MARSH

The 100 Largest Losses 1974-2015

Large property damage losses in the hydrocarbon industry
24th edition

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FOREWORD

As I was flying out of Houston on April 21, 2010, on one of the first flights out after the Icelandic volcanic ash eruption, I heard a brief news story that an oil rig had caught fire in the Gulf of Mexico. Little did I know that this was the Deepwater Horizon-Macondo accident, which eventually became the largest blowout and offshore oil spill in history. More pertinently, it was a tragedy in which 11 people lost their lives and 17 others were injured. In human, financial, and reputational terms this was a major avoidable tragedy, and it is one which features prominently in this latest edition of Marsh's unique and valuable catalogue of the largest hydrocarbon industry losses.

Back home, I became heavily involved in explaining through the media the engineering facts behind the unfolding safety and environmental disaster. Subsequently, in the review of the UK offshore oil and gas regulatory system, I sought to understand the lessons that could be learned from the root causes of the accident and the way the process was managed. One of the major findings of that enquiry was that there is still much scope for improved processes to ensure that lessons are learned from every incident – not just from accidents, but also from near-misses and unexpected occurrences – and are then communicated clearly across the industry around the world.

Marsh's *100 Largest Losses* is firmly established as the key industry record of major incidents, and a helpful aid to assist companies, regulators, and researchers alike to digest lessons from past failures and build much more robust and reliable process safety management (PSM) systems. It deserves careful study, for the grim history it catalogues also demonstrates that lessons are still not readily learned from previous accidents, despite the fact that similar well-identified root causes underlie accidents across different sectors.

So although they make grim reading, the accidents recorded in this 24th edition of Marsh's *100 Largest Losses* are a stark reminder and wake-up call to all in the process engineering sector that we need to learn from every incident. From top management to process operator, everyone has a role to play in ensuring we have appropriate robust safety procedures and that they are fully and professionally maintained and implemented.

That is why IChemE is so passionate about the pivotal role of process safety awareness and training across the engineering industries and, through its Global Safety Center, sets out to play its role in accrediting the best safety people and identifying and spreading best practice – communicating lessons learned. The Center works closely with similar organisations such as the Mary Kay O'Connor Center in Texas to ensure that the world of process safety is one of continuous improvement.

Although the financial losses documented in this volume are high, the human losses are of course far more significant and irreplaceable. So while I am very pleased to write this foreword and commend this publication to you, it is my earnest wish that it will one day no longer need to be updated – that we really do learn how to learn from the failures of the past and that loss of life from process accidents becomes a thing of the past. It is in all our hands.

Therefore, please use this book to alert yourself and your organization to where, in your own process operations, there might be as yet unidentified risks and what needs to be done to manage them safely. I hope you will find the lessons and insights embedded in the pages of *100 Largest Losses* as valuable in your management of process safety as I do.

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IMPACT OF THE PRICE OF OIL

Over the past 20 months, oil prices have fallen by around 70%. The substantial fall in price (from US$115 in June 2014) has had a significant impact on the global oil and gas industry, resulting in significant changes in the strategic decision-making of industry players around the world. This, coupled with lower-than-projected demand due to the slowing of economies like China, is resulting in major projects being postponed or even canceled, in addition to significant reductions in staffing numbers. For example, the US Bureau of Labor Statistics reported a reduction of employment in oil and gas production between October 2014 and November 2015 in the US alone of 87,000, from a peak of 538,000 to 440,000[1]. This represents a reduction in employment in this segment of industry of 18.2% in just 13 months.

There is a concern, from a process safety and loss control point of view, that lower revenues from oil and gas production and falling demand could potentially result in reductions in investment in risk-control measures; to the point that a reduction in maintenance and inspection activity could result in compromises to asset integrity.

Of course, it's not the first time the oil industry has been subject to rapid variations in the price of crude oil, and it is highly informative when we look at the historical precedent of major loss trends compared with the oil price variation (see FIGURE 1).

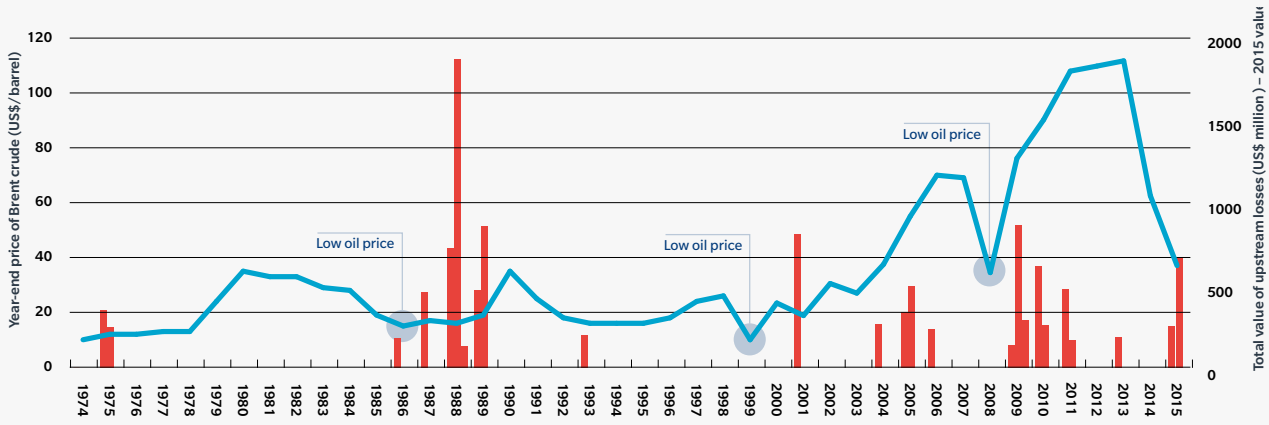
DO COST SAVINGS RESULT IN MORE LOSSES?

Significant reductions in the crude oil price also occurred between 1980 and 1986 when the price of Brent crude fell from US$35 to US$15 per barrel. In the late 1990s, the price fell again, this time below US$10 per barrel, and in 2008 it fell from more than US$100 per barrel to US$32.

Looking at the distribution of upstream losses in the 100 largest losses list, we can see that there was a significant frequency of losses in the years 1986 to 1988 and a cluster of high-value losses between 2008 and 2010. Both of these instances occurred either during or immediately after significant reductions in the crude oil price.

[1] *Current Employment Statistics,* US Bureau of Labor Statistics, November 2015.

FIGURE 1 CRUDE OIL PRICE VERSUS UPSTREAM LOSSES BY YEAR – 1974-2015
Source: Marsh Research



It is understood that correlation does not mean causation: the fact that a relationship is observed between two variables does not always mean there is a direct linkage between them. It is also important to remember that the cause of every major loss is a combination of a unique and complex interaction of faults and failures of hardware systems, management systems, human error, and/or emergency procedures.

COST-SAVING INITIATIVES

Following the low oil price in the early 1990s, initiatives were devised to reduce the cost of oil and gas production operations. These required risk-based assessment work to prioritize inspection and maintenance activity and reduce staffing levels based on an assessment of needs. They were very successful in maintaining operations in mature fields and making marginal fields operationally viable.

However, both at the same time as, and in response to, the rapid changes in revenue from oil production, there were reductions in investment in safety measures and training. Today, there is a concern that some of these may have resulted in an increase in the risk of major accidents by compromising the effectiveness of critical loss prevention measures.

LEARNING LESSONS FROM THE PAST

With today's new oil price paradigm, it is important that the industry looks to the past for lessons on how best to manage cost savings in a measured manner that limits any potential downside.

This includes taking decisions based on the conclusions of assessments to ensure that any risks of major losses introduced by changes to safety expenditure are reduced and mitigated effectively. For example, any significant organizational changes as a result of staffing reductions should be subject to an organizational management of change assessment – including a risk assessment – to ensure that any risk introduced as a result of loss of knowledge or expertise due to staffing changes is mitigated.

In such instances, it is also important to ensure that critical inspection and maintenance tasks continue to be delivered on schedule. Senior managers should therefore receive regular reports of key performance indicators (KPIs) regarding maintenance and inspection performance. These should be selected and tracked so that they are indicative of the key tasks required to maintain process safety performance.

When carried out in ways such as these, cost-saving initiatives will have long-term value and impact, rather than simply transferring savings today into major costs tomorrow.

ADJUSTING TO THE NEW NORMAL

Many forecasters are predicting that oil prices will remain low for some time to come. It is vital that cost-saving measures implemented by oil companies are considered and measured. Cuts that extend too deeply into an organization could have a significant impact on loss records and, ultimately, cost more to rectify than they initially saved.

BUSINESS INTERRUPTION LOSSES

The loss values included in the latter half of this report relate to the ground-up property damage loss values, which represent the total cost to repair and/or rebuild the facility and to return it to the condition that it was in prior to the loss. Within the energy sector, however, the total cost of insurance claims associated with major losses can often be dominated by the compensation for commercial loss suffered as a result of the facility being shut down.

As a result, major energy industry operators routinely purchase business interruption (BI) insurance to ensure that they are able to continue their business in the event that a major accident results in a significant interruption to a key revenue stream.

The size of a BI claim is dependent upon the commercial loss suffered by the insured during the period that a plant is restricted in its operation as a result of the insured damage. BI insurance claims can therefore be complex, as insurers and the insured need to agree on the market conditions that would have been expected from the time of the loss until normal operations are resumed.

Because of complexities such as these and the confidential nature of the data, it is much more challenging to obtain detailed information on losses and the size of claims. The information is often kept confidential because, if released, it could be analyzed by competitors to determine the profitability of a facility that has suffered a loss, potentially resulting in the insured losing a competitive advantage.

The size of BI claims are also strongly dependent upon the detail of the insurance cover purchased, the waiting period selected, and the market conditions at the time. The operator of the asset will have selected the BI insurance on the basis of their appetite for risk; that is, how large a loss they can tolerate before they require support from insurers.

Typically, BI claims following losses in the energy sector are two or three times the size of the property-loss value and, in some circumstances, can be much more than that. For example, where process units that make a significant contribution to refinery or chemical plant margins are dependent for their continued operation on a single un-spared machine (such as a compressor or high-pressure pump), loss of that machine can have a disproportionate impact on the profitability of the business.

Typically, BI claims following losses in the energy sector are two or three times the size of the property-loss value, and, in some circumstances, can be much more than that.

A typical machinery breakdown loss may have a value of a few million dollars, but it could potentially result in the shutdown or reduced throughput of a whole facility for the period during which a replacement machine is sourced and delivered. As evidenced by instances such as these, there is the potential for a relatively small machinery breakdown claim to result in a very substantial BI loss.

It is therefore important that, when reviewing critical items of plant and machinery for inspection, maintenance, and spare parts, consideration is given to the potential for loss of business in the event of equipment failure.

From the limited information that we are able to obtain about the size of BI insurance claims, and understanding that this is an incomplete picture, the following are identified as some of the energy sector's losses that have resulted in large BI claims.

FIGURE 2 SELECTED BUSINESS INTERRUPTION LOSS VALUES FOR EVENTS LISTED IN THE *100 LARGEST LOSSES*
Source: Marsh Research

DATE	PLANT TYPE	EVENT TYPE	LOCATION	COUNTRY	BUSINESS INTERRUPTION LOSS (US$ MILLIONS)1
06/03/2008	DISTRIBUTION	EXPLOSION	VARANUS ISLAND	AUSTRALIA	1,500
01/04/2005	REFINERY	EXPLOSION	FORT MCMURRAY	CANADA	870
07/26/1996	GAS PROCESSING	EXPLOSION	CACTUS, REFORMA	MEXICO	750
10/23/1989	PETROCHEMICAL	EXPLOSION	PASADENA, TEXAS	USA	680
01/06/2011	REFINERY	EXPLOSION	FORT MCKAY	CANADA	620
02/04/2011	UPSTREAM	PRODUCTION LOSS	NORTH SEA	UK	500
08/14/2001	REFINERY	FIRE	LEMONT, ILLINOIS	USA	330
11/14/1987	PETROCHEMICAL	EXPLOSION	PAMPA, TEXAS	USA	300
03/25/1999	REFINERY	EXPLOSION	RICHMOND, CALIFORNIA	USA	240

It is therefore important that, when reviewing critical items of plant and machinery for inspection, maintenance, and spare parts, consideration is given to the potential for loss of business in the event of equipment failure.

NOTES:

1 Values represent the financial loss at the time of the loss, converted to US$, using a rate of exchange at the date of the loss.

NEWLY QUALIFYING LOSSES: TO HAVE OCCURRED SINCE MARCH 2014

The following are the largest losses to have occurred in the hydrocarbon industry since the publication of the 23rd edition of *The 100 Largest Losses* in 2014, and that are of sufficient size to make the 100 largest losses list. Further details of these losses are available in the relevant sections of the publication.

FIGURE 3 LARGESTLOSSES 2014-2015
Source: Marsh Research

DATE	PLANT TYPE	EVENT TYPE	LOCATION	COUNTRY	PROPERTY LOSS (US$ MILLIONS)
02/11/2015	UPSTREAM	EXPLOSION	CAMARUPIM FIELD	BRAZIL	250
04/01/2015	UPSTREAM	FIRE	BAY OF CAMPECHE	MEXICO	>1,000
08/13/2015	PETROCHEMICALS	EXPLOSION	LITVINOV	CZECH REPUBLIC	177

NATURAL-CATASTROPHE ACCUMULATION

Although it is considered that the frequency and magnitude of severe weather events are increasing, there have been limited events over the last two years that have resulted in major energy sector losses.

In late 2015, there was a major fire on an offshore platform in the Caspian Sea that was reported to have resulted in 30 fatalities. This was as a result of damage to a gas pipeline in severe weather. It has not been possible to obtain an estimate of the property damage value associated with this loss.

An earthquake in Japan in 2014 was reported to have resulted in a fire in the ethylene unit and shutdown of all of the production units. The fire was extinguished within two hours and there were no reports of extensive fire damage.

FIGURE 4 DISTRIBUTION OF THE 100 LARGEST LOSSES BY YEAR
Source: Marsh Research

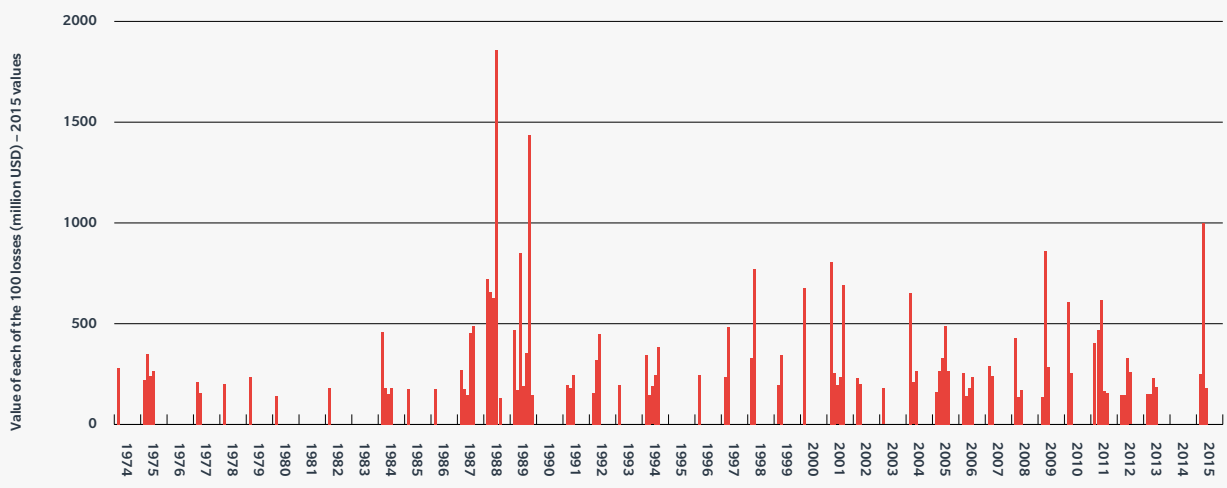


FIGURE 5 THE 20 LARGEST LOSSES 1974-2015
Source: Marsh Research

DATE	PLANT TYPE	EVENT TYPE	LOCATION	COUNTRY	PROPERTY LOSS (US$ MILLIONS)
07/06/1988	UPSTREAM	EXPLOSION	NORTH SEA	UK	1,860
10/23/1989	PETROCHEMICALS	EXPLOSION	PASADENA, TEXAS	USA	1,440
04/01/2015	UPSTREAM	FIRE	BAY OF CAMPECHE	MEXICO	>1,000
06/04/2009	UPSTREAM	COLLISION	NORTH SEA	NORWAY	860
03/13/1989	UPSTREAM	EXPLOSION	GULF OF MEXICO	USA	850
01/15/2001	UPSTREAM	EXPLOSION	CAMPOS BASIN	BRAZIL	810
09/25/1998	GAS PROCESSING	EXPLOSION	LONGFORD, VICTORIA	AUSTRALIA	770
04/24/1988	UPSTREAM	BLOWOUT	CAMPOS BASIL	BRAZIL	720
09/21/2001	PETROCHEMICALS	EXPLOSION	TOULOUSE	FRANCE	690
06/25/2000	REFINERY	EXPLOSION	MINA AL-AHMADI	KUWAIT	680
05/04/1988	PETROCHEMICALS	EXPLOSION	HENDERSON, NEVADA	USA	660
01/19/2004	GAS PROCESSING	EXPLOSION	SKIKDA	ALGERIA	650
05/05/1988	REFINERY	EXPLOSION	NORCO, LOUISIANA	USA	630
03/11/2011	REFINERY	EXPLOSION	SENDAI	JAPAN	620
04/21/2010	UPSTREAM	EXPLOSION	GULF OF MEXICO	USA	610
07/27/2005	UPSTREAM	EXPLOSION	MUMBAI HIGH NORTH FIELD	INDIA	490
11/14/1987	PETROCHEMICALS	EXPLOSION	PAMPAS, TEXAS	USA	490
12/25/1997	GAS PROCESSING	EXPLOSION	BINTULU, SARAWAK	MALAYSIA	480
02/04/2011	UPSTREAM	STORM	NORTH SEA	UK	470
01/20/1989	UPSTREAM	BLOWOUT	NORTH SEA	NORWAY	470

NOTES:

1 Inflated to December 2015 values. Values are ground-up, property damage only.

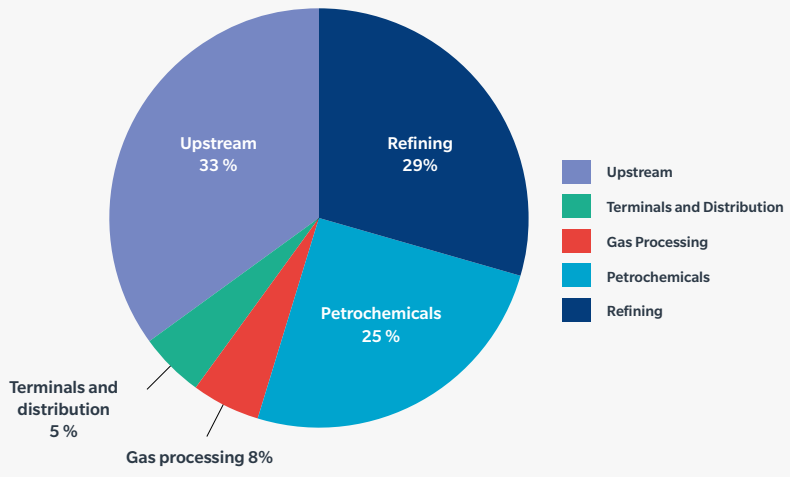
Although it is considered that the frequency and magnitude of severe weather events are increasing, there have been limited events over the last two years that have resulted in major energy sector losses.

UPSTREAM, REFINERIES, AND PETROCHEMICALS DOMINATE PROPERTY DAMAGE VALUES

Based on 2015 property damage values, the total accumulated value of the 100 largest losses listed in this report is more than US$33 billion. As shown in FIGURE 6, the property damage values are dominated by the upstream and refining sectors, closely followed by the petrochemicals sector. The gas processing and distribution sectors account for a much smaller fraction of the total value. This reflects the smaller capital value of individual assets in these sectors, which limits the size of the largest potential losses associated with these activities.

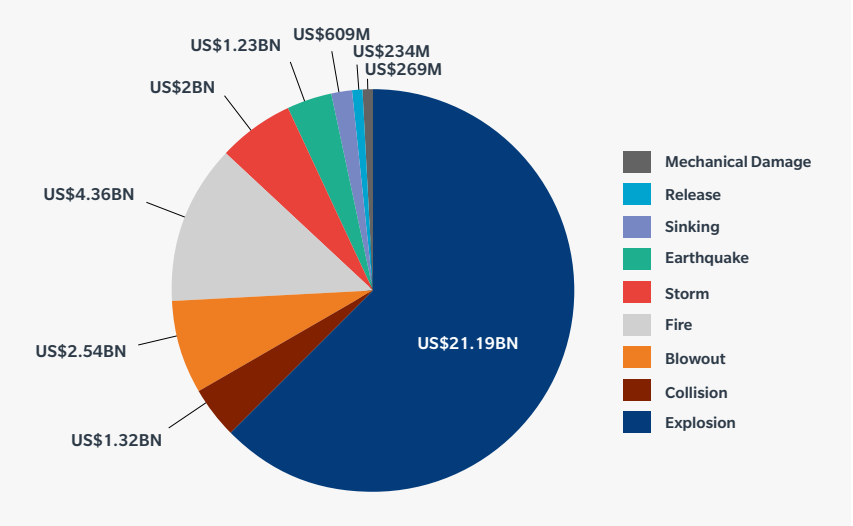
The gas processing and distribution sectors account for a much smaller fraction of the total value.

FIGURE 6 PERCENTAGE OF PROPERTY DAMAGE VALUES OF 100 LARGEST LOSSES BY SECTOR
Source: Marsh Research



EXPLOSIONS ACCOUNT FOR NEARLY TWO THIRDS OF LOSSES

FIGURE 7 PROPERTY DAMAGE VALUES OF 100 LARGEST LOSSES BY EVENT TYPE (US$ MILLIONS)
Source: Marsh Research



Explosions account for the greatest frequency of losses, by far, in the energy sector (SEE FIGURE 7). These are typically vapor-cloud explosions (VCEs) that occur following the loss of containment of light hydrocarbons, which consequently form a cloud, engulf a congested or confined area, and find a source of ignition. The resulting explosions produce shockwaves with enough energy to cause substantial physical damage to process plants and equipment. There are also examples of dense phase explosions – explosions of solid materials such as ammonium nitrate which, if contaminated, have the potential to detonate in a similar manner to TNT.

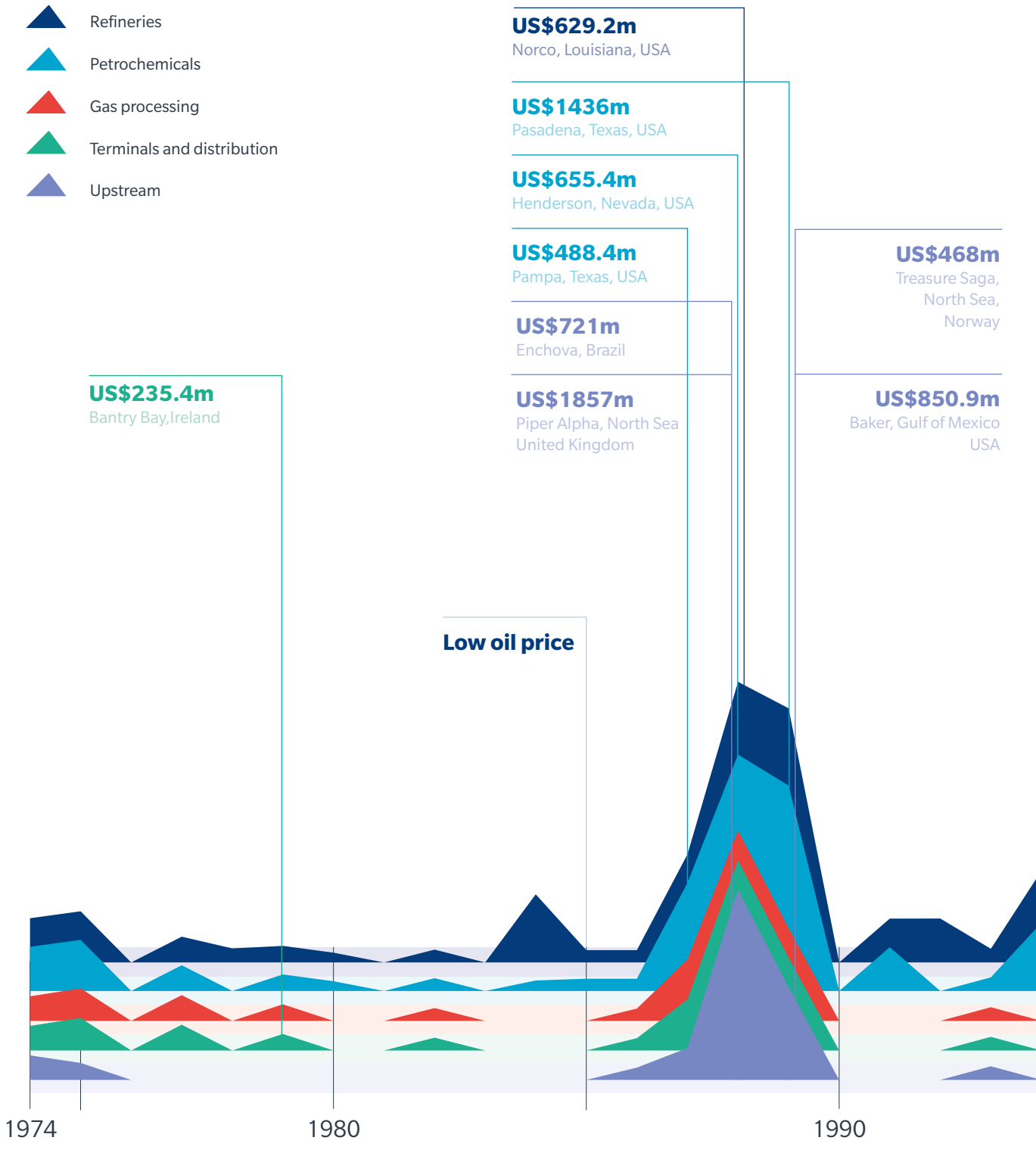
Due to explosions accounting for such a high proportion of property damage loss values, significant effort and investment is currently being put into updating the methodology to estimate potential losses as a result of explosions.

Where the maximum foreseeable property damage loss is less than the total value of the asset (due to there being no foreseeable credible accident that has the potential to result in the catastrophic loss of the whole asset), it may be appropriate to link the insurance purchased to the foreseeable maximum loss, rather than the total value of the asset. For this purpose, risk engineers will determine an estimated maximum loss (EML) value for the property loss value associated with the largest foreseeable property damage accident scenario.

It is therefore necessary to be able to model the likely consequences of explosions on energy assets in terms of insurable physical damage. The accuracy of such modeling is dependent on an understanding of the physical layout of the asset, the distribution of property value, the physical and chemical properties of the hydrocarbons being processed, and the congestion and confinement of the plant structures. With this information and a well-validated software model, it is possible to calculate an estimate of the property damage loss associated with an explosion event. This vital information can be used to prioritize risk reduction and control measures, and to support decision-making with respect to risk mitigation and risk transfer.

Due to explosions accounting for such a high proportion of property damage loss values, significant effort and investment is currently being put into updating the methodology to estimate potential losses as a result of explosions.

FIGURE 8 **PROPERTY DAMAGE VALUE OF 100 LARGEST LOSSES BY SECTOR**
Source: Marsh Research



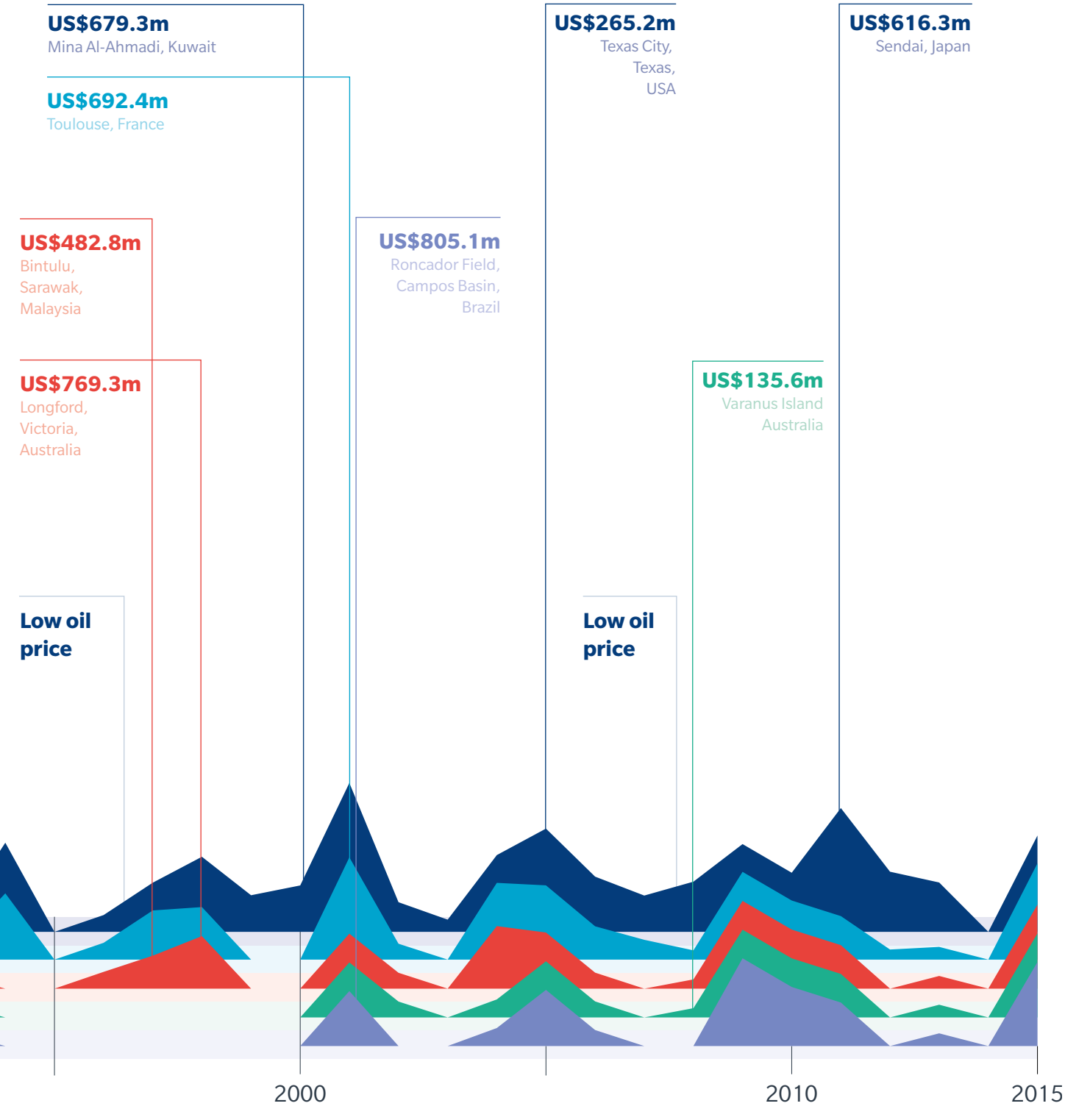
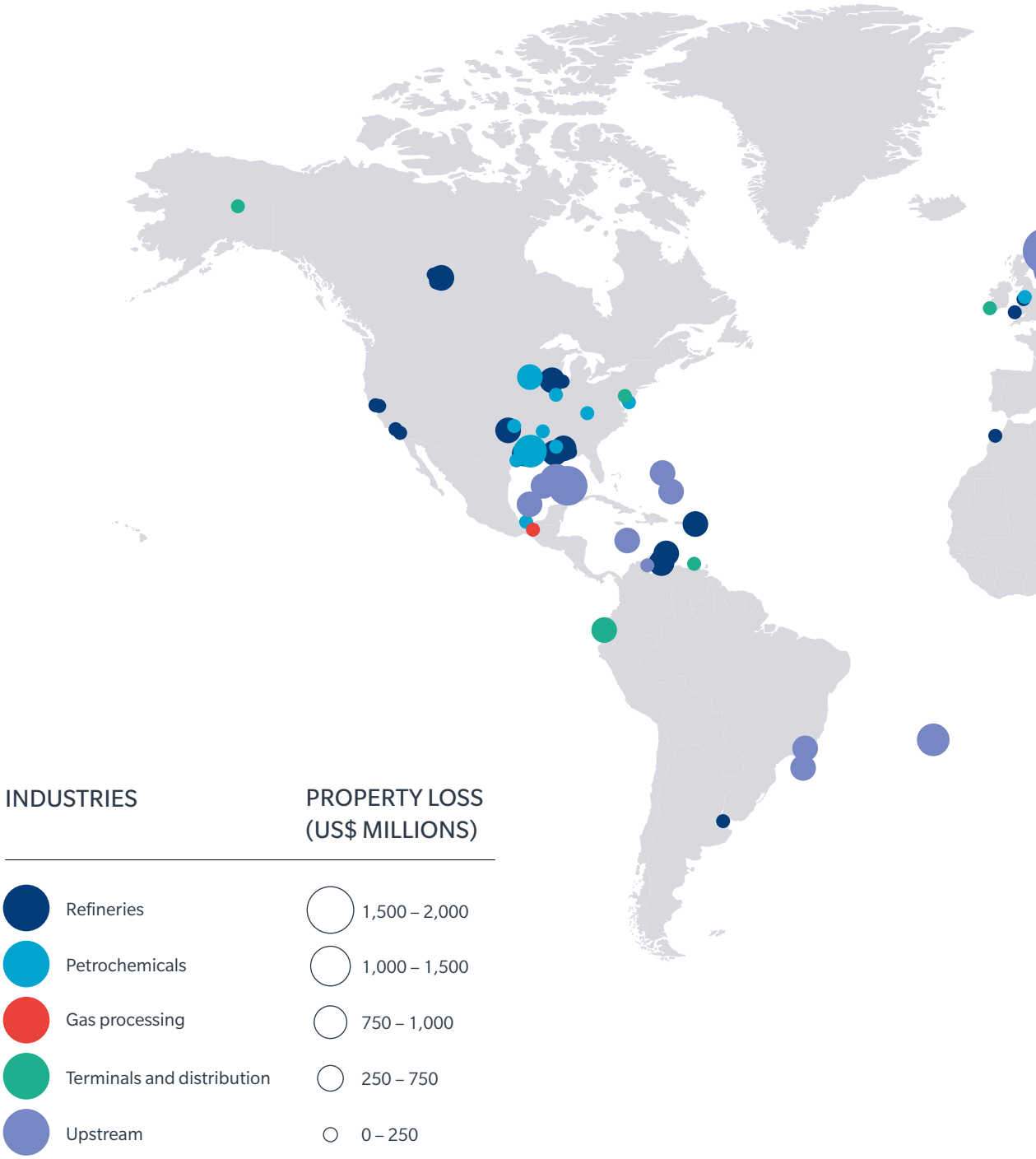
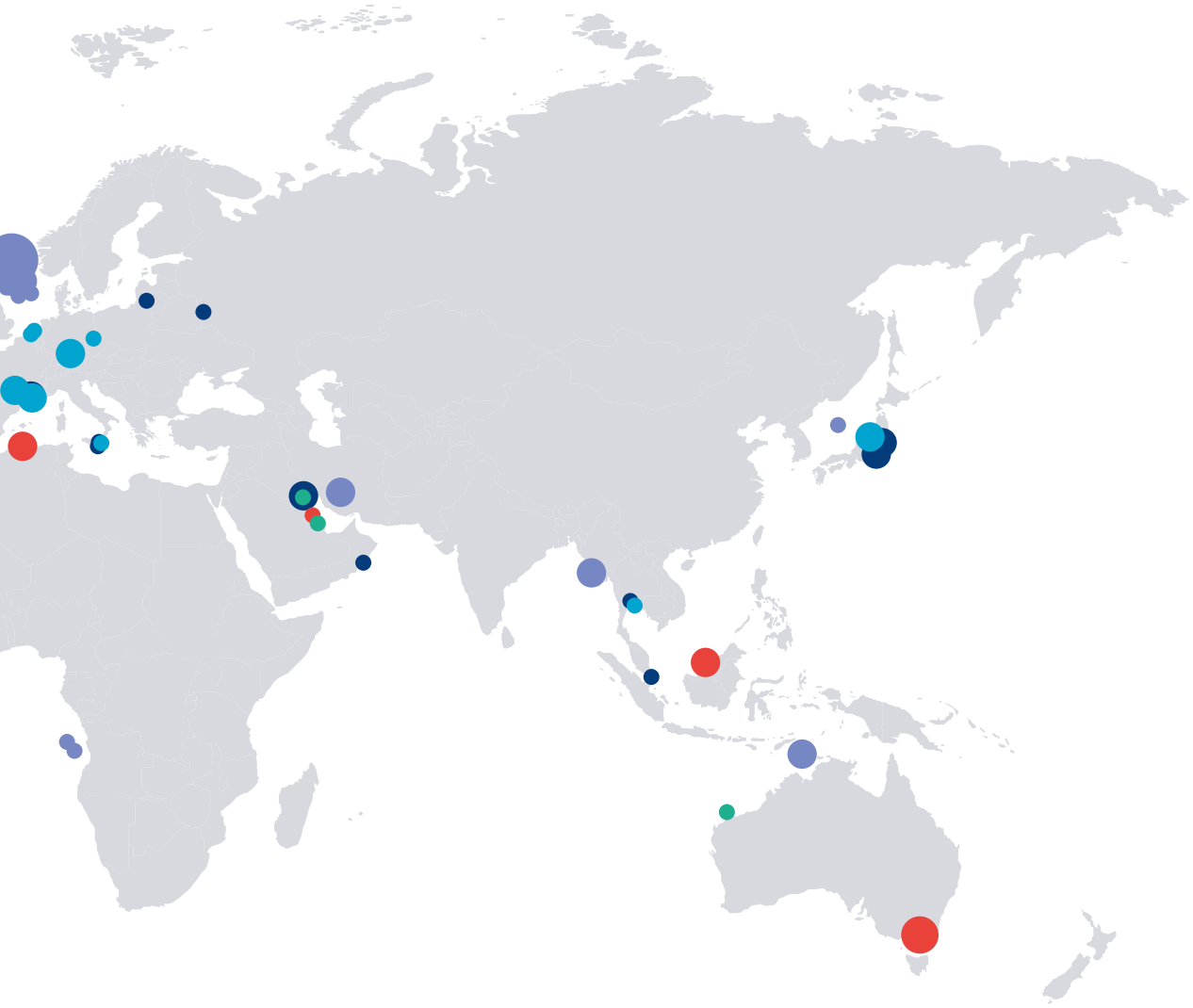

US$679.3m
Mina Al-Ahmadi, Kuwait
US$692.4m
Toulouse, France
US$482.8m
Bintulu, Sarawak, Malaysia
US$769.3m
Longford, Victoria, Australia
Low oil price
US$805.1m
Roncador Field, Campos Basin, Brazil
US$265.2m
Texas City, Texas, USA
Low oil price
US$135.6m
Varanus Island Australia
US$616.3m
Sendai, Japan
2000
2010
2015

FIGURE 9 **GEOGRAPHICAL DISTRIBUTION OF 100 LARGEST LOSSES**
Source: Marsh Research





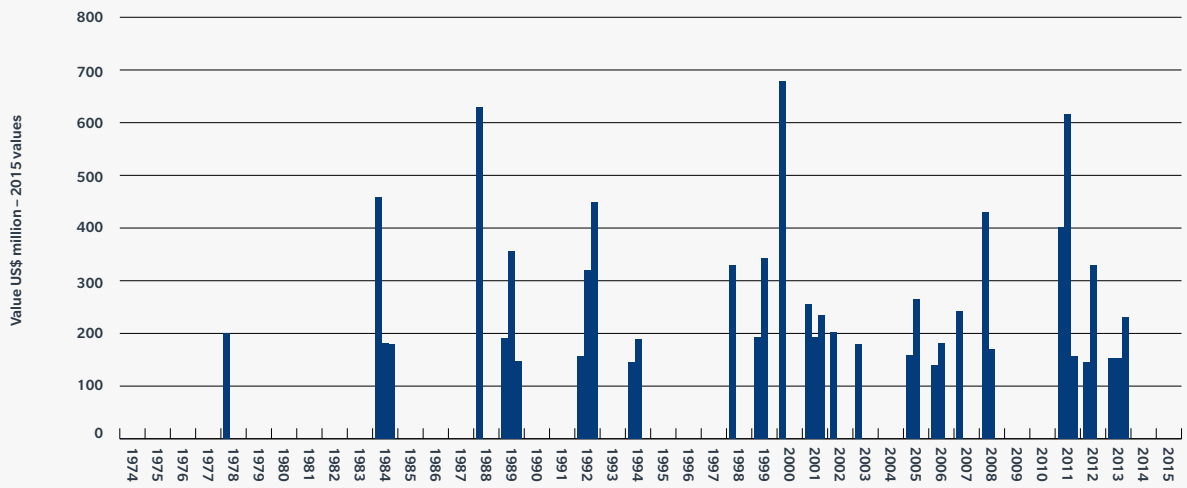
REFINERIES

For refineries, there has been an increasing trend in the frequency and size of losses (SEE FIGURE 10).
For the large part, the worldwide group of oil refineries is, with some significant exceptions, a collection of aging assets with an average age in excess of 35 years.
These older assets have therefore commonly been subject to expansion projects and revamping to increase their throughput rates and the earnings for each barrel that is processed. This is considered to have resulted in higher levels of complexity at these refineries and a greater level of concentration of asset value.

In addition, in recent years there have been periods when refining margins have been significantly reduced, resulting in reduced profits and some operators pushing the crude oil processing envelopes.

Together, these factors are considered to have contributed to the increasing frequency and property damage value of losses occurring in the sector.

FIGURE 10 REFINERY PROPERTY DAMAGE LOSSES BY YEAR
Source: Marsh Research



DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ESTIMATED CURRENT VALUE US$ MILLION
05/30/1978	EXPLOSION	TEXAS CITY, TEXAS US	55	199.6

A failure led to the release of light hydrocarbons that dispersed and found an ignition source. An intense fire followed in the tank farm. After less than five minutes, a 5,000-bbl storage sphere failed, which resulted in a large fireball and rocketed pieces of the sphere throughout the plant. Within the next 20 minutes, five 1,000-bbl horizontal vessels, four 1,000 bbl vertical vessels, and one additional 5,000 bbl sphere failed, either as a result of missile damage or due to a boiling liquid expanding vapor explosion (BLEVE). Pieces of the tanks traveled in all directions, falling into a number of operating units and tank farms, starting more fires. Fragments also hit the firewater storage tank and electric fire pumps, leaving only the two diesel fire pumps operational.

07/23/1984	EXPLOSION	ROMEOVILLE, ILLINOIS US	191	458

Just prior to the rupture of a 55-foot-tall, 8.5-foot-diameter monoethanolamine absorber column, a refinery operator noted a six-inch-long horizontal crack at a circumferential weld which was leaking propane. As the operator attempted to close the inlet valve, the crack spread to about 24 inches. The area was being evacuated and the plant fire brigade was arriving when the column failed. Propane at 200 psig and 100ºF propelled most of the 20-metric ton-vessel 3,500 feet, where it struck and toppled a 138,000-volt power transmission tower.

The weld separation occurred along a lower girth weld joint made during a repair to the column 10 years earlier. The vessel was constructed of one-inch-thick ASTM SA 516 Gr 70 steel plates, rolled and welded with full penetration submerged arc joints, but without post-weld heat treatment.

This explosion resulted in severe fires in the unsaturated gas plant, as well as fires in the fluid catalytic cracker (FCC) and the alkylation units. After about 30 minutes, a BLEVE occurred in a large process vessel in the alkylation unit. One piece of this vessel travelled 500 feet shearing off pipelines before striking a tank in the water treatment unit. Another fragment landed in a unifining unit more than 600 feet away, causing a major fire where it landed.

The first explosion, believed to be from a vapor cloud, broke windows up to six miles from the plant. The explosion also caused extensive structural damage to refinery service buildings and disrupted all electric power at the refinery, rendering a 2,500-US-gallons-per-minute (US-gpm) electric fire pump inoperable. One explosion sheared off a hydrant barrel, resulting in a reduction of fire water pressure from the two 2,500-US-gpm, diesel-engine-driven fire pumps, which were operating at the time. The refinery's blast-resistant control center, approximately 400 feet northeast of the absorber, sustained little structural damage.

An estimated 30 paid and volunteer public fire departments, together with equipment from refineries and chemical plants within a 20-mile radius, responded promptly. Many of the pumpers took suction from the adjoining canal and from a quarry. The pumpers and a 12,000 US-gpm pump on a fireboat eventually provided water at pressures sufficient for fire fighting.

08/15/1984	FIRE	FORT MCMURRAY, ALBERTA CANADA	76	182.2

Erosion failure in a 10-inch-diameter slurry recycle oil line in an 82,000 bbl/d fluid bed coking unit released liquids close to their autoignition temperature. A vapor cloud, which covered a large area, ignited almost immediately, resulting in a ground fire covering a large area and the failure of six or seven additional lines. The fire eventually extended over a 150-feet-diameter area with damage in the unit structure up to a height of more than 100 feet. Metallurgical examination revealed that a 1.8-inch-long piece of carbon steel pipe had inadvertently been inserted into the slurry recycle line made of 5-chrome during an earlier metals inspection.

The reactor fractionator, light gasoil stripper, 15,000-hp air blower, pumps, and pipe racks were severely damaged or destroyed.

About 2,700 barrels of hydrocarbon liquids were released from process equipment during the fire. Much of this was by gravity flow from ruptured lines, although pumps, which could not be shut down, contributed much of the flow. A 900-psig steam line, which supplied the turbine drivers of the compressors, ruptured hampering fire fighting efforts.

12/13/1984	EXPLOSION	AMUAY VENEZUELA	75	179.8

A straight run of eight-inch-diameter line carrying hot oil from the high pressure separator to the low pressure stripper in a refinery Hydrodesulphuriser fractured circumferentially in the parent metal in the heat zone about 1.5 inches from a weld. Hot oil at 700 psi and 650 ºF sprayed across the roadway into the hydrogen units where ignition occurred.

An intense fire around the pipe rack in the hydrogen plant caused a 16-inch-diameter gas line to rupture, adding a second blow torch to the fire. More pipes ruptured with explosive force in adjacent areas.

The fire resulted in a crash shutdown of the entire 600,000 bbl/d refinery. After six and a half hours, the fire was extinguished. Damage was extensive. The three hydrogen plants and the four hydrodesulfurization (HDS) units were heavily damaged or destroyed. Before the loss, the line which failed was judged as having excessive vibration. It is believed that the hot oil line failed due to fatigue, considered in turn to be largely due to hydrogen embrittlement.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ESTIMATED CURRENT VALUE US$ MILLION
05/05/1988	EXPLOSION	NORCO, LOUISIANA US	288	629.2

Operations were normal in a 90,000 bbl/d fluid catalytic cracking (FCC) unit when internal corrosion caused the failure of the outside radius of an eight-inch-diameter carbon steel elbow, located 50 feet above grade in the depropaniser column overhead piping system. An estimated 20,000 lb of C3 hydrocarbons escaped through the resulting hole, forming a large vapor cloud during the 30 seconds between failure and ignition. Both the depropaniser column (operating at 270 psi and 130 ºF) and the depropaniser accumulator depressurised through the opening. Ignition of the vapor cloud was probably caused by the FCC charge heater.

The initial blast destroyed the FCC control building and toppled the 26-foot-diameter main fractionator from its 15-foot-high concrete pedestal. The column separated from its 10-foot-high skirt before falling. Analysis of bolt stretching of towers in the blast path indicated over pressures as high as 10 psi.

The refinery immediately lost all utilities, including fire water and the four diesel fire pumps, greatly limiting the fire-fighting effort for several hours. Steam pressure dropped abruptly due to severed lines. 20 major line or vessel failures occurred in the FCC and elsewhere throughout the 215,000 bbl/d refinery. Blast damage throughout the plant was extensive, but was most severe in the FCC unit. About 5,200 property claims were received for off-site damage at distances of up to six miles. The FCC unit was eventually demolished and one was constructed.

A preliminary report stated that the failed elbow was located downstream of an injection point where ammoniated water was added to reduce depropaniser condensation or fouling. The elbow was a designated inspection point in the overhead piping system for taking ultrasonic thickness measurements during turnarounds. These inspections had constantly shown the expected corrosion rates of 0.05 mils per year. Measurements taken at the failed elbow and in the downstream piping after the explosion revealed unexpectedly high localized corrosion rates.

04/10/1989	FIRE	RICHMOND, CALIFORNIA US	90	191.5

A two-inch-diameter line carrying hydrogen gas at 3,000 psi failed at a weld, resulting in a high pressure hydrogen fire. The fire resulted in flame impingement on the calcium silicate insulation of the skirt for a 100-feet-high reactor in a hydrocracker unit. The steel skirt for this reactor, which was between 10 and 12 feet in diameter and had a wall thickness of seven inches, subsequently failed. The falling reactor damaged air coolers and other process equipment, greatly increasing the size of the loss.

At the time of the loss, the hydrocracker unit was being shut down for maintenance and the reactor was in a hydrogen purge cycle. The initial hydrogen leak is believed to have resulted from the failure of an elbow to reducer weld in the two-inch-diameter hydrogen preheat exchanger by-pass line.

09/18/1989	MECHANICAL DAMAGE	ST CROIX, VIRGIN ISLANDS US	167	355.3

Hurricane Hugo struck this refinery, causing extensive damage to 14 of the 500,000 - 600,000-bbl storage tanks in the tank farm area, the administration building and the company housing. The damage to process units, which were idled in preparation for the hurricane, was limited to the asbestos insulation on process columns and piping. A maximum wind speed of 192 mph was reported for this hurricane before the wind speed measuring device at the St. Croix airport was damaged.

Because of the damaged asbestos insulation, approximately 1,500 company employees and contractors worked seven days a week for 15 weeks to remove the asbestos debris from the refinery at a substantial extra expense.

A contractor specializing in the construction of atmospheric storage tanks worked for more than one year rebuilding the 14 storage tanks damaged in the tank farm area.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ESTIMATED CURRENT VALUE US$ MILLION
12/24/1989	EXPLOSION	BATON ROUGE, LOUISIANA US	68.9	146.6

An eight-inch-diameter pipeline operating at approximately 700-pounds-per-square-inch ruptured, releasing a mix of ethane and propane. The record low temperature of 10 °F for the region is believed to have contributed to the rupture. After a few minutes, the resulting release was ignited, causing a vapor cloud explosion.

The explosion shattered windows up to six miles away and could be felt as far as 15 miles away. Seventeen additional pipelines, in a pipe rack containing 70 lines, were ruptured by the explosion. The resulting fire involved two large storage tanks holding 3,600,000 gallons of diesel, 12 small tanks containing a total of 882,000 gallons of lube oil, and two separator units.

The explosion resulted in the partial loss of electricity, steam, and fire water for the refinery since two power lines, two steam lines and a 12-inch diameter fire water line were located in this pipe rack. Upon the initial explosion, the lines for the dock fire pumps were damaged. Therefore, the water for fire fighting had to be supplied with the remaining plant fire pumps and municipal fire trucks taking draught from alternate sources.

Approximately 48,000 gallons of AFFF foam concentrate, 200 fire brigade members, and 13 pumper units were used during the fire fighting effort, which was successful in extinguishing the fire approximately 14 hours after the initial explosion.

Because of this incident, the refinery was completely shut down for three days and operated at reduced capacity for an additional three weeks.

10/08/1992	EXPLOSION	LOS ANGELES, CALIFORNIA, US	78.3	156

An explosion originating in the hydrogen processing unit occurred in this 75,000-bbl/d refinery. Extensive damage was caused to the hydrocracker, hydrodesulphurisation, and hydrogen processing units by the explosion and subsequent fires. The fires were fueled by hydrocarbons released from the damaged process column and equipment. The explosion, which damaged nearby buildings and shattered windows several miles away, was recorded as a "sonic boom" at the California Institute of Technology in Pasadena, approximately 20 miles from the refinery.

The explosion resulted from the rupture of the outside radius of a six-inch-diameter carbon steel 90° elbow and the release of a hydrocarbon-hydrogen mixture into the atmosphere. The vapor cloud ignited within seconds of the rupture. There were no out-of-range or warning indications relevant to the incident until after the failure of the pipe elbow. An inspection after the failure found the line at nearly full design thickness a short distance away from the failure. On these facts, it was concluded that the line failure was the result of the thinning of the carbon steel elbow due to long-term erosion/corrosion.

The fire-fighting effort was coordinated by the refinery emergency response team, with the Los Angeles City and Los Angeles County Fire Departments utilizing the Joint Incident Command System. The refinery emergency response team placed booms in the Dominguez Channel storm drain to stop oily water run-off generated by the fire-fighting effort from reaching the Los Angeles Harbor. The fire was finally extinguished after three days.

The refinery's gasoline production was reduced to 35,000 bbl/d (approximately 70% of rated capacity), until repairs to the damaged process units were completed.

10/16/1992	EXPLOSION	SODEGAURA JAPAN	161	320.7

An explosion and subsequent fire resulted in significant property damage at this 146,500 bbl/d refinery. The explosion occurred following a heat exchanger failure in the hydrodesulphurisation unit for light oil. The channel cover and lock ring of a breech-lock-closure-type heat exchanger were hurled into an adjacent factory, which was located approximately 650 feet from this plant. The channel cover and lock ring were each five feet in diameter, and weighed 4,000 lb and 2,000 lb, respectively.

The hydrodesulphurisation unit was being restarted following catalyst exchange work when plant personnel noticed that hydrocarbon was being released from the heat exchanger. Plant personnel were working to complete the additional tightening work required on the heat exchanger bolts due to thermal expansion when the explosion occurred. The subsequent fire was brought under control in two hours and 45 minutes by fire fighters using 15 fire trucks.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ESTIMATED CURRENT VALUE US$ MILLION
11/09/1992	EXPLOSION	LA MEDE FRANCE	225	448.2

A vapor-cloud explosion occurred in the gas plant associated with the 29,700-bbl/d fluid catalytic cracker (FCC) unit on a 136,000-bbl/d refinery.

The initial vapor-cloud explosion and several subsequent lesser explosions could be heard in Marseilles, approximately 18 miles from the refinery. An estimated 11,000 pounds of light hydrocarbons were involved in the initial explosion.

A gas-detection system in the FCC unit sounded an alarm indicating a major gas leak. While the unit operator was contacting the security service to warn of this situation, the initial explosion occurred. The initial gas release is believed to have resulted from a pipe rupture in the gas plant, which was used to recover butane and propane produced in the FCC unit.

The explosions and subsequent fires devastated about two hectares of this refinery, which covers an area of about 250 hectares. The gas plant, FCC unit and associated control building were completely destroyed by this incident. Two new process units, which were under construction and scheduled to come into operation in 1993, were seriously damaged. Outside of the refinery, roofs were damaged in the nearby town of Chateauneuf les Martigues and windows were broken within a radius of 3,000 feet. Some windows were broken up to six miles away.

The refinery fire brigade and more than 250 firemen from three neighbouring industrial sites and four nearby towns were utilized for more than six hours to bring this incident under control. Approximately 37,000 US gallons of foam concentrate were used during the fire-fighting effort. Some fires were intentionally left burning after the incident was under control to allow safe depressurizing of the process units since the flare system was partially damaged by the explosions.

07/24/1994	FIRE	MILFORD HAVEN UNITED KINGDOM	77.5	146.1

A severe thunderstorm passed over this refinery between 07:20 and 09:00 on July 24. Lightning strikes resulted in a 0.4 second power loss and subsequent power dips throughout the refinery. Consequently, numerous pumps and overhead fin-fan coolers tripped repeatedly, resulting in the main crude distillation column pressure safety valves lifting. Major process unit upsets occurred in other refinery units, including those within the 90,000 bbl/d fluid catalytic cracking (FCC) complex.

The refinery crude unit was shut down following ignition of vapor escaping from the main crude column pressure safety valves by a subsequent lightning strike. All of the units in the cracking complex, except the FCC unit itself, were also shut down. However, a process upset in the FCC unit's gas recovery section ultimately led to a high liquid level in the on-plot flare drum and several shutdowns of the wet gas compressor, together with other process anomalies.

As a result of the wet gas compressor shutdown, there was a large vapor load on the FCC flare system, which led to a high liquid level in the on-plot flare drum. When the hydrocarbon liquid overflowed into the outlet line of this drum, the line ruptured due to mechanical shock. A pulsing leak appeared at the flare drum discharge elbow where the outlet line had ruptured and fell to the ground.

The hydrocarbon liquid and vapor mixture released from this flare system formed a vapor cloud that drifted through the process area prior to being ignited by a heater. The explosion was centerd in the process area approximately 360 feet (110 meters) from the FCC on-plot flare drum.

Following the explosion, a number of isolated fires continued to burn at locations within the FCC, butamer, and alkylation units. In view of the entrained hydrocarbons in damaged areas of the plant and a non-operative flare system, these small fires were allowed to burn out under controlled conditions with the last fire being extinguished on the morning of July 27. The fire fighting was handled by the refinery emergency services with assistance from the Dyfed County Fire Service.

As a result of this incident, an estimated 10% of the total refining capacity in the United Kingdom was lost until this complex was returned to service.

08/07/1994	EXPLOSION	RYAZAN RUSSIA	100	188.5

This event occurred on a crude unit at this 360,000-bbl/d refinery. A furnace was undergoing maintenance when a worker performed a hot cut and material was released. Inadequate flushing and blinding, and a work scope that did not meet normal industry practices, appear to be likely causes.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ESTIMATED CURRENT VALUE US$ MILLION
09/01/1998	PRODUCTION LOSS	PASCAGOULA, MISSISSIPPI US	190	330

The entire refinery was shut down for three months after being struck by hurricane Georges. The hurricane left the entire plant submerged under more than four feet of salt water from the Gulf of Mexico. Although the hurricane was only a Category 2 storm, its slow movement subjected the refinery to 17 hours of high wind and rain. The storm surge overtopped the dikes built to protect the refinery. In all, some 2,100 motors, 1,900 pumps, 8,000 instrument components, 280 turbines, and 200 miscellaneous machinery items required replacement or extensive rebuilding. Newer control buildings and electrical substations sustained little or no damage as they had been built with their ground floors elevated approximately five feet above grade.

03/ 25/1999	EXPLOSION	RICHMOND, CALIFORNIA US	113	193.5

This explosion was caused by the failure of a valve bonnet in a high-pressure section of a 60,000-bbl/d hydrocracker. A vapor cloud formed from the release ignited and was followed by a large fire fed by escaping hydrocarbons at high pressure. The explosion resulted in the collapse of a large section of pipe rack and the destruction of a large fin fan cooler mounted above the rack. Many pumps were destroyed and a separator was badly damaged. Approximately 300 firefighters and 33 fire trucks participated in the two-and-a-half-hour effort to control the fire. Foam concentrate consumption totaled 3,200 US gallons. The hydrocracker was out of service for 12 months.

08/ 17/1999	EARTHQUAKE	KORFEZ, GULF OF IZMIT TURKEY	200	342.4

An earthquake measuring 7.4 on the Richter scale caused a collapse of a 312-feet-high concrete chimney on one of the crude units, setting off fires at this 226,000 bbl/d refinery. Fires also broke out on a number of storage tanks on the site. The process teams successfully isolated and tackled the crude unit fire. Fires on the tank farm were allowed to burn themselves out after storage tanks were pumped out as much as possible. Due to broken water mains, fire-fighting efforts were limited to attempts by aircraft to drop chemicals on the fires. The US and many other countries sent foam supplies, personnel, and equipment to fight the fires. Damage to the refinery included total loss of six storage tanks, a further four storage tanks were deformed, and there was some 50% damage to other floating roof tanks. Damage to process units included the fire on the crude distillation unit, and damage to a reformer and several connecting pipelines. All employees evacuated. Airplanes were used to spray chemicals to extinguish the fire because of a shortage of water due to a broken main.

06/25/2000	EXPLOSION	MINA AL-AHMADI KUWAIT	412	679.3

An explosion occurred when employees were attempting to isolate a leak on a condensate line between an offsite natural gas liquid (NGL) plant and the refinery gas plant. Three crude units were damaged and two reformers were destroyed. The fire was extinguished approximately nine hours after the initial explosion. Five people were killed and 50 others were injured. The investigation into the loss indicated a lack of inspection and maintenance of the condensate line, which was not owned by the refinery. A lack of clear understanding of the ownership of the line is thought to have delayed the isolation of the line.

04/09/2001	FIRE	WICKLAND, ARUBA DUTCH ANTILLES	159.1	256.2

An oil spill occurred due to a failure of a block valve to seat properly during maintenance on a pump strainer in the visbreaker unit. The oil auto-ignited and the ensuing fire spread and destroyed the visbreaker and damaged adjacent equipment. Subsequent explosions and heat restricted fire-fighting access, inadequately trained fire brigade personnel, and damage to the firewater distribution system, further hindered extinguishing the fire in a timely manner. The fire was spread by the firewater application, and was finally extinguished with the help of the local fire department.

04/23/2001	FIRE	CARSON, CALIFORNIA US	120	193.2

A piping leak resulted in a fire in this refinery coker unit. Smoke rose to over 3,000 feet and the coker was shut down for approximately two months.

08/14/2001	FIRE	LEMONT, ILLINOIS US	145	233.5

The 160,000-bbl/d capacity refinery was shut down due to a pool fire as a result of a pipework release on the crude distillation unit. Three days later, the crude column suffered a structural failure due to an internal fire caused by air ingress from the previously ruptured pipework reacting with pyrophoric material and oil in the column. The crude distillation unit was shut down for 12 months. The cause of the initial pool fire was due to incorrect piping material specification in one elbow, which failed.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ESTIMATED CURRENT VALUE US$ MILLION
11/22/2002	EXPLOSION	PORT OF MOHAMMEDIA MOROCCO	130	201.4

Following torrential rain, rising floodwater allowed waste oil floating on the surface to be brought into contact with hot equipment on the refinery, causing explosions and a fire. A second blaze broke out and several storage tanks reportedly caught fire and exploded. Damage to the refinery was extensive, two were killed, and a further three reported missing. Later reports said that two or three production units had been affected by the fire. The processing units affected were 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. At the time, it was stated that the units not affected by the fire would restart within fifteen days, although the other units would not be operational for a further eight to 12 months.

01/06/2003	EXPLOSION	FORT MCMURRAY, ALBERTA CANADA	120	178.5

The incident occurred at an oil sands facility, specifically with minor explosions occurring in the froth treatment plant. Damage appeared to be mainly limited to electrical cables in the solvent recovery area. The cause of the fire appears to have been a hydrocarbon leak in piping. The plant's emergency response team was assisted by the local fire brigade and the fire was extinguished in two hours. Only one minor injury was reported. The incident occurred eight days after the new facility began operating.

01/04/2005	EXPLOSION	FORT MCMURRAY, ALBERTA CANADA	120	159.1

A fire broke out at the oil sands refinery in Upgrader 2, an area of the plant that converts bitumen into crude oil products. 250 people were evacuated from the plant but no injuries were reported. The fire burned for nine hours before being extinguished. Witnesses reported two explosions minutes apart, which sent a fireball six-storeys-high into the air. The plant also suffered ice damage from water used to fight the fire as temperatures in the area fell below -35C. On February 3, 2005, the company announced that a ruptured cycle line was the most likely cause of the fire. Oil production was reduced from 225,000 bbl/d to about 110,000 bbl/d for about nine months.

03/23/2005	EXPLOSION	TEXAS CITY, TEXAS US	200	265.2

A total of 15 people were killed and 105 injured following an explosion at the 460,000-bbl/d refinery. The explosion occurred in the isomerisation unit, which was being restarted following its annual major maintenance turnaround. Loss of control of the restart of the isomerization unit resulted in one of the splitter columns on the unit becoming full of light hydrocarbon. Eventually, hot liquid was released from the column through relief valves to a 30-meter-high blowdown stack on the unit. The release generated a large vapor cloud in the vicinity of the unit. There was a group of temporary buildings supporting planned turnaround activity on another unit located in close proximity to the blowdown stack, and many of the fatalities were attending a meeting in these buildings when the vapor cloud found a source of ignition and exploded.

04/30/2006	FIRE	PRIOLO, SICILY ITALY	110	139.4

Two firefighters were injured tackling a blaze at a refinery. The incident occurred when crude oil leaked from a pipe supplying the refinery from bulk storage tanks.

10/12/2006	EXPLOSION	MAZEIKIU LITHUANIA	142.9	181

The fire on the vacuum distillation unit (VDU) weakened the main vacuum distillation column supports, allowing it to collapse onto the heat exchange train. The VDU was shutdown completely and the refinery was left running but at a much reduced capacity. An investigation identified that the fire was caused by a leak from a branch on the column that was fabricated from an incorrect material.

08/16/2007	FIRE	PASCAGOULA, MISSISSIPPI US	200	241.5

A fire broke out in Crude Unit Number 2 of a 325,000-bbl/d refinery and burned for over six hours. No injuries were reported. Company officials said a major portion of the refinery was able to continue to operate. Crude Unit Number 1 at the refinery remained operational.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ESTIMATED CURRENT VALUE US$ MILLION
02/18/2008	FIRE	BIG SPRING, TEXAS US	380	429.4

An explosion at this 70,000-bbl/d oil refinery caused damage to the fluid catalytic cracker (FCC), utilities, storage tanks, and asphalt unit. One employee was hospitalized for burns. Another person was injured when her car was struck by debris from the explosion on the nearby highway. There was a total of four injuries. A skeleton crew of just 40 people were on site because it occurred on a public holiday. There would typically have been about four times as many people on duty at the time of the explosion. The fire was brought under control the same day by the site fire brigade, supported by local fire departments.

The release is believed to have occurred during a start-up on the propylene splitter unit as a result of the catastrophic failure of a pump. Some processing resumed about two months later and the FCC was recommissioned some eight months after the incident.

10/13/2008	EXPLOSION	PRIOLO GARGALLO. SICILY ITALY	150	169.5

An explosion and fire in a 562MW-capacity, integrated gasification combined cycle electricity generating plant at a refinery caused a fire in the gasification unit on a refinery. No one was injured as a result of the explosion and fire, but the loss resulted in the temporary closure of the refinery.

01/06/2011	EXPLOSION	FORT MCKAY, ALBERTA CANADA	385	402.2

An explosion occurred on this oil sands upgrader site north of Fort McMurray, Alberta. Five workers were injured in the blast, including one who received third-degree burns. A subsequent fire occurred at the top of one of the site's four coke drums and burned for nearly four hours. As a result, two of the coke drums were disabled. Workers returned to work to normal shifts the following morning. The majority of the damage was sustained above the cutting deck and derrick infrastructure of the coke drum.

At the time of the incident the plant was operating on bypass conditions due to process upsets. An internal investigation team determined that the fire resulted from the opening of the top unheading valve on an active low-pressure coke drum. This allowed hot hydrocarbons to be released within the coker cutting deck building and was followed by ignition leading to the explosion and fire.

Exceptionally cold weather following the incident hampered efforts to gain access to the coker unit's cutting deck, due to the deluge protection in this area. Additional damage as a result of the fire fighting in freezing conditions was also experienced.

03/11/2011	EXPLOSION	SENDAI JAPAN	590	616.3

A major explosion occurred at a 145,000-bpd refinery in the northeastern city of Sendai, hours after the largest earthquake in the country's history was followed by a tsunami.

The fire at the Sendai refinery originated from an oil product shipping facility. Workers at the refinery were being evacuated, and there was no capacity available to extinguish the fire.

Fire in the storage and shipping facilities resulted in damage to a 35,500-bpd fluid catalytic cracker (FCC) at the refinery.

09/28/2011	FIRE	PULAU BAKOM SINGAPORE	150	156.7

A fire broke out in a refinery, reported to have started in a pump house used for blending refined products, as it was being prepared for maintenance. Site firefighters were supported by state fire-authority forces. Non-essential staff were evacuated from the site, and neighboring units were shut down as a precaution. Further fire eruptions and explosions were reported the next morning, and the company began steps to shut down the whole refinery. The fire was reported as finally extinguished late in the evening of the second day, about 34 hours after it was first reported. The production units on the refinery were progressively restarted, and all units were back in production by the end of 2011.

07/04/2012	FIRE	BANGKOK THAILAND	140	144.5

An explosion and fire occurred in the kerosene stripper of the crude distillation unit at an 80,000-bbl/d refinery located in an industrial zone surrounded by residential areas. This resulted in fires in the area, but no injuries were reported. The refinery operator said it would postpone a maintenance shutdown at its refinery, which was set for late July, to reduce the risk of supply shortages as a result of the fire. The crude distillation unit that was damaged by the fire was expected to be replaced within three months.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ESTIMATED CURRENT VALUE US$ MILLION
08/25/2012	EXPLOSION	FALCON STATE VENEZUELA	320	330.2

A very powerful explosion occurred in an area of pressured propane and butane storage at the refinery. At least 48 people were killed and more than 80 injured. The explosion hit an area of storage tanks, damaging nine of them. It was reported that there had been a significant number of leaks at the refinery in the previous year.

01/12/2013	FIRE	STANLOW, CHESHIRE UNITED KINGDOM	150	153.3

Refinery and local fire fighters spent more than six hours battling a fire on a large oil refinery. A warning was issued to local residents because of thick non-toxic smoke generated from a stack on the site. The fire is thought to have broken out in a furnace. No injuries were reported.

03/11/2013	FIRE	SOHAR OMAN	150	153.3

A refinery suffered a fire in a wet gas scrubber while conducting heavy maintenance on a unit. Personnel were evacuated from the site and there were no injuries. The site was conducting a planned shutdown and maintenance of the plant equipment, including the polypropylene plant.

04/02/2013	EXPLOSION	LA PLATA DISTRICT, ENSENADA ARGENTINA	225	230

A fire broke out in the 188,000-bpd refinery, caused by flash-floods during heavy rain. The rain overwhelmed the storm drainage system on the refinery, resulting in hydrocarbons being washed out of the drains and around the site. An explosion was reported in the crude distillation unit (CDU). There were two fires in the CDU, one in the coking plant and two in the topping distillation plant. The government agency said the incident had been caused by hydrocarbons exploding in one of the coke-manufacturing furnances. The furnaces had been shut down, but were still hot enough to ignite the hydrocarbon. It took eight hours to extinguish the fire and 10 hours before the incident was under control. The oil company said there were no fatalities or injuries.

PETROCHEMICALS

Property damage losses in the petrochemicals sector (SEE FIGURE 11) are dominated by the major loss event in Texas in 1989, which is the largest onshore energy property damage event recorded.

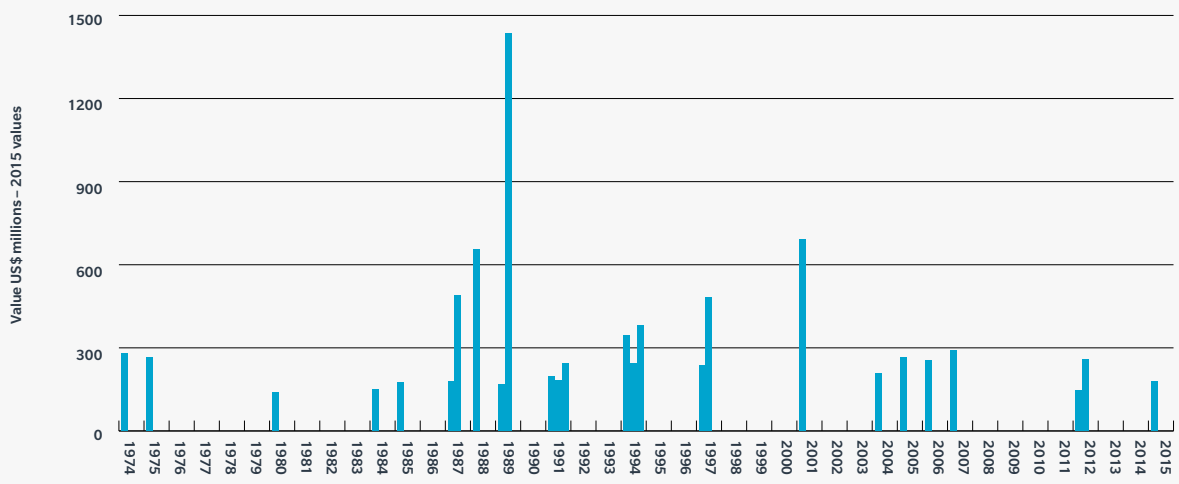
There are no significant trends identifiable from the information presented, however: While there was a cluster of large losses between 1985 and 1995, there has been a steady, fairly infrequent occurrence of losses in this sector ever since.

The issue of aging plants is less severe in the petrochemicals sector as, unlike in refineries, the materials being processed have already been subject to some processing (generally in refineries) to remove contaminants.

That said, petrochemical plants are often operating at high temperatures and pressures, and require the careful control of violent chemical reactions.

The total insured loss at the port of Tianjin, following the two blasts that ripped through it on August 12, 2015, is likely to exceed US$1.5 billion. Although the port is a major base for petrochemicals, the vast majority of the losses will not come from the oil and gas sector. Despite the fact that the Tianjin port explosion could be the most expensive man-made loss since the Deepwater Horizon in 2010, it is unlikely to feature in this report – even after the total value of the loss has been realized.

FIGURE 11 PETROCHEMICAL PROPERTY DAMAGE LOSSES BY YEAR
Source: Marsh Research



DATE OF LOSS	EVENT TYPE	SITE TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
06/01/1974	EXPLOSION	CHEMICAL	FLIXBOROUGH UNITED KINGDOM	57.5	279.9

This chemical facility was severly damaged by a large vapor-cloud explosion. Twenty-eight workers were killed and a further 36 suffered injuries. The number of fatalities would have been higher had it not been a weekend, as the main office block was not occupied. Offsite consequences resulted in 53 reported injuries. Properties in the surrounding area were damaged to varying degrees. Prior to the loss a reactor had been removed and a bypass assembly installed to enable production to be continued. On June 1, the 20-inch bypass system ruptured. This may have been caused by a fire on a nearby 8-inch pipe. This resulted in the release of 30 metric tons of hot cyclohexane that formed a flammable cloud that subsequently found a source of ignition. Eighteen fatalities occurred in the control room as a result of windows shattering and collapse of the roof. The ensuing fires burned for more than three days.

10/02/1975	EXPLOSION	CHEMICAL	ANTWERP BELGIUM	60	265.2

An explosion and fire caused extensive damage at a low-density polyethylene plant. The cause was a leak of ethylene at high pressure due to fatigue failure of a vent connection on the suction of a compressor. Six people were killed and 13 injured.

04/30/1980	EXPLOSION	CHEMICAL	NEWCASTLE, DELAWARE US	45	139.1

On a petyrochemicals plant, polypropylene polymerization was being carried out in three parallel reaction trains (A,B,C). The reactants were carried in a hexane solvent with several catalysts and processed onto pellets.

Following a maintenance error, a 100-milimeter plug valve was blown out of a line in Train A, releasing hydrocarbons and polymers. The vapor cloud rose upward, carried by a light wind into the finishing building, where an explosion occured.

Further fires resulted from broken flammable liquid lines in the process area and from the released products in the finishing area. The loss included the three trains (outside equipment), the control building, the compressor building, and part of the finishing building.

09/15/1984	FIRE	CHEMICAL	WARRINGTON, CHESHIRE UNITED KINGDOM	62.3	149.4

A fire occurred in this petrochemical site's oxidation plant. One hundred and thirty firemen using 25 appliances controlled the blaze after four hours. The local railway line, ship canal, and roads were closed and 200 people were evacuated.

05/19/1985	EXPLOSION	CHEMICAL	PRIOLO ITALY	73.9	175

A faulty temperature probe on a 600,000-metric-ton-per-year ethylene plant initiated an isolation of the hydrogenation reactor located within the cold section. While the operators were attempting to regain normal control, the pressure-relief system operated. About the same time, fire was noted near grade level at the base of the Deethaniser column. The source of fuel was believed to have been a flange at the deethaniser column reboiler or in the relief system pipe work.

Leaking hydrocarbon, mostly propylene at 375 psig, was possibly ignited by hot steam piping. The intense fire rapidly engulfed the adjoining ethylene and propylene distillation columns and spread 180 feet to the storage area. Eventually, one vertical pressurized propane storage tank exploded, its top section traveling 1,500 feet and missing a gas holder by 30 feet. Two other propylene tanks toppled; one onto a pipe rack and the other against an ethylene tank. All were protected by deluge waterspray systems, which apparently were ineffective under the intense fire exposure. Five of the eight ethylene and propylene tanks collapsed or exploded. The fire also spread to the API separator and to three floating roof tanks. Pipe racks, motor control centers, and pumps were severely damaged or destroyed.

A few minutes after the fire brigade responded, the ethylene column released its 9,300 US gallon inventory, destroying one of the plant's two foam trucks. Assisted by outside fire-fighting agencies, the plant fire brigade brought the fire under control after more than 40 hours, and finally extinguished it four days after the initial ignition.

07/03/1987	EXPLOSION	CHEMICAL	ZWIJNDRECHT, ANTWERP BELGIUM	78.2	177.4

An explosion occurred in the final purification column of an ethylene oxide manufacturing plant, resulting in 14 people being injured. The explosion inititated several secondary fires on the orginal units as well as other units nearby, but all were under control within 30 minutes. The root cause was identified as being due to a rapid overpressurization of the column as a result of decomposition of material within it, although the ingnition source was not identified.

DATE OF LOSS	EVENT TYPE	SITE TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
11/14/1987	EXPLOSION	CHEMICAL	PAMPA, TEXAS US	215.3	488.4

An explosion occurred in an air line in a reactor used for the liquid phase oxidation of butane as it was being started up. The explosion ruptured the external portion of the air line to the reactor, allowing the reactor contents to vaporize and form a cloud. The vapor cloud drifted and ignited about 25 to 30 seconds after the initial release. There was extensive property damage in the immediate area as a result of the vapor cloud explosion and significant damage throughout the site. Windows were broken seven miles away. The immediate cause was believed to be insufficient purging of the reactor when it had previously been down.

05/04/1988	EXPLOSION	CHEMICAL	HENDERSON, NEVADA US	300	655.4

An explosion at a plant that manufactured ammonium perchlorate (AP) for rocket fuel flattened the local industrial park, left a crater 125 meters across, and cracked walls 15 miles away. Two people were killed. The cause is thought to be a fire in a batch dryer. The intial explosion was equivalent to 108-tons of TNT, with a second explosion four minutes later equivalent to 235 tons of TNT. Approximately 50% of the buildings in the nearby town of Henderson, Nevada, were destroyed. A natural gas pipeline that ran under the plant was ruptured in the event and burned for one week.

03/07/1989	EXPLOSION	CHEMICAL	ANTWERP BELGIUM	79.4	168.9

A hairline crack in a welded seam of piping to the level indicator system on an Aldehyde column resulted in a minor ethylene oxide leak on this gas-processing plant. As a result of this crack, which was caused by low-cycle fatigue, ethylene oxide escaped near the level indicator and formed polyethylene glycols (PEG) in the mineral wool insulation.

It is believed that both the leak and accumulation of PEG occurred over a period of time. During repairs to the level indicator, the metal sheathing of the insulation was removed and air contacted the insulation soaked with PEG. Auto-oxidation of the PEG resulted and the insulating material was ignited. The piping to the level indicator system was heated to such a degree that auto-decomposition of the ethylene oxide within the piping occurred. This auto-decomposition propagated into the aldehyde column which subsequently exploded.

The force of the explosion completely destroyed the distillation section of this plant. The large resulting fire and impact of flying debris to other process sections resulted in extensive damage throughout the plant.

10/23/1989	EXPLOSION	CHEMICAL	PASADENA, TEXAS US	675	1436

A large flow of ethylene and isobutane was released from one of the high-density polyethylene (HDPE) units at a chemical complex. The vapor cloud drifted north toward the centre of the HDPE process area before ignition. This is believed to have occurred approximately 60 seconds after the release. The explosion had the strength of a 3.5 magnitude (Richter scale) earthquake.

The explosion destroyed two HDPE units, which included a total of eight particle form, loop reactor trains. The heat from the explosion caused boiling liquid expanding vapor explosions (BLEVEs) of nearby pressurized storage tanks. Other process units at this chemical complex sustained only minor damage and resumed normal production within a few weeks of the incident.

The initial release of ethylene and isobutane occurred through an eight-inch-diameter ball valve settling leg of one of the loop reactors. The function of these pneumatic valves is to isolate the settling leg and other downstream equipment from the reactor for maintenance. The company maintenance procedures for opening a settling leg included closing the ball valve, inserting a lock-out device into this closed valve, closing the block valves to the air hoses for the valve operator, and disconnecting these air hoses.

Company personnel confirmed that these maintenance procedures were performed two days before the loss, but maintenance work had not commenced due to changes in priorities. The work on the settling leg was started on October 23.

After the explosion, investigations indicated that the lock-out device had been removed from the valve and the air hoses had been reconnected to the valve operator on the settling leg. The valve was found in the open position and the settling leg was open to atmosphere at the bottom of the leg, where a swedge/reducer spool leading to the product take-off valve should have been connected.

03/11/1991	EXPLOSION	CHEMICAL	PAJARITOS, COATZACOALCOS MEXICO	97	197

A gas leak involving the pipe rack that runs to the terminal in this petrochemical complex led to an explosion. An initial explosion occurred near the complex chemical plant, causing additional damage to the pipe rack and resulting in a major gas leak. A powerful second explosion occurred that 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.

Because of this incident, the chemical plant at this complex was completely shut down for seven months, to allow for the rebuilding of the plant and the pipe rack.

DATE OF LOSS	EVENT TYPE	SITE TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
03/12/1991	EXPLOSION	CHEMICAL	SEADRIFT, TEXAS US	90	182.8

An explosion occurred in the ethylene oxide process unit at this plant. As a result of the explosion, the ethylene oxide refining column was completely destroyed, the ethylene glycol unit was substantially damaged, and the co-generation unit was partially damaged. A pipe rack near the storage area for liquid ethylene oxide was damaged when a large piece of shrapnel from the explosion hit the rack, rupturing lines which contained methane and other hydrocarbon products. The subsequent fire that resulted from the released products was the only significant fire to occur during this incident.

As a result of the explosion, all utilities at the plant were lost for approximately one week. Additionally, a significant number of the fixed fire protection systems were damaged by the explosion or inadvertently actuated due to a loss of plant air. These systems were shut off and isolated or placed back in service, as appropriate. A manual fire-fighting effort was used to extinguish the fire in the pipe rack once the lines in the rack were isolated.

The polyethylene production was restarted in early April 1991, using imported ethylene. The olefins production unit was restarted in late April 1991.

05/01/1991	EXPLOSION	CHEMICAL	STERLINGTON, LOUISIANA US	120	243.7

Workers were preparing to check a compressor in the nitroparaffin unit when they noticed a small fire and sounded the plant fire alarm. Approximately 30 seconds later, an explosion occurred that was followed by a series of smaller explosions. The effects of the initial explosion were reported as far away as eight miles from this plant. Additionally, the initial explosion completely damaged an area of the plant approximately the size of a city block. Subsequent fires were reported to have burned for more than seven hours.

Although the incident did not damage the two ammonia units on site, the entire plant was temporarily shut down for precautionary measures.

05/27/1994	EXPLOSION	CHEMICAL	BELPRE, OHIO US	182	343.1

An abnormal chemical reaction occurred during the batch production of a thermoplastic rubber product, resulting in an explosion at this plant. As a result of the explosion, the reactor, process controls, accessories, control room, and building for this production unit were completely destroyed.

The fire then spread to involve part of the tank farm, resulting in the destruction of five atmospheric storage tanks. At approximately 12:30 p.m., the first of four 1,000,000-US-gallon, and one 500,000-US-gallon, styrene storage tanks exploded. A fire-fighting attack utilizing cooling water and foam hose streams was used to prevent the fire from involving other nearby storage tanks, two of which contained butadiene. The fire was extinguished after approximately nine hours.

10/20/1994	MECHANICAL DAMAGE	CHEMICAL	CEDAR BAYOU, TEXAS US	130	245

The Texas floods along the San Jacinto river shut down the site, involving 650,000-t/y ethylene; 200,000-t/y linear low-density polyethene (LLDPE); 280,000-t/y low-density polyethene (LDPE) plants, and general utilities. The loss of utilities affected further downstream clients. Flood water breached dikes around the main substation and inundated control rooms and offices.

12/13/1994	EXPLOSION	FERTILIZER	PORT NEAL, IOWA US	203	382.6

An explosion occurred in the ammonium nitrate process area of this plant. As a result of the explosion, the seven-story main process building was completely destroyed and a 30-foot-diameter crater was created.

Metal fragments from the explosion punctured one of the plant's two 15,000-metric ton, refrigerated ammonia storage tanks. The punctured tank released an estimated 5,700 metric tons of ammonia, causing the evacuation of approximately 2,500 people from the surrounding area. Metal fragments also punctured a nitric acid tank, resulting in the release of approximately 100 metric tons of acid. The explosion tore metal siding from adjacent buildings, damaged three third-party electric generating stations, broke windows of buildings 16 miles away in Sioux City, and was felt more than 30 miles away.

06/22/1997	EXPLOSION	CHEMICAL	DEER PARK, TEXAS US	135	237

An explosion and large fire occurred in the Olefins Plant Number III at a petrochemical plant. The explosion was felt and heard more than 10 miles away and the ensuing fire burned for approximately 10 hours. The explosion and fire resulted in extensive damage to the facility, and several workers received minor injuries. In addition, nearby property was damaged, nearby transport routes were closed for several hours, and residents were advised to remain indoors. The incident originated at the cracked gas compressor system in the olefins unit and was caused by the structural failure of a 36-inch, pneumatically-assisted non-return valve located on a high pressure light hyrdocarbon gas line. The escaping gas formed a vapor cloud and eventually found a source of ignition, resulting in the unconfined vapor-cloud explosion.

DATE OF LOSS	EVENT TYPE	SITE TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
09/21/2001	EXPLOSION	CHEMICALS	TOULOUSE FRANCE	430	692.4

An explosion at the fertilizer plant killed 31 people, and hospitalized more than 600. The blast shattered windows and ripped doors from their hinges in the center of the city 3 kilometers away. Two chimneys and several buildings at the factory were flattened and caused damage to more than 3,000 homes, 500 of which were reported uninhabitable. There was a secondary blast at a nearby explosives factory, said to be caused from sparks created by the first explosion. The thick red and yellow fumes that spread over the city were first thought to be toxic and the public was advised to remain indoors. The blast left a crater 50 meters in diameter and 15 meters deep.

04/23/2004	EXPLOSION	CHEMICAL	ILLIOPOLIS, ILLINOIS US	150	208.1

Five people were killed and two seriously injured following an explosion at a plastics plant producing 200 million barrels per year of speciality grade PVC. The highway was shut and local residents evacuated. The explosion occurred in a reactor where vinyl chloride and vinyl acetate were being mixed. Up to 75% of the plant was destroyed in the explosion. The explosion was felt eight kilometers away.

12/10/2005	EXPLOSION	CHEMICAL	MUNCHMUSTER GERMANY	200	265.2

A release of hexane created a vapor cloud, which was ignited on an electric motor and caused an explosion. This resulted in damage to a process unit and 20 injuries. The plant was eventually replaced.

04/29/2006	EXPLOSION	CHEMICAL	PORT ARTHUR, TEXAS US	200	253.4

A shelter-in-place was ordered 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 shutdown of the facility for some six months, but caused no deaths or serious injuries.

03/20/2007	EXPLOSION	CHEMICAL	NIIGATA JAPAN	240	289.8

An explosion occurred at a methylcellulose manufacturing facility and was followed by a fire, which was extinguished about seven hours later.

A total of 17 people, who were working at the site, were injured in this accident; three critically, five seriously, and nine with minor injuries. There was one minor injury off site. Ignition of the methylcellulose powder is thought to have been due to static electricity, resulting in a powder dust explosion. All methylcellulose operations were suspended for two months before sequentially restarting.

05/05/2012	EXPLOSION	CHEMICAL	MAP TA PHUT THAILAND	143	147.6

At least 12 people were killed and 129 injured in an explosion and fire at a petrochemicals plant that manufactured polybutadiene. In addition, thousands of people were evacuated from adjacent factories and communities within a three-kilometer radius of the site. The explosion and subsequent fire sent thick black smoke into the air above the site. The deaths and injuries were as a result of blast injuries, burns ,and the inhalation of toxic fumes. It was reported that the explosion and fire occurred while workers were cleaning the polymer production line to change between batches and using toluene as a cleaning solvent.

12/22/2012	FIRE	CHEMICAL	LAVERA FRANCE	250	258

The incident happened as a two-train, ethylene cracker was being started up after its major six-year turnaround. A spanner was left in the pipework going to the medium pressure (MP) stage of a compressor. This resulted in the compressor tripping on high vibration. The trip caused an overpressure in the high pressure (HP) stage of the compressor and a loss of containment of hydrocarbon that was ignited.

08/13/2015	EXPLOSION	CHEMICAL	LITVINOV CZECH REPUBLIC	180	177

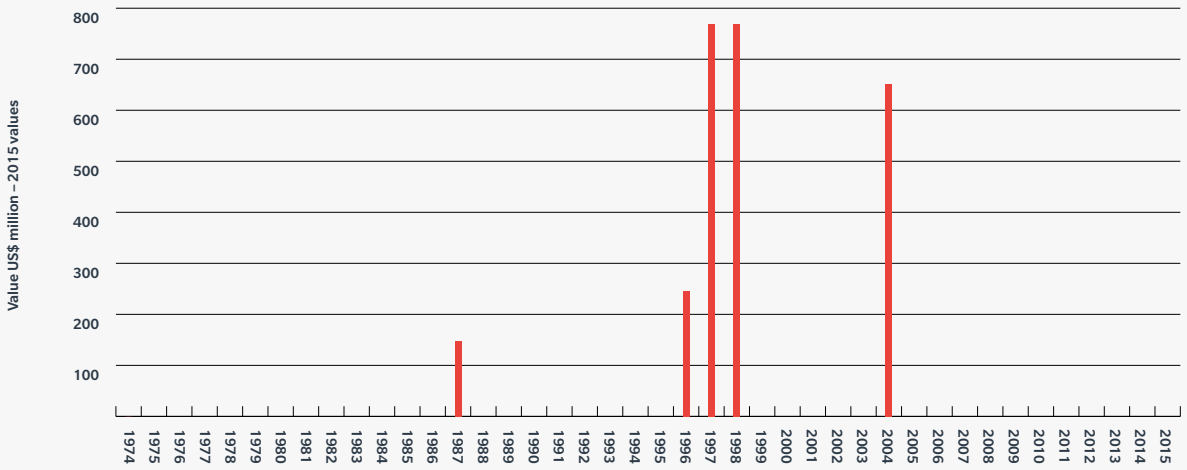
A short interruption in the supply of cooling water to a separation column downstream of a steam cracker resulted in the pressure relief valves opening. These valves vibrated excessively, resulting in failure of the bolted flanges and the release to atmosphere of the propylene-rich column overhead line. The resultant explosion led to the failure of utility lines to the cracker requiring a crash shutdown. The lack of process steam due to the interruption to the utility supply resulted in the failure of furnace tubes and the release of quench oil. There was subsequently a pool fire from the released quench oil under the cracker, resulting in damage to four of the 10 cracker furnaces.

GAS PROCESSING

Figure 12 shows the small number of gas-processing losses that have occurred throughout the years. Although infrequent, there have been some particularly large losses, which reflect the concentration of value typically found on these sites.

New plants have recently been built and projects continue to be developed to liquefy, transport, store, and regasify natural gas. These projects will typically incorporate good risk management practices in their design, layout, and operations to minimize losses.

FIGURE 12 GAS PROCESSING PROPERTY DAMAGE BY YEAR
Source: Marsh Research



DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
08/15/1987	EXPLOSION	JUAYMAH SAUDI ARABIA	65	147.5

At this gas-processing plant, a series of electrical power interruptions caused several shutdowns of one or both of the identical 165,000-bbl/d gas fractionation process trains. The parallel trains were separated from one another by approximately 100 feet. At the time of the loss, the propane feed was approximately 100% of design capacity for Plant I, and 25% of design capacity for Plant II. It is believed that there was a release of approximately 1,900 bbl of propane in Plant I over a 30-minute period. Ignition of the large vapor cloud is believed to have been done by a security vehicle, which had stalled and was being restarted. The probable source of the propane was a flange in a four-inch-diameter relief valve line.

07/26/1996	EXPLOSION	CACTUS, REFORMA, CHIAPAS MEXICO	137.1	245.8

A vapor-cloud explosion centered in the Cryogenic Unit No. 2 and two subsequent explosions in the Cryogenic Unit No. 1 occurred at this gas-processing complex. As a result of the explosions, the Cryogenic Unit No. 2 and liquid petroleum gas (LPG) product pumps in the Cryogenic Unit No. 1 were extensively damaged, the control rooms for both units were destroyed, and the remainder of the Cryogenic Unit No. 1 experienced minor damage.

Plant personnel noticed that one of the two LPG product pumps in the Cryogenic Unit No. 1 had a seal leak. Consequently, plant personnel decided to have the faulty seal replaced. In preparation for the maintenance work on the LPG product pump, the motor-operated valve (MOV) in the suction line and the isolation valve in the discharge line of this pump were manually closed. A spectacle blind was then inserted into the pump flange on the suction side of the pump. After the seal was replaced, plant personnel removed the blind and were in the process of tightening the flange bolts when LPG product began to leak from this flange. A vapor cloud formed and drifted into the Cryogenic Unit No. 2. It was ignited and resulted in the initial explosion. Following the explosions, it was determined that the MOV in the suction line of the pump was in the open position, which allowed the LPG product to reach the pump flange. The fire brigades successfully extinguished the fire following the explosions after approximately three hours, and protected the adjacent LPG spheres. If these spheres had failed due to BLEVE, the property plant damage would have been substantially greater. Although the explosions damaged the electric power in the plant and rendered the electric motor-driven fire water pumps non-operational, fire water was provided by two diesel engine driven fire water pumps. Because of this incident, the 2.13 billion ft^3/y gas-processing capacity at this complex was shut down, disrupting one third of Mexico's total gas-processing capacity.

12/25/1997	EXPLOSION	BINTULU, SARAWAK MALAYSIA	275	482.8

An explosion and fire occurred at a gas-to-liquids (GTL) plant in Bintulu, Sarawak. The fire was brought under control the next day.

The plant was one of only two commercially successful GTL plants in the world at the time, with a capacity to produce 12,500 bbl/d of middle distillates and waxes from natural gas feedstocks. The explosion occurred in the air separation unit (ASU), which supplied oxygen for the production of synthesis gas feedstock. The investigation into the incident pointed to an initial combustion event in the ASU as the most probable cause. This combustion event is thought to have initiated explosive burning of the aluminium heat exchanger elements in the presence of liquid oxygen, such that the elements ruptured explosively. Twelve people were injured, none seriously, and the plant was shut down for several months for repairs.

09/25/1998	EXPLOSION	LONGFORD, VICTORIA AUSTRALIA	443	769.3

Gas supplies to Australia's Victoria State were virtually shut down following an explosion and fire at this gas-processing plant. The specific cause of the accident was attributed to the rupture of a heat exchanger following a process upset that was set in motion by the unintended, sudden shutdown of hot oil pumps. The loss of hot oil supply allowed some vessels to be chilled by cold oil, and when the hot oil was reintroduced to the heat exchanger, the vessel ruptured due to a brittle fracture. An initial release of approximately 22,000 lb of hydrocarbon vapor exploded, and an estimated 26,000 lb burned as a jet fire. The fire burned for two and a half days. Operator error and improper training of employees was sited in the report issued by the Longford Royal Commission formed to study the incident. One of the pipes at the plant had sprung a leak and ignited, this heat had burst other pipes. Five explosions ripped through the gas plant at 12.30 p.m. In addition to the 120 workers evacuated from the site, police evacuated houses within a five -kilometer radius of the gas plant. The plant has a daily production capacity of 200,000-barrels-per-day of stabilized crude oil, 40,000-barrels-per-day of raw liquid petroleum gas (LPG), and 450,000 million cubic feet per day of gas to supply natural gas customers. The gas outage has affected 1.4 million users statewide and forced small and large businesses to temporarily shut down. The estimated insurance payout is US$590 million. It is estimated that the shutdown cost the industry nationally up to US$745 million in lost production.

01/19/2004	EXPLOSION	SKIKDA ALGERIA	470	652.1

A total of 27 people were killed, 72 injured, and seven reported missing, following an explosion at this liquid natural gas (LNG) plant. The explosion destroyed three out of six liquefaction trains, damaged a nearby power plant and led to the shutdown of a 335,000-bbl/d refinery. There was also some damage to the neighboring industrial facilities. A faulty boiler was initially blamed for the incident. Investigations, however, indicated that a large release of hydrocarbon from a cold-box exchanger was ignited upon ingestion into the boiler. Train six of the LNG Complex restarted in May 2004, and trains five and 10 in September 2004. Trains 20, 30, and 40 were destroyed in the incident, representing 50% of the capacity of the LNG complex.

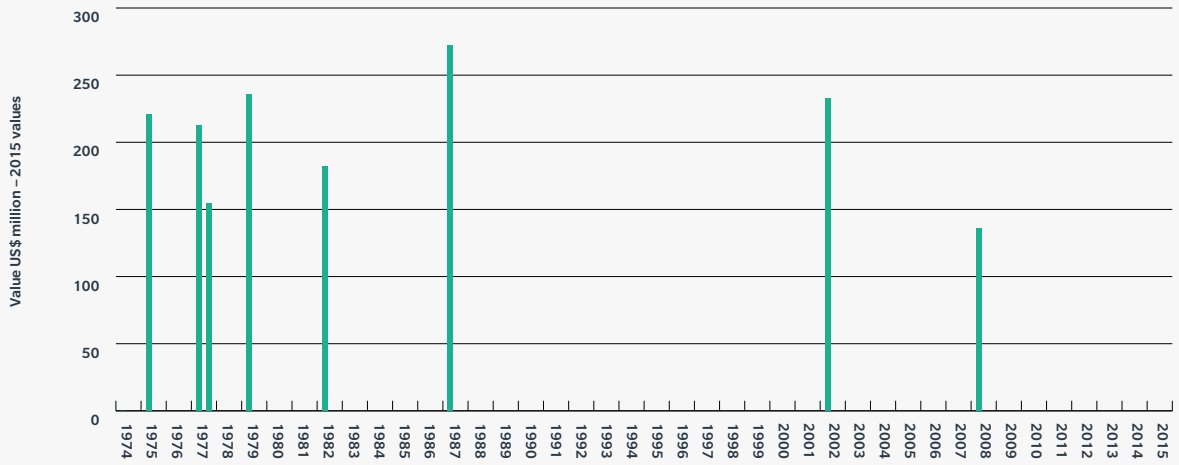
TERMINALS AND DISTRIBUTION

In terms of property damage losses to terminals and other distribution assets, FIGURE 13 reveals that there was a high frequency of large events 30-40 years ago. Today, however, these events have become far less common.

The physical layout of most terminals and distribution assets, as well as the value of the plant and equipment located there, mean there are fewer sites with the concentration of value to result in the very largest physical damage accidents, if the worst were to occur. In addition, there have been recent improvements in the hardware and management systems on these sites, which have reduced the likelihood of these major losses occurring. However, despite this, there have been some accidents on distribution terminals that have resulted in significant third-party impacts.

Major fires at the Buncefield, UK tank farm in 2005, at a tank farm in Jaipur, India, in 2009, and at a tank terminal in Puerto Rico in 2009, all resulted in significant damage. The Jaipur incident resulted in 11 fatalities and all of the incidents resulted in major damage to the sites and to third parties. However, the value of property damage from these incidents was insufficient to place them in the *100 Largest Losses*.

FIGURE 13 TERMINALS AND DISTRIBUTION PROPERTY DAMAGE LOSSES BY YEAR
Source: Marsh Research



DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
01/31/1975	EXPLOSION	MARCUS HOOK US	50	221

The US flag tanker *Edgar M. Queeny* rammed the Greek tanker *Corinthos* while the latter was discharging 400,000 bbl of crude oil at a refinery jetty at Marcus Hook on the Delaware River. A massive initial explosion and subsequent explosions and fires occurred on the Greek ship as a result of the collision. Some 25 crew members were killed on board this vessel, in addition to one crewman from the flag tanker. The *Corinthos* sank shortly afterwards and was later removed for scrapping.

05/11/1977	FIRE	ABQAIQ SAUDI ARABIA	54.5	212.3

A 30-inch-diameter crude oil pipeline failed and destroyed three spheroids, pumping units, and other equipment. Ignition was caused by motor vehicles.

07/08/1977	FIRE	FAIRBANKS, ALASKA US	39.6	154.3

A pipeline pump started while the strainer coverplate was being removed, and the oil released ignited. The fire was mostly confined to the pump house.

01/08/1979	EXPLOSION	BANTRY BAY IRELAND	70	235.4

An 11-year-old, 121,000-deadweight-ton tanker had completed unloading its first parcel of Arabian heavy crude when a small fire was noticed on deck. About 10 minutes later, fire spread at both sides of the ship. Later, a massive explosion occurred. The initiating event of the disaster was probably the buckling of the ship's structure at or about deck level. Explosions in the ballast tanks and the breaking of the ship's back followed. These events were produced by the conjunction of two separate factors: a seriously weakened hull due to inadequate maintenance, and an excessive stress due to incorrect ballasting at the time of the disaster. In addition to the total loss of the ship, 1,130 feet of the concrete and steel jetty were damaged or destroyed.

12/19/1982	FIRE	TACOA VENEZUELA	70	182.3

A huge boil-over occurred on a fuel oil tank killing at least 160 people in a huge fire ball. An explsoion occurred on a fuel oil tank while it was being gauged, blowing the roof off the tank and setting it on fire. Eight hours after the tank fire started, a violent boil-over occurred. Burning oil flowed down the hill where the tank was located and surronded a second tank.

03/05/1987	EARTHQUAKE	ECUADOR	120	272.2

Twenty-five miles of Trans-Andean pipeline disappeared in this event, which also damaged natural gas and gasoline pipelines. All 285 producing wells were shut down and oil exports were suspended and swap arrangement made with Venezuelan suppliers. The first earthquake registered 6.0 on the Richter scale, the second 6.8, and there were a total of 10 earthquakes in total. Repairs took several months.

01/31/2002	EXPLOSION	RAUDHATAIN KUWAIT	150	232.4

Four people were killed in an explosion and fire at an oil-gathering center, gas booster station and power substation. The explosion occurred after a leak from a buried oil pipeline in the gathering station spread to a power substation, sparking the blaze. The flash explosion and resulting blaze hit the gathering center and the adjacent gas-booster station. Nineteen people were also injured in the incident, suffering mainly first- and second-degree burns. The fire was extinguished two days after the event.

06/03/2008	EXPLOSION	VARANUS ISLAND AUSTRALIA	120	135.6

A gas release from a corroded pipeline resulted in an explosion at a gas plant. This resulted in a 30% reduction in the state's domestic gas supply and a 45% reduction in the supply of gas to mines and other industries. Workers were evacuated from the island as a precaution. It took six months before the plant was returned to full-capacity operation.

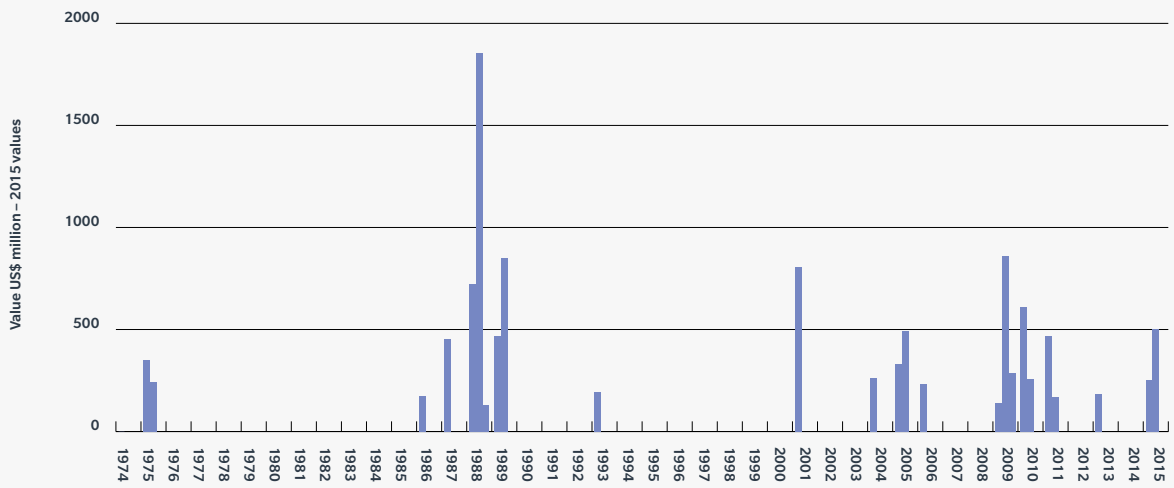
UPSTREAM

The distribution of upstream losses is dominated by the Piper Alpha loss in 1988. There continue to be regular, major losses in the upstream sector, including two of the major losses to occur over the last two-year period.

Operations in the upstream sector are taking place in increasingly challenging environments, with developments moving into deeper waters. Lessons have been learned from previous losses in the sector, and these are applied in the facility layout, fire protection, and loss mitigation. However, these large projects present greater exposure in the event of loss than most others.

At the same time, there are increasing numbers of on-shore upstream projects associated with fracking. There have been accidents associated with these operations, but they are typically small installations and do not result in multimillion-dollar losses in the event of being destroyed by fire.

FIGURE 14 UPSTREAM PROPERTY DAMAGE LOSSES BY YEAR
Source: Marsh's Benchmarking Survey Analysis



DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
07/01/1975	BLOWOUT	FATEH L3 DUBAI UNITED ARAB EMIRATES	79	349.2

The Fateh Field L-3 development well had reached 4,180 ft when a "kick" occurred. The kick control effort was terminated and the rig abandoned when gas broke around the 20-inch-shoe and bubbled up under the platform. Eight days after the blowout, the gas ignited, and after two weeks the rig and platform disappeared beneath the waters.

08/ 01/1975	COLLISION	AUK FIELD, NORTH SEA UNITED KINGDOM	54.7	241.8

Platform was struck by the *Stad Sea*.

08/26/1986	STORM	SEA OF JAPAN JAPAN	75	175.1

A semi-submersible barge ran aground near Uslan, Japan during a typhoon.

11/04/1987	BLOWOUT	BOURBON FIELD, WELL A17, GULF OF MEXICO US	200	453.7

Sustained casing head pressure leaked from the production casing into the outer casing strings, resulting in the failure of one of the casing strings. This caused an underground blow-out that resulted in extensive damage to the platform and a gas plume around the platform. The well was killed to stabilize conditions on the seabed.

04/24/1988	BLOWOUT	ENCHOVA, CAMPOS BASIN BRAZIL	330	721

During the conversion of one of the platform wells from oil to gas production, a high-pressure gas pocket was encountered that forced the drill pipe out of the well. The blow-out preventer failed to shut in the well and sparks, caused by the drill pipe that was ejected from the well hitting one of the platform legs, ignited the escaping gas. The fire lasted for 31 days. Most of the topside structure was destroyed and the facility was later declared a total loss. Redesign of the production module was completed in 45 days in an effort to shorten, as much as possible, the loss of production. Full production was restored 18 months after the loss.

07/ 06/1988	EXPLOSION	PIPER ALPHA, NORTH SEA UNITED KINGDOM	850	1857

A release and ignition of gas condensate from a section of piping in the gas compression module of this platform set off a chain of fires and explosions, resulting in the almost total destruction of the facility. The condensate was released from the site of a pressure relief valve, which had been removed for maintenance, when this section of piping was inadvertently pressurized. The severity of the accident was due in large part to the contribution of oil and gas from ruptured pipelines connected to the platform, and the disabling of nearly all emergency systems as a result of the initial explosion. The compression module had been retrofitted to the platform adjacent to the control room, and the control room was rendered useless by the initial explosion.

In addition, the firewater pumps had been placed into manual operation mode due to divers being in the water prior to the accident.

There were 226 people on the platform at the time of the accident; only 61 survived. Contributing to the loss of life was the location of the quarters directly over the site of the initial release and resulting explosion and fire.

12/24/1988	MECHANICAL DAMAGE	FULMAR FIELD, NORTH SEA UK	60	131.1

Failure of a seabed component in bad weather resulted in a floating storage unit to break free, interrupting about 10% of UK North Sea oil production. The unit took about six months to be reinstated.

01/20/1989	BLOWOUT	TREASURE SAGA, NORTH SEA NORWAY	220	468

A semi-submersible rig had a gas kick at 15,527 feet during an attempt to clear the drill pipe of cement previously pumped in to control the well, and the well then suffered a blow-out. The well was stabilized after 11 months by pumping heavy mud down a relief well. The well was later sealed.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
03/19/1989	EXPLOSION	BAKER, GULF OF MEXICO US	400	850.9

Contract personnel were installing a pig trap on an 18-inch-diameter export gas pipeline on the platform. As a cold cut was made into the pipeline, hydrocarbons sprayed from the cut and ignited. The explosion and fire burned the main structure and caused subsequent explosions when six other pipelines ruptured due to the intense heat. The accident resulted in the total destruction of the platform and seven fatalities. Two years were required to replace the platform.

03/25/1993	EXPLOSION	LAMA, LAKE MARACAIBO VENEZUELA	100	194.1

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. Eleven fatalities resulted from the incident.

03/15/2001	EXPLOSION	RONCADOR FIELD, CAMPOS BASIN BRAZIL	500	805.1

The world's largest offshore production facility was rocked by a series of explosions caused by a gas release. The explosions knocked out a support pillar of the semi-submersible platform, allowing seawater to enter the vessel. Workers pumped in nitrogen and compressed air and tried to pump out almost 3,000 metric tons of seawater to keep the rig afloat, but were unsuccessful. On March 20, the rig sank to the sea floor. The incident killed a total of 11 workers.

08/10/2004	BLOWOUT	TEMSAH EGYPT	190	263.6

A fire broke out during drilling operations at an offshore gas production platform following a well-control incident. The fire on the production platform, initially under control, spread to a nearby jack-up drilling rig, owned by a major drilling contractor, which suffered major damage and collapsed. All 79 people on board the drilling rig were safely evacuated. The production platform, with 150 persons onboard, had been evacuated before the fire spread. The drilling rig sank and was not salvageable. The platform was damaged beyond repair and its destruction was ordered by the state.

07/10/2005	STORM	THUNDERHORSE, GULF OF MEXICO US	250	331.5

Hurricane Dennis passed through the area where the platform was located, causing it to partially sink. A seawater valve in a ballast tank had been wronly installed resulting in excess water in the tanks. The platform had already been evacuated and there was no leakage of oil, fuel, or other hazardous substances.

The loss resulted in the project commencing production three years behind schedule. The company retrieved and rebuilt all the sea-bed production equipment after a series of tests revealed metallurgical failure in components of the field subsea systems.

07/27/2005	EXPLOSION	MUMBAI, HIGH NORTH INDIA	370	490.6

A total of 22 people were killed when a fire completely destroyed an oil platform. It is believed that a multi-purpose support vessel, which was evacuating a worker to a medical center, hit the platform's riser causing an explosion. The vessel also caught fire and sank, but two nearby platforms were saved when connecting bridges collapsed. The 150 people on board managed to transfer to a nearby water injection platform, and a further 348 people were evacuated from the oil platform. However, the rescue operation was hampered by bad weather. A cantilever jack-up rig, linked by a bridge to the process platform, was also involved in the fire. Seventy-three people were evacuated from the rig but during the evacuation, however, one employee died during the evacuation. Six divers in a saturation chamber on the vessel were rescued 36 hours later.

11/05/2006	RELEASE	NORTH SEA NORWAY	185	234.4

Offshore gas alarms were triggered on this floating production unit and, upon investigation, it was established that a leak was emanating from one of the production risers. Upon further investigation, five other risers were found to be similarly affected. Remedial work was subsequently carried out.

01/26/2009	MECHANICAL DAMAGE	OFFSHORE ANGOLA	120	137.7

An anchor-handling tug, operating around an offshore field, lost control and drifted over a subsea centre. The anchor wires snagged the subsea equipment, causing damage to a christmas tree, well conductor, and subsea-control module. The remedial actions required included the plugging and abandonment of one well and the drilling of a relacement well.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
06/04/2009	COLLISION	NORTH SEA NORWAY	750	860.4

A well-intervention vessel lost power and collided with an unmanned platform forming part of this 230,000-bbl/d complex. Heavy damage was caused to the vessel and the platform, including damage to the platform structure, linking access bridge and well equipment. Some 23,000 bbl/d of oil production was reportedly affected. The force of the collision caused the bow of the vessel to compress by about two meters, with the platform pushed partly out of position, loosening several support legs from the main load-bearing structure. One of the water injection risers on the platform was bent extensively and several wellheads were moved, with a catalogue of further damage from the collision also identified.

08/21/2009	BLOWOUT	TIMOR SEA AUSTRALIA	250	286.8

Oil, condensate, and hydrogen sulphide leaked from a wellhead on a platform being serviced by a jack-up rig in the Timor Sea. Sixty-nine workers on the rig were evacuated. Oil and gas started to spill after a plug blocking one of the project's 1,200-meter-deep wells came free. The next day, a 12-kilometer-long and 30-meter-wide spill was reported. Attempts were made to plug the well over the next two months. It was estimated that the well was leaking 400 bbl/d of oil and gas.

On November 1, it was reported that drillers had successfully intercepted the well and were beginning to put heavy mud into the shaft. However, a fire broke out on the drilling platform as they attempted to plug a deeper leak. The fire was extinguished two days later. A total of 4,140 metric tons of oil were estimated to have been lost. This incident affected both the platform and the drilling rig.

04/21/2010	EXPLOSION	GULF OF MEXICO US	560	609.5

A semi-submersible drilling rig working in the Mississippi Canyon Block 252, approximately 48 miles off the coast of Louisiana, suffered a major explosion and fire following a well-integrity failure. The rig had a crew of 126. Eleven people were immediately identified as missing and subsequently confirmed as fatalities, with a further 17 injured. The rig sank within 36 hours of the initial explosion in a water depth of approximately 5,000 feet. The exploration well had reached a depth of 18,360 feet (total depth) and was undergoing cementing works, prior to the well-control event, with a view to temporarily abandoning the well.

Hydrocarbons continued to flow through the damaged blow-out preventer (BOP) for 87 days, before a successful static kill was performed. The release caused a spill of national significance and resulted in an unprecedented subsea and surface spill control response. The well was declared finally killed five months after the original event by successful interception by a relief well.

The loss led to a temporary ban on drilling activity in US coastal waters.

05/13/2010	SINKING	CARIBBEAN SEA VENEZUELA	235	255.8

A natural gas drilling rig sank in the Caribbean Sea, but all 95 workers were evacuated safely and there was no reported leakage. The sinking was caused by a sudden surge of water entering one of the submarine rafts that the platform legs floated on. Automatic subsea safety valves sealed the wells and no leakage of oil occurred.

02/04/2011	STORM	NORTH SEA UNITED KINGDOM	450	470

Heavy storm conditions in the North Sea caused four of this floating production, storage, and offloading (FPSO) unit's 10-anchor chains to break, resulting in the vessel moving off its position. It is estimated that the FPSO was subject to 53-knot winds and nine-meter waves. Normally, a complex piping system runs from the wells on the sea bed up to the FPSO, and this infrastructure was damaged in the incident.

Following the vessel moving off its position, all of the wells were immediately shut in. Subsequent surveys showed that no oil had been lost. Seventy-four non-essential crew were evacuated to nearby platforms and 43 essential crew remained on board. Two members of crew received minor injuries.

The facility was projected to be producing an average of 18,400 bbl/d of oil prior to the loss.

04/12/2011	SINKING	GULF OF MEXICO MEXICO	160	167.1

A total of 638 workers were evacuated from this flotel after it began to lean to one side when water entered a pontoon. The flotel was located about 80 kilometers offshore of Campeche state, Mexico. There were no injuries reported as a result of the sudden inclination. It was reported that a total loss of the flotel resulted.

DATE OF LOSS	EVENT TYPE	LOCATION COUNTRY	PROPERTY DAMAGE $US MILLION	ADJ PROPERTY $US MILLION
07/01/2013	SINKING	ATLANTIC OCEAN ANGOLA	182	186

A jack-up sank after the sea bed collapsed under one of the three legs. The rig sank while being positioned for drilling operations in approximately 40 meters of water. One hundred and three workers were on-board the rig when it suddenly tilted, causing the rig to take on water and capsize. One crew member was missing and six others received minor injuries.

03/11/2015	EXPLOSION	CAMARUPIM FIELD BRAZIL	250	250

An explosion on a floating production, storage, and offloading (FPSO) unit off the coast of Brazil resulted in nine fatalities and multiple wounded. The accident happened as the vessel was anchored in the Atlantic 120 kilometers from the coast of Espirito Santos, southeast Brazil. The FPSO was a converted very large crude oil tanker (VLCC) and designed to produce up to 10 million cubic meters of natural gas. It is understood there was a condensate leak during a fluid transfer operation, which released a cloud of flammable vapor into the engine room, resulting in an explosion in the machinery space. The majority of fatalities are believed to be part of the emergency response team. The incident resulted in the FPSO taking on water, but the explosion did not result in a breach of the hull of the vessel.

04/01/2015	FIRE	ABKATUN, BAY OF CAMPECHE	MEXICO	500	>1,000

A complex of six platforms located in 30 meters of water in the Gulf of Mexico was subject to a major fire. The fire originated on the lower decks of the production platform and resulted in major damage to that platform, radiation, and fire damage to an adjacent compression platform, plus loss of bridge links and pipelines, and radiation damage to other bridge links.

The root-cause investigation required by the government identified corrosion of a small bore pipeline as the cause of the initial failure.

About Marsh

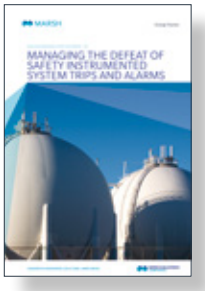
Marsh is a global leader in insurance broking and risk management. Marsh helps clients succeed by defining, designing, and delivering innovative industry-specific solutions that help them effectively manage risk. Marsh's approximately 30,000 colleagues work together to serve clients in more than 130 countries. Marsh is a wholly owned subsidiary of Marsh & McLennan Companies (NYSE: MMC), a global professional services firm offering clients advice and solutions in the areas of risk, strategy, and people. With annual revenue of US$13 billion and approximately 60,000 colleagues worldwide, Marsh & McLennan Companies is also the parent company of Guy Carpenter, a leader in providing risk and reinsurance intermediary services; Mercer, a leader in talent, health, retirement, and investment consulting; and Oliver Wyman, a leader in management consulting. Follow Marsh on Twitter, @MarshGlobal; LinkedIn; Facebook; and YouTube.

FURTHER READING
ENGINEERING POSITION PAPERS

Marsh's engineering position papers leverage our knowledge on best practices to establish standards that don't currently exist. These papers define the key attributes that we would define as being "very good."

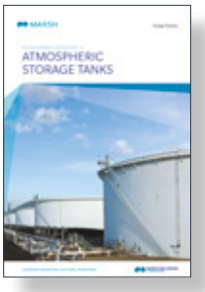
PRE-START-UP SAFETY REVIEW

These recommendations can be used to support and define risk improvements and also provide detailed advice to clients seeking to improve their management systems.



MANAGING THE DEFEAT OF SAFETY-INSTRUMENTED SYSTEM TRIPS AND ALARMS

Whenever a safety-instrumented system (SIS) is defeated, the risk exposure is increased to an extent that depends on the nature of the hazard involved.



ATMOSPHERIC STORAGE TANKS

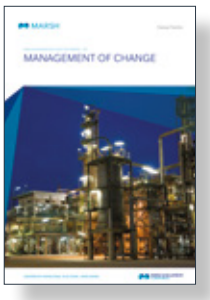
Following numerous incidents involving atmospheric storage tanks, data has been compiled indicating that overfilling of atmospheric storage tanks occurs once in every 3,300 filling operations.

PROCESS-SAFETY PERFORMANCE INDICATORS

The process industry has a long history of major incidents that are well-publicized. The underlying causes of major incidents are often related to failures in process-safety management.

FIRE PRE-PLANS

There have been numerous large damaging fires over the years, including tank fires. These involve massive product losses and process unit fires that cause major plant damage and process interruption.



MANAGEMENT OF CHANGE

During the lifetime of an operating process plant, many changes will occur, including to the physical hardware of the plant, control systems, business processes, and/or to the organization running the plant.

BENCHMARKING

Marsh uses a proprietary risk-ranking system to provide an absolute measure of risk quality when compared against a defined set of criteria. From these rankings, Marsh developed its benchmarking tool to provide a proactive risk-improvement approach based on current standards and best practices, in sharp contrast to improvement plans that are based on historical performance. For many of our clients, Marsh's benchmarking reports have already proved to be a catalyst for change.

ENERGY RISK QUALITY BENCHMARKING IN THE MIDDLE EAST

This paper contextualizes risk quality in the Middle East and explores regional trends to gauge the comparative risk quality of oil, gas, and petrochemical facilities relative to more than 500 similar facilities worldwide.

BENCHMARKING THE ASIAN ENERGY INDUSTRY: STRENGTH AND OPPORTUNITY IN A RAPIDLY DEVELOPING MARKET

A benchmarking study to gauge the comparative risk quality of Asian onshore oil, gas, and petrochemical facilities relative to more than 400 similar facilities worldwide.

NOTES

NOTES

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