit was ultimately replaced due to extensive damage. Preliminary findings revealed unexpectedly high localized corrosion rates in the failed elbow.	288	**857**
#20 **Natural catastrophe**	**Sendai, Japan** 11 March, 2011 A major explosion occurred at a 145,000 bpd refinery in Sendai after Japan's largest-ever earthquake and a subsequent tsunami. The fire originated in the oil product shipping area, with workers in the process of evacuation and no fire suppression capabilities in place. This fire extended to the storage and shipping facilities, causing damage to a 35,500 bpd fluid catalytic cracker (FCC) at the refinery.	590	**837**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#23 **Fire and explosion**	**Limbe, Cameroon** 31 May, 2019 A fire and subsequent explosion occurred near the distillation unit of a refinery, necessitating a complete site shutdown. Among the 13 units at the site, four were entirely destroyed, and three suffered partial damage. The cause of the incident has not been widely shared.	600	**727**
#28 **Mechanical failure**	**Romeoville, Illinois, US** 23 July, 1984 Prior to the rupture of a 55-foot-tall, 8.5-foot-diameter monoethanolamine absorber column at a refinery, a crack was discovered at a circumferential weld, leaking propane. Efforts to close the inlet valve were underway when the crack expanded to 24 inches. The area was evacuated, and the plant's fire brigade was called. The column eventually failed, propelling most of the 20-ton vessel 3,500 feet before striking and toppling a 138,000-volt power transmission tower. The rupture happened along a lower girth weld made during repairs a decade earlier. Substantial fires occurred in various refinery units, with an explosion breaking windows up to six miles away. Extensive structural damage disrupted electrical power, affecting firefighting capabilities. Responding fire departments, including neighboring plants, worked collectively to manage the incident.	191	**639**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#31 **Mechanical failure**	**Lemont, Illinois, US** 14 August, 2001 The 160,000 bbl/d capacity refinery underwent a shutdown due to a pool fire originating from a pipework release within the crude distillation unit. Three days later, an internal fire caused a structural failure in the crude column, resulting from air ingress due to the previous ruptured pipework's reaction with pyrophoric material and oil in the column. This led to a 12-month shutdown of the crude distillation unit. The initial pool fire resulted from incorrect piping material specification in one elbow, which ultimately failed.	285	**625**
#34 **Mechanical failure**	**La Mede, France** 9 November, 1992 A vapor cloud explosion disrupted the gas plant associated with a 29,700 bbl/d fluid catalytic cracker (FCC) unit in a 136,000 bbl/d refinery. Audible for miles, the initial explosion involved around 11,000 pounds of light hydrocarbons. It stemmed from a gas leak signaled by the unit's detection system, likely due to a ruptured recovery pipe for butane and propane from the FCC unit. The incident severely damaged nearly two hectares of the refinery, including the gas plant, FCC unit, and control building. Nearby construction of two new process units was also heavily impacted, and windows were broken in neighboring areas. Firefighters from several locations, along with the refinery's brigade, spent over six hours controlling the situation, using around 37,000 US gallons of foam concentrate.	225	**611**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#36 **Explosion**	**Big Spring, Texas, US** 18 February, 2008 An explosion took place at a 70,000 bbl/d oil refinery, resulting in damage to several components, including the fluid catalytic cracker (FCC), storage tanks, and the asphalt unit. Four individuals sustained injuries in the incident, one of whom was hospitalized for burns, and another was hurt when her vehicle was struck by debris from the explosion near the adjacent highway. The accident occurred on a public holiday, with only 40 people present on-site (typically, four times that number would be on duty). The refinery's fire brigade, with assistance from local fire departments, managed to control the fire on the same day. The release is believed to have been linked to a pump's catastrophic failure during a propylene splitter unit start-up. Some processing operations resumed approximately two months later, while the FCC was re-commissioned eight months after the event.	380	**585**
#37 **Explosion**	**Fort McKay, Alberta, Canada** 6 January, 2011 An explosion shook an oil sands upgrader site north of Fort McMurray, Alberta, causing injuries to five workers, one of whom suffered third-degree burns. Shortly afterward, a fire broke out at the top of one of the facility's four coke drums and burned for nearly four hours, rendering two coke drums inoperable. Most of the damage was concentrated above the cutting deck and derrick infrastructure of the coke drum. The plant was already operating under bypass conditions due to process upsets during the incident. The fire resulted from the opening of the top unheading valve on an active low-pressure coke drum, allowing hot hydrocarbons to be released within the coker cutting deck building, leading to ignition and the ensuing explosion and fire. Freezing conditions following the incident hindered access to the coker unit's cutting deck and caused additional damage during firefighting efforts.	385	**546**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#39 **Fire and explosion**	**Wisconsin, US** 26 April, 2018 An explosion and ensuing fire at the refinery caused injuries to 36 individuals and the partial evacuation of the nearby town of Superior, Wisconsin. This incident transpired while the refinery's fluid catalytic cracking unit (FCCU) was undergoing planned maintenance. The probable cause was the erosion of the FCCU spent catalyst slide valve, which couldn't maintain the catalyst level necessary to prevent the mixing of air and hydrocarbons during transient operation. Consequently, air traveled backward from the regenerator into the reactor and then into downstream equipment, leading to a substantial explosion. Debris from the explosion scattered across the plant, with one fragment piercing a nearby large above-ground storage tank. This breach resulted in the release of approximately 15,000 barrels of hot asphalt, which subsequently ignited, sparking a substantial fire.	400	**485**
#40 **Natural catastrophe**	**St Croix, Virgin Islands** 18 September, 1989 Hurricane Hugo struck the refinery, severely damaging 14 of the 500,000 to 600,000 barrel storage tanks in the tank farm area, along with the administration building and company housing. The process units, which were safely shut down in anticipation of the hurricane, incurred limited harm, primarily affecting asbestos insulation on process columns and piping. The hurricane's maximum recorded wind speed was 192 mph until it damaged the wind speed measuring device at the St. Croix airport. Due to the asbestos insulation damage, roughly 1,500 company employees and contractors worked daily for 15 weeks, incurring significant additional costs, to remove asbestos debris from the refinery.	167	**484**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#43 **Natural catastrophe**	**Korfez, Gulf of Izmit, Türkiye** 17 August, 1999 A seismic event registering 7.4 on the Richter scale triggered the collapse of a 312-feet-high concrete chimney situated within one of the crude units, leading to fires at the 226,000 bbl/d refinery. Fires also ignited on various on-site storage tanks. The refinery's emergency response teams promptly isolated and extinguished the fire in the affected crude unit. For the fires in the tank farm, the decision was made to allow them to burn out after draining the storage tanks as extensively as possible. The firefighting efforts faced considerable challenges due to broken water mains. However, international support, including personnel and equipment, was mobilized to address the situation. The incident resulted in the complete loss of six storage tanks, deformation of another four storage tanks, and 50% damage to several floating roof tanks. Damage extended to various process units, including the fire in the crude distillation unit, harm to a reformer, and damage to several connecting pipelines.	200	**466**
#44 **Explosion**	**Falcon State, Venezuela** 25 August, 2012 A powerful explosion took place at the refinery, impacting an area where propane and butane were stored under pressure. This incident resulted in the loss of at least 48 lives and left over 80 individuals injured. The explosion caused significant damage to nine storage tanks, highlighting a concerning history of reported leaks at the refinery over the past year.	330	**463**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#45 **Mechanical failure**	**Fort McMurray, Alberta, Canada** 4 January, 2005 A fire ignited within the upgrader 2 section of the oil sands refinery, dedicated to the conversion of bitumen into crude oil products. Approximately 250 personnel were safely evacuated, and no injuries were reported. The fire blazed for nine hours before being successfully extinguished. Witnesses observed two explosions occurring minutes apart, which generated a substantial fireball reaching six stories in height. The plant endured additional damage from ice formation due to firefighting efforts in the extreme cold, with temperatures plunging below -35°C. The likely source of the fire appeared to be a ruptured recycle line.	256	**462**
#48 **Natural catastrophe**	**Pascagoula, Mississippi, US** 1 September, 1998 Hurricane Georges inflicted severe damage, forcing the complete shutdown of the refinery for three months. The plant was submerged under more than four feet of saltwater from the Gulf of Mexico, despite the hurricane being classified as a Category 2 storm. Prolonged exposure to its slow-moving winds and rain over 17 hours led to the storm surge breaching the protective dikes surrounding the facility. Extensive repairs were needed, including replacements for about 2,100 motors, 1,900 pumps, 8,000 instrument components, 280 turbines, and 200 other machinery items. Notably, newer control buildings and electrical substations, built with elevated ground floors, suffered minimal or no damage during the incident.	190	**449**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#50 **Explosion**	**Sodegaura, Japan** 16 October, 1992 An explosion and ensuing fire caused significant property damage at the 146,500 bbl/d refinery. This incident stemmed from a heat exchanger failure within the light oil hydrodesulfurization unit. During the event, parts of the heat exchanger - specifically, the channel cover and lock ring, each measuring five feet in diameter and weighing 4,000lb and 2,000lb, respectively - were forcefully ejected into a neighboring factory located approximately 650 feet from the refinery. The incident occurred during the unit's restart following catalyst exchange work. Initial signs of hydrocarbon release from the heat exchanger prompted tightening work on the bolts. Ultimately, the subsequent fire was contained by firefighters employing 15 fire trucks within two hours and 45 minutes.	161	**437**
#53 **Fire**	**Sannazzaro de Burgondi, Italy** 1 December, 2016 A process disruption occurred when the recycle gas compressor linked to the site's prototypical processing unit tripped, leading to the loss of hydrogen quench flow to the ebullated bed reactor. This event triggered an exothermic runaway reaction within the reactor. Allegedly, the reactor was not promptly depressurized in accordance with the operating guidance. Consequently, a 12" coupling experienced a failure due to the rising pressure. This failure resulted in the loss of primary containment and a subsequent significant fire.	309	**404**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#58 **Fire and explosion**	**Philadelphia, US** 21 June, 2019	300	**363**
#60 **Explosion**	**Texas City, Texas, US** 23 March, 2005	200	**361**

#58

Fire and explosion

Philadelphia, US

21 June, 2019

A significant loss of process fluid containment, primarily involving propane and hydrofluoric acid (HF), occurred in the refinery's HF alkylation unit, leading to a substantial fire and ensuing explosions. A 38,000 lb fragment from one of the larger explosions was propelled approximately 2,100 feet before coming to rest outside the refinery's designated area. The firefighting efforts continued for over 24 hours, and five individuals sustained injuries during the incident.

The release is believed to have resulted from the rupture of a thinned pipe elbow, which was installed around 1973. Although the pipe elbow complied with metallurgical requirements at the time of its installation, it did not align with the updated recommendations of the American Society for Testing and Materials made some 20 years later.

Following the incident, the refinery ceased operations, and the operating company filed for bankruptcy.

#60

Explosion

Texas City, Texas, US

23 March, 2005

An explosion at the 460,000 bbl/d refinery resulted in 15 fatalities and 105 injuries. The incident happened during the restart of the isomerization unit after its annual major maintenance turnaround. Issues during the restart led to the overfilling of one of the unit's splitter columns with light hydrocarbon. This ultimately caused the release of hot liquid through relief valves to a 30-meter-high blowdown stack on the unit. The release created a substantial vapor cloud in the unit's vicinity. Tragically, a source of ignition triggered an explosion, particularly impacting temporary buildings near the blowdown stack where a meeting was taking place.

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#64 **Mechanical failure**	**Wickland, Aruba** 9 April, 2001 An oil spill occurred as a consequence of a block valve failing to seat correctly during maintenance on a pump strainer within the visbreaker unit. The oil auto-ignited, leading to a subsequent fire that consumed the visbreaker and impaired adjacent equipment. Successive explosions and intense heat obstructed firefighting efforts. Additionally, an insufficient number of fire brigade personnel, coupled with damage to the firewater distribution system, further complicated extinguishing the blaze. The fire was inadvertently propagated by the firewater application but was ultimately quelled with assistance from the local fire department.	159	**349**
#67 **Natural catastrophe**	**Texas, US** 12 September, 2008 The 365,000 bbl/d refinery incurred severe damage when Hurricane Ike swept through the Houston area, bringing extensive flooding that extended as far as Louisiana. Hurricane Ike's unusually large storm surge inundated the refinery.	220	**339**
#73 **Fire**	**Pascagoula, Mississippi, US** 16 August, 2007 A fire erupted in the refinery's crude unit number 2, with a capacity of 325,000 barrels per day, and blazed for a period exceeding six hours. There were no reported injuries. Company representatives noted that a substantial portion of the refinery was able to sustain operations, with the number 1 crude unit remaining fully operational.	200	**329**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#76 **Fire**	**Fort McMurray, Alberta, Canada** 2 June, 2007 A fire ignited within the Boiler unit of the flue gas section at the Coker facility. The incident was triggered by a blockage caused by freezing water at valve XV-4, where heat tracing was insufficient, leading to a hazardous accumulation of combustible coke in the precipitators. Importantly, the facility was in full operation when the incident occurred.	195	**321**
#81 **Natural catastrophe**	**La Plata District, Ensenada, Argentina** 2 April, 2013 During a severe rainstorm, a fire erupted at the 188,000 bpd refinery due to flash floods. The refinery's storm drainage system was overwhelmed by the heavy rainfall, leading to the runoff of hydrocarbons across the site. An explosion was reported in the crude distillation unit (CDU), resulting in two fires within the CDU, one in the coking plant, and two in the topping distillation plant. The government agency determined that the incident occurred when hydrocarbons exploded within one of the still-hot coke manufacturing furnaces, despite its shutdown status. It took eight hours to extinguish the fire and an additional ten hours to regain control of the situation. There were no reported fatalities or injuries.	225	**312**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#87 **Explosion**	**Fort McMurray, Alberta, Canada** 6 January, 2003 An incident occurred at an oil sands facility, resulting in minor explosions in the froth treatment plant. The damage was primarily limited to electrical cables in the solvent recovery area. The likely cause of the fire was a hydrocarbon leak in the piping. The plant's emergency response team, along with assistance from the local fire brigade, managed to extinguish the fire within two hours. There was only one minor injury reported. This incident took place eight days after the new facility commenced operations.	137	**278**
#88 **Natural catastrophe**	**Port of Mohammedia, Morocco** 25 November, 2002 Following torrential rain, rising floodwater brought waste oil floating on the surface into contact with hot equipment at the refinery, resulting in explosions and a fire. A second blaze broke out, and several storage tanks reportedly caught fire and exploded. The damage to the refinery was extensive. Two people were killed, with three others reported missing. Later reports indicated that the fire had affected two or three production units, including the crude unit, the 20,000 bbl/d vacuum distillation unit, the 24,000 bbl/d catalytic reformer unit, and the 24,000 bbl/d distillate hydrotreater. It was initially stated that unaffected units would restart within 15 days, while other units would be inoperative for an additional eight to twelve months.	130	**274**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#89 **Mechanical failure**	**Texas City, Texas, US** 30 May, 1978 A failure led to the release of light hydrocarbons, which quickly dispersed and found an ignition source. An intense fire erupted in the tank farm. After less than five minutes, a 5,000 bbl storage sphere tragically failed, resulting in a large fireball and sending fragments of the sphere rocketing throughout the plant. Within 20 minutes, five 1,000 bbl horizontal vessels, four 1,000 bbl vertical vessels, and one additional 5,000 bbl sphere failed, either due to missile damage or a boiling liquid expanding vapor explosion. Fragments from the tanks traveled in all directions, causing additional fires. Some fragments struck the firewater storage tank and electric fire pumps, leaving only the two diesel fire pumps operational.	55	**272**
#92 **Mechanical failure**	**Richmond, California, US** 25 March, 1999 The incident stemmed from a valve bonnet failure within a high-pressure segment of a 60,000 bbl/d hydrocracker. This malfunction led to the release of hydrocarbons, forming a vapor cloud. Subsequently, the cloud ignited, resulting in a substantial fire fueled by high-pressure hydrocarbons. The explosion caused a large section of the pipe rack to collapse, and a significant fin-fan cooler mounted above the rack was destroyed. Multiple pumps were also damaged, and a separator suffered extensive harm. Firefighters, numbering approximately 300, and 33 fire trucks worked for a period of about two and a half hours to bring the fire under control. Approximately 3,200 US gallons of foam concentrate were utilized. The hydrocracker remained out of service for a duration of 12 months.	113	**263**

Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#93 **Mechanical failure**	**Carson, California, US** 23 April, 2001 A fire occurred in the refinery's coker unit, stemming from a piping leak. Significant smoke emissions reached an altitude exceeding 3,000 feet. Consequently, the coker unit was prudently shut down, and this shutdown lasted for approximately two months.	120	**263**
#94 **Mechanical failure**	**Richmond, California, US** 10 April, 1989 A fire incident occurred due to the failure of a two-inch diameter hydrogen gas line pressurized at 3,000 psi, stemming from a weld issue. The fire led to the impingement of flames on the calcium silicate insulation of a reactor skirt standing at a height of 100 feet within the hydrocracker unit. Subsequently, the reactor, featuring a steel skirt with dimensions between 10 and 12 feet in diameter and a wall thickness of 7 inches, sustained damage and fell. This incident resulted in extensive damage to air coolers and various process equipment, amplifying the overall scale of the incident. Notably, the hydrocracker unit was undergoing a maintenance shutdown when the hydrogen leak transpired. The initial leak appears to have originated from a weld failure in the elbow-to-reducer connection of a two-inch diameter hydrogen preheat exchanger bypass line.	90	**261**
#95 **Fire**	**Ryazan, Russia** 7 August, 1994 An incident took place within a crude unit at the 360,000 bbl/d refinery. During maintenance activities, a worker conducted a hot cut, inadvertently releasing material. The probable causes of this incident appear to be inadequate flushing and blinding procedures and a work scope that did not align with typical industry practices.	100	**257**

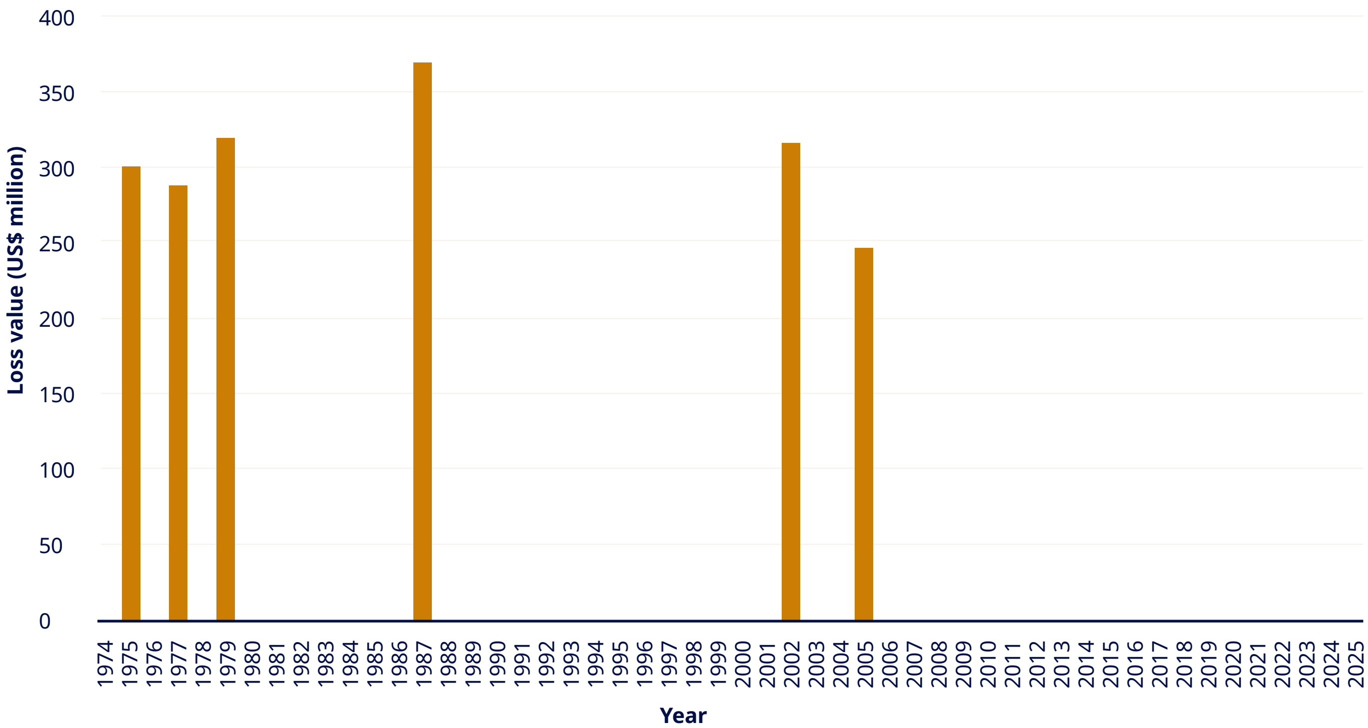
Refining		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#96 **Fire**	**Fort McMurray, Alberta, Canada** 14 March, 2017 A naphtha leak occurred, resulting in the formation of a pooled naphtha at the northeast end of Plant 13-1. This accumulation gave rise to a vapour cloud. Subsequently, the vapour cloud migrated towards a hot exchanger located on another unit, where it ignited, along with the pooled naphtha. This incident led to fire damage, process disturbances, and freeze/thaw events at the plant. An important contributing factor to this loss was the internal component failure in an electrically heat-traced controller.	197	**251**
#97 **Mechanical failure**	**Fort McMurray, Alberta, Canada** 15 August, 1984 In an 82,000 bbl/d fluid bed coking unit, a 10-inch diameter slurry recycle oil line experienced erosion failure, releasing liquids near their auto-ignition temperature. The resulting vapor cloud spread over a large area and ignited immediately, causing a ground fire that led to the failure of additional lines. This incident caused extensive damage to the reactor fractionator, light gas-oil stripper, 15,000-hp air blower, pumps, and pipe racks. Metallurgical analysis revealed that a 1.8-inch-long piece of carbon steel pipe had been inadvertently inserted into the slurry recycle line, worsening the situation. Approximately 2,700 barrels of hydrocarbon liquids were released, significantly complicating firefighting efforts.	75	**251**

100 largest losses by sector *Terminals and distribution*

Over the 49-year period analyzed, only six terminal and distribution losses appear in the top 100 dataset, with the most recent incident dating back to 2005. In fact, no new losses from the terminals and distribution sector have entered the report in the past 20 years.

While large losses are infrequent, the importance of evaluating this sector remains critical, as losses can still occur and have significant consequences, including supply chain disruptions, fuel shortages, price volatility, and environmental damage affecting ecosystems and local communities.

Figure 35. Terminals and distribution losses



Source: Marsh

Terminals and distribution		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#57 **Natural catastrophe**	**Andes, Ecuador** 5 March, 1987 A total of 25 miles of the Trans-Andean pipeline disappeared during the event, resulting in damage to natural gas and gasoline pipelines. All 285 producing wells were taken offline, and oil exports were halted, necessitating a swap agreement with Venezuelan suppliers. The initial earthquake registered 6.0 on the Richter scale, followed by a second one at 6.8, with a total of ten earthquakes recorded. The required repairs extended over several months.	120	**371**
#77 **Fire**	**Bantry Bay, Ireland** 8 January, 1979 A significant incident unfolded involving an 11-year-old tanker with a weight of 121,000 deadweight tons, which had recently discharged its first Arabian heavy crude parcel at a deep-water port. No transfer activities were occurring between the ship and the jetty when a small fire was detected on the ship's deck. Within about 10 minutes, the fire rapidly expanded across the vessel, extending into the surrounding sea on both sides. After approximately 30 minutes, a massive explosion took place. This occurrence appears to have been set in motion by the buckling of the ship's structure, particularly around the deck level, swiftly followed by explosions within the ballast tanks and the ship breaking. These events resulted from the interplay of two critical factors: 1) significant hull weakening due to inadequate maintenance, and 2) excessive stress due to erroneous ballasting practices at the time of the incident. Consequently, the ship was entirely lost, and extensive damage was inflicted on the concrete and steel jetty, extending to 1,130 feet.	70	**321**

Terminals and distribution		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#80 Explosion	**Raudhatain, Kuwait** 31 January, 2002 In an explosion and fire that consumed the oil gathering center, gas booster station, and power substation, a severe incident unfolded. Triggered by a leak from a buried oil pipeline at the gathering station, the explosion propagated to a power substation, sparking a fierce blaze. The rapid flash explosion and ensuing fire wrought significant damage upon the gathering center and adjacent gas booster station. Nineteen people suffered injuries, predominantly characterized as first- and second-degree burns. Four individuals lost their lives during this tragic event. The fire was successfully extinguished two days following the incident.	150	**317**
#83 Collision	**Marcus Hook, Pennsylvania, US** 31 January, 1975 The United States flag tanker "Edgar M. Queeny" collided with the Greek tanker "Corinthos" while the latter was unloading 400,000 barrels of crude oil at a refinery jetty in Marcus Hook on the Delaware River. The collision led to a massive initial explosion, followed by subsequent explosions and fires on the Greek ship. The incident resulted in the loss of twenty-five crew members on board the Corinthos, as well as one crewman from the American tanker. The Corinthos subsequently sank and was later salvaged for scrapping.	50	**301**
#85 Mechanical failure	**Abqaiq, Saudi Arabia** 11 May, 1977 A 30-inch diameter crude oil pipeline ruptured, leading to the destruction of three spheroids, pumping units, and other equipment. The ignition of the released oil was caused by motor vehicles.	55	**289**

Terminals and distribution		Original loss value (US$ million)	Adjusted property loss value 2025 (US$ million)
#98 **Fire and explosion**	**Hemel Hempstead, Hertfordshire, UK** 11 December, 2005 At a fuel terminal, a gasoline storage tank was being filled from a pipeline when safety systems and barriers designed to prevent overfilling failed. This failure caused gasoline to spill from vents on the tank roof, releasing a heavy, flammable vapor cloud that ignited. The initial explosion set off a series of subsequent explosions and fires throughout the terminal. Firefighters battled the blaze for several days before fully extinguishing the flames. The incident resulted in injuries to over 40 people and caused extensive damage to nearby properties and businesses, forcing approximately 2,000 residents to be displaced.	164	**248**

Risk engineering position papers

A Marsh risk engineering position paper defines the high-level standards expected in the oil, gas, and petrochemical industries. They include technical guidance, share best practices, and include suggestions for improving operations.

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- Management of organizational change (minimum staffing)
- Management of temporary repairs
- Managing the defeat of safety instrumented systems (SIS) trips and alarms
- Pneumatic pressure testing
- Pre-start-up safety review
- Process hazard analysis
- Process isolations
- Process safety performance indicators
- Remotely operated emergency isolation valves (ROEIVs)
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