Incident

Revisiting the Jonava ammonia tank rupture – 35 years on

Ewan Stewart, IChemE Australia Deputy Chair, Australia

Summary

An incident on 20 March 1989 is regarded as Lithuania's "Chemical Chernobyl"; this was an industrial catastrophe on a scale unheard of in the then Soviet-occupied republic. Poor design and operator error at the state-owned "Azotas" fertiliser plant led to an ammonia storage tank rupturing at its base, smashing through its containment bund, and flooding the facility with 7,000 tonnes of chilled liquid ammonia. As the evaporating vapours caught fire, this spread to a nearby store, initiating the decomposition of large stockpiles of nitrophoska fertiliser. A poisonous cloud of ammonia, nitrogen oxide and chlorine gas drifted towards neighbouring villages as residents panicked. Whilst officially there were seven fatalities and 57 injuries, it was only remarkable good fortune that prevented the toll from being much worse.

Keywords: Ammonia, tank, rupture

Introduction

I learned of this incident some years ago as I was preparing for a field trip to my local fertiliser plant. I can recall gazing up at the site's ammonia storage tank. At 10,000 tonnes this was identical in capacity to that used at Jonava, making it easily one of the most imposing structures on the site. As I watched wisps of cloud form across its hemispherical dome, I couldn't help comparing the two locations. One in the eastern European countryside largely surrounded by farms and rural communities. The other on the fringes of the third most populous city in the Australasian continent. What happened at Jonava was serious enough. The same incident elsewhere could have been inconceivable.

The engineering community owes a debt to Bengt Orvar Anderson, who visited the facility several weeks after the accident and publicised his findings in issue 107 of the *Loss Prevention Bulletin*. Whilst his work on this topic is the most widely referenced, the French Bureau for Analysis of Industrial Risks and Pollutions (BARPI) also has a very informative accident case study (#717) which draws upon investigations conducted by both the Russian and Lithuanian authorities. I was unable to locate these commissioned reports, however my research did unearth more contextual information including press clippings and first-hand accounts. This article aims to supplement the previous work, view the event through the lens of history, and raise awareness for the current generation of engineering and safety professionals.

The Jonava *"Azotas"* facility

In February 1965, an ammonia production association was opened to much fanfare near the small town of Jonava in rural Lithuania. Then part of the Soviet Union, this was one of many such facilities constructed under the direction of Moscow's central planning authorities. Population growth was to be sustained by increased crop yield. Fertile soils required an unprecedented scale-up in the manufacture of nitrogen-based products for which ammonia was the chemical stepping-stone. The newly opened facility was given the same name as similar plants in other republics; "Azotas". Translating to "*Nitrogen*", this signified the element being extracted from the air for chemical transfer to the earth.

The Jonava association saw rapid growth, with new production trains launched every other year; from methanol to urea, nitric acid, ammonium nitrate and formalin. In 1978, a third ammonia plant was brought online, with the expansion including a new storage facility near the perimeter of the thriving chemical complex. From here, rail tankers were loaded for distribution of ammonia to the republics.

Another important upgrade in 1987 brought the capacity to produce nitrophoska, a type of NPK fertiliser. The abbreviation NPK signifies the presence of each of the three main macronutrients, nitrogen (N), phosphorous (P) and potassium (K), that promote the various aspects of plant growth. These elements are contained within a complex mix of chemical compounds in pelletised form. From the new workshop, nitrophoska was conveyed to a warehouse where massive stockpiles were kept onsite for direct delivery to the fields. This eliminated the requirement for additional storage facilities closer to the agricultural enterprises.

Atmospheric liquified gas storage

To fully appreciate this accident, it is useful to understand a little about liquified gases. Where bulk storage or shipping is required, practicality dictates that the gas must be converted into its most dense form. Most often this is achieved by liquification and storage at near atmospheric pressure. With the product existing at its boiling point, -33 degrees Celsius in the case of ammonia, any heat entering the tank will result in vapour generation. If there is nowhere for the vapour to go, the temperature and pressure will both increase along the boiling point curve.

To minimise product loss whilst maintaining the operating envelope, it is necessary to thermally isolate liquified gas storage tanks from their surroundings. As such, the Azotas ammonia storage tank featured a thick layer of perlite around its single steel wall. This insulation was held in place by an outer steel jacket.

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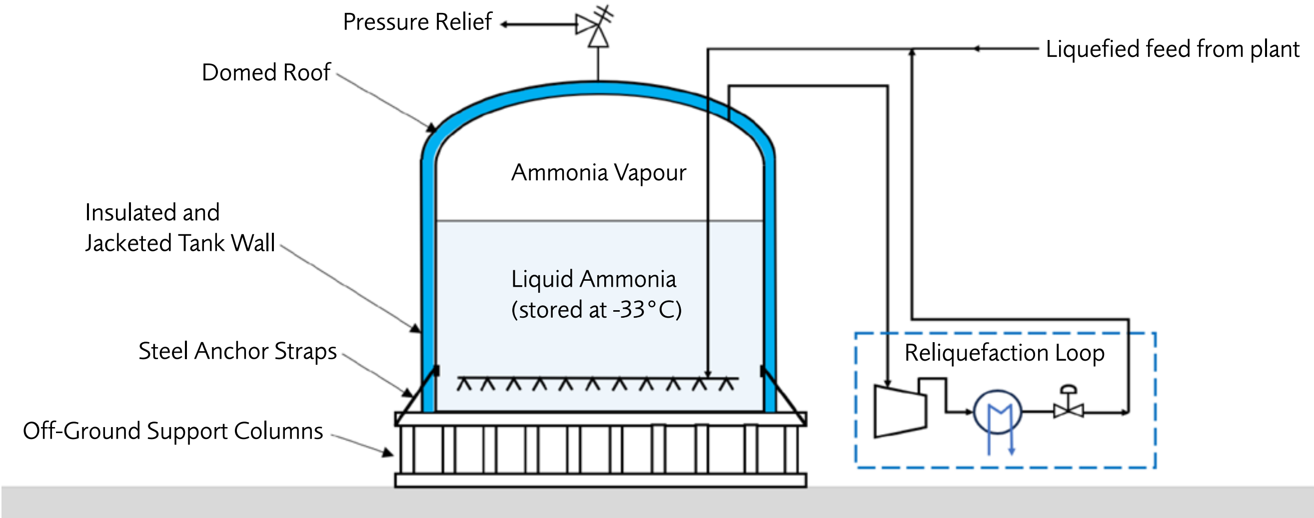

Figure 1– Schematic diagram of the Azotas ammonia storage tank

Similarly, the thermal interface underneath such tanks must be protected to avoid foundation damage due to ground freezing. To this end, the Jonava tank was elevated above ground, air-gapped by hundreds of support columns between its upper and lower concrete base slabs. The tank was secured in place by anchors along its periphery.

Despite insulating measures, heat will always enter a refrigerated tank, albeit at a reduced rate. When the tank is being filled, the chilling effect of incoming refrigerated liquid is generally enough to counteract any heat input. When the tank is not being filled, specially designed reliquefication loops compress boiled-off gas, condensing it against a refrigerant before returning to the storage tank.

The line is drawn, the curse is cast

On the morning of 20 March 1989, staff at Azotas were under reasonable duress. Long term maintenance activities had left the plant relying on a single production compressor. When

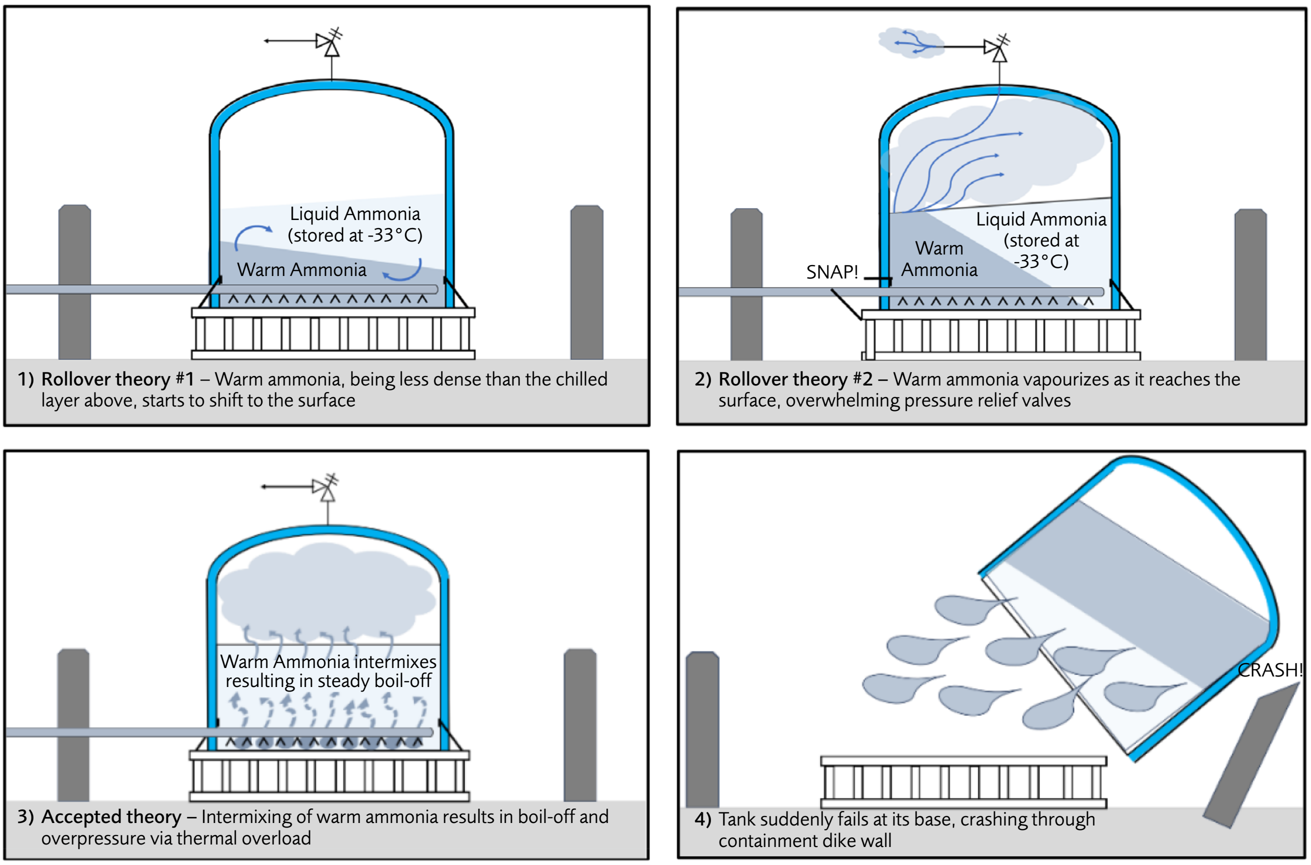

Figure 2– Different theories on the cause of the tank failure

the last remaining machine had to be halted for repairs, the operators set about shutting down the plant, diverting ammonia to flare, and ceasing flow to awaiting rail tankers. Anticipating a period of downtime, they worked to initiate the reliquefication loop, however, they ran into difficulties with the compressor cooling circuit. As the workers strived to re-establish the offline equipment, something critical had been missed. A routing from the production plant had been left open, allowing warm ammonia to backflow via superfluous lines eventually reaching the ammonia storage.

What happened next has been subject to much confusion over the years. The theory presented in the official reports is that of a "*rollover*". It was postulated that as the inadvertent routing of warm ammonia continued, it formed an unstable layer (or layers) at the base of the tank. Held in the liquid phase only by the hydrostatic pressure of the original tank inventory and having a lower density than the stratified chilled ammonia above, the buoyant warm layer became increasingly fragile as it grew. Suddenly a critical mass was reached, and the whole layer shifted to the surface, flashing to vapour, and overwhelming the relief valves.

It has since been proven that rollover cannot occur in ammonia storage tanks, owing to the fact that any warm ammonia added to a liquified tank is immediately unstable. The generally accepted theory is instead that of *"thermal overload"*. Simply put, the flow of warm ammonia represented a heat source, which intermixed with the tank contents generating a continual boil-off. In the absence of the reliquefication loop, the pressure increased steadily until the relief valves opened. However, this was not enough. The pressure became too much for the storage tank, which tore from its base, broke away from its anchors and rocketed through its reinforced concrete containment bund, coming to rest some distance away.

No longer contained by the tank or the bund wall, chilled ammonia spread freely over the locality in a large evaporating pool. Initially it was reported that this ammonia ignited, however this is not strictly true. Ammonia tends not to do so owing to its unusually high lower flammability limit and ignition temperature. What appears to have happened is that the displaced tank collided with a subsidiary pipe trestle, pulling it from the main rack and rupturing a natural gas line in the process. It is the natural gas which found an ignition source, thought to be a nearby flare. The whole area was soon engulfed in a fire fed by both the evaporating ammonia and the fractured gas line.

The world is closing in

With the emergency rapidly developing, many found themselves trapped inside the burning NPK workshop with the only escape through knee-deep sub-zero ammonia and its lethally toxic vapours. Production personnel were alerted to the emergency via intercom and toxic gas alarms. The local military fire brigade was quickly on the scene and set about rescuing workers as first responders treated the severely frost-bitten, burnt, and poisoned casualties. If the situation wasn't

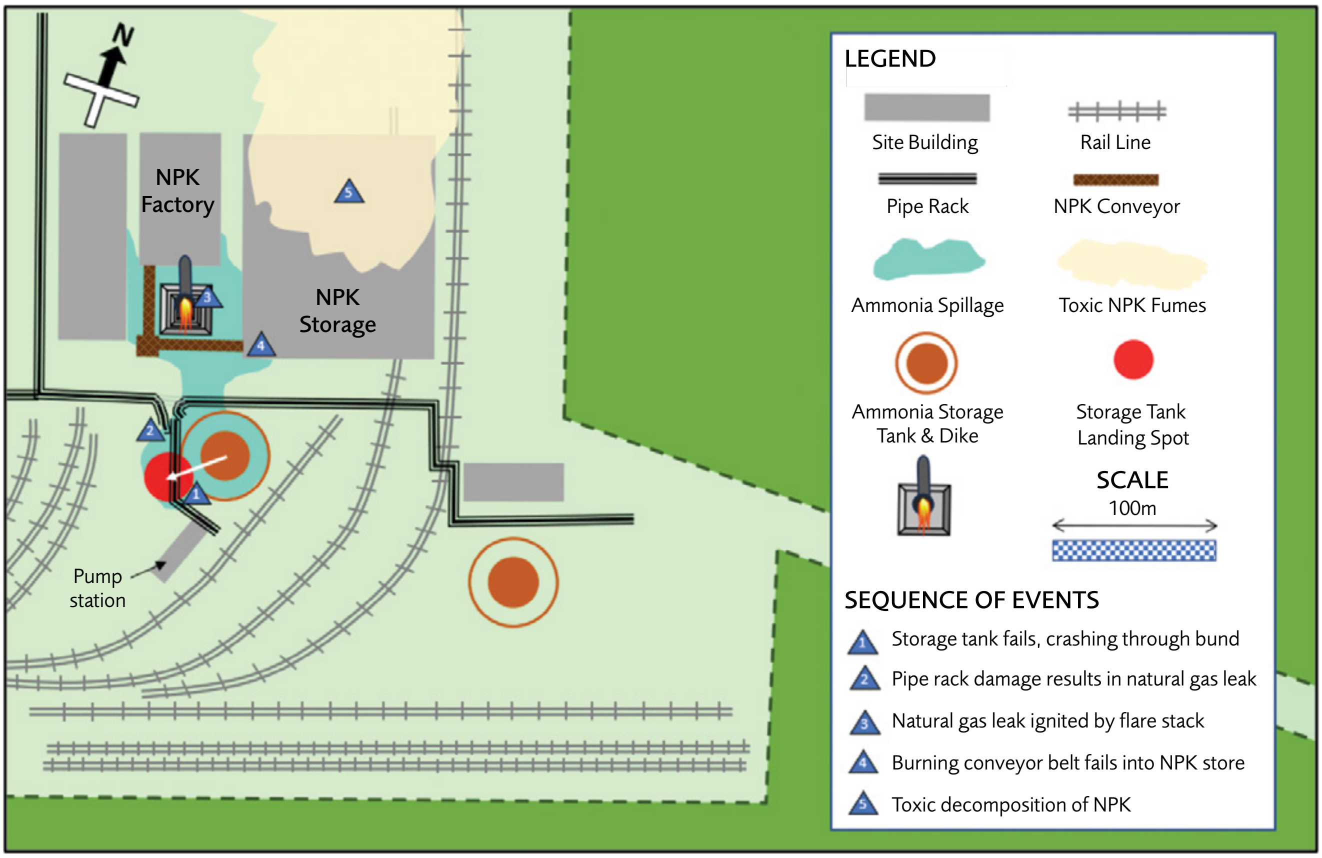

Figure 3 – Map of incident approximated by the author based on google maps, photographs and documented extent of ammonia spillage. Note that a second near-identical tank was under construction at the time of the incident.

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already bad enough, it was about to reach a whole new level of intensity. Surrounded by flames, a conveyor belt feeding the nitrophoska warehouse weakened and snapped, with the searing rubber plummeting into the fertiliser stockpiles below.

As the collapsed belt smouldered in the heaps of nitrophoska, this provided sufficient heat to initiate a self-sustaining decomposition. First ammonium nitrate broke-down, producing nitric acid and emitting more ammonia. Nitric acid further decomposed adding toxic nitrogen oxides to the mix. Before long there was sufficient heat to sustain a series of chemical reactions, each of these adding to the acrid yellow plume billowing from the slate roof of the storehouse.

The situation was becoming almost as dramatic in the emergency dispatcher's office. As per the pre-arranged protocol, the signal "Ammonia-15" was to be transmitted to external emergency services via the city telephone exchange. However, there was a breakdown in communication and the telephone operator would not pass on the message, not knowing what it meant. The dispatcher was forced to call Jonava's military registration office and transmit details of the unfolding emergency in plain text. This had to be reported up the military command chain before the city civil defence headquarters were finally notified. In all, it was a full 25 minutes before the message reached the relevant authorities.

Changing winds

Had the wind been blowing westward at this point, toxic gas would have reached Jonava city long before residents received the first radio reports. Fortunately, the prevailing wind was to the north-east over state forests. This bought time as the ever-expanding vapour cloud approached smaller settlements further away. The intense fire on site was also believed to have lessened the impact of the evaporating ammonia; some of this combusted into harmless water and nitrogen; radiant heat channelled other portions high into the atmosphere. Despite this, the visible vapour cloud at its peak would grow to measure 50 km in length and 7km in width with ammonia concentrations detectable in Finland some 500 km away. By early evening, the wind direction began to oscillate towards Jonava. With toxic gas levels increasing, the evacuation of 32,000 residents was initiated.

Most of the spilled ammonia evaporated within 12 hours, however the nitrophoska decomposition proved to be much more prolonged. Unlike combustion, the reactions involved do not require oxygen, and so attempts to smother the fertiliser could only serve to slow down the self-propagating process. Toxic vapours continued to be released from site until the decomposition of fertiliser was finally halted on 23 March, three days after it had started.

Distant memories buried in the past

The statistics became clear as Lithuania reeled in the aftermath. Officially, there were seven confirmed deaths at the Azotas plant and 57 injuries. Most of the casualties occurred in the early minutes of the incident. Many of these were plant workers who were not carrying personnel protective equipment despite company policy to do so. Poor contingency planning meant that first responders did not have the luxury of skin protection or appropriate gas masks. To quote a senior inspector in the paramilitary firefighting unit: "*to work in a hazardous area without the most basic protective equipment is a real triumph over the human instinct for self-preservation*". One firefighter was among the fatalities, having fallen into the decomposing nitrofoska stockpiles.

A key area of focus was the mineral pulp that had formed in the attempts to extinguish the fertiliser decomposition. Azotas staff had blocked the sewer intakes to prevent contaminated run-off from the nitrophoska warehouse reaching the Neris river. This was held in temporary containers whilst a 2 km pipeline was hastily constructed to a nearby quarry for further treatment. With the help of an army battalion, a reserve pit was excavated, and a dam wall built to protect the river. Conditions had to be monitored very closely over fears of groundwater penetration.

Lessons learned

The root cause of this incident was an overpressure of the ammonia storage tank by the inadvertent routing of warm ammonia to the tank base. The report issued by the soviet commission made several recommendations relating to process design. One of these was that backflow of warm ammonia to storage could have been significantly reduced through the presence of non-return valves, if not eliminated by the removal of unnecessary piping sections. Further, it was recommended that systems be installed to automatically divert ammonia gas to the flare stack should the tank pressure exceed a set value. In any case, the pressure relief valve sizing should have accounted for all credible scenarios.

Questions were raised as to why the tank failed at its base rather than at its roof to shell seam as would normally be expected. This was found to have resulted from an innovative footing design aimed at cost reduction. Modelling carried out at the soviet design house had justified the use of thinner support slabs than was industry practice. This flexible footing allowed the over-pressured tank to "balloon-up" at its base whilst the anchors held its edges rigidly in place. These competing forces led to the tank rupturing at one side. Similar cost-saving initiatives were responsible for the lack of strength in the concrete bund wall which should have resisted the impact. This was not built to its specified thickness.

Modern day photos of the plant show a fertiliser storage shed with a vastly reduced footprint, indicating that the company had learned to minimise its stockpiles held in the vicinity of hazardous plant. Similarly, these photos also show an ammonia storage tank which could not be more remote from the production processes. To mitigate similar incidents in the future, the organisation undertakes extensive scenario simulations in coordination with the emergency services. These are so realistic that the casual onlooker could be forgiven for mistaking the drills for a real accident in progress.

Winds of change

The Jonava tragedy was just one of the many industrial cataclysms that plagued the Soviet Union in the second half of the 1980s. By the spring of 1989, the communist leadership had ceded to reforms allowing for a more open press. As a result, an outraged public was only just awakening to the true extent of the 1986 nuclear fallout at Chernobyl. The

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Figure 4 – Aerial views of collapsed ammonia storage tank (https://www.lrt.lt/mediateka/irasas/2000260243/jonavos-azoto-avarija-bei-jos-pasekmes)

state's efficacy in managing similar emergencies, including Jonava, came under increasing scrutiny, all of which served to undermine the leadership's legitimacy.

In recognition of the state's shortcomings in emergency management, a new framework was created. In July 1989, the State Commission for Emergency Situations was formed to centralise the response to all disasters whether industrial, natural, ecological, or social. Before long, a situation room was up and running, processing information from throughout the union. Centralising the response to 100+ emergency situations per month, this was one of the unsung successes of the era.

Bigger changes were afoot, however. By August 1989 stunning scenes were broadcast worldwide, as two million peaceful protestors linked hands in a 600km human chain spanning the Baltic states. The people wanted an end to the soviet occupation which had been imposed since the outset of World War II. Almost exactly a year to the day after the horrific events at Jonava, the mood was one of elation as Lithuania became the first nation to proudly break free of the Soviet Union. An island of nationalism, it wasn't long before the neighbouring territories began to splinter off, and soon the entire union had disintegrated into its composite states.

The future's in the air

In the shift from a communist to capitalist society, the Azotas was found to be hugely profitable. The association was formally privatised and renamed "Achema" in 1994. Under the soviet system, production plans were to be met at all costs, often at the expense of environmental initiatives. As part of its integration into global markets, Achema was required to modernise and to reduce pollution to atmosphere, which it achieved by a factor of four. In the years that followed, the company went from strength to strength, implementing power cogeneration as well as progressively expanding its portfolio of chemical products.

In more recent years, it seems that the fate of the Jonava chemical complex has become inextricably linked to its soviet beginnings. Embargos on Russia stemming from the Ukrainian conflict have created record high prices for natural gas, the raw material which Achema reforms into hydrogen for its ammonia reactors. With its products no longer viable under such market conditions, Achema has been forced to suspend most of its operations, which has resulted in severe lay-offs and furloughing. The production trains are now only brought online whenever economics present an opportunity.

This is not the end of the story however, as Achema has emerged with a bold new plan. Through a €2 billion-euro investment program, it will transform its production to green processes. The first step will be the decarbonisation of ammonia synthesis, replacing blue hydrogen (from natural gas) with green hydrogen generated onsite by renewable energy powered electrolysers. Within the next three years alone, Achema expects a third of its ammonia capacity to be de-linked from the volatility of gas markets.

As much as ammonia producers are being driven towards green hydrogen, it also appears that the green hydrogen industry needs ammonia, at least in the near term. A major challenge with the shipment of hydrogen is its energy density. Of the technologies competing to transport hydrogen in a more dense form, ammonia has emerged as a front-runner, and has been selected for many of the first-out-the-gate projects. With no carbon content, it can be converted to and from hydrogen without carbon dioxide emissions, making it consistent with net-zero drivers.

As we emerge into this brave new low carbon, green energy future, we will only see an increased number of facilities for the storage and transport of liquified ammonia. The learnings of the Jonava tragedy are therefore as relevant going forward as they ever have been. And if indeed, the greatest industrial transformation of our generation is to be facilitated by nitrogen, then the future is, quite literally, in the air.

This article is dedicated to the families of those that lost their lives in the Jonava Ammonia Tragedy of 20 March 1989; Valerij Ergardt, Alfonsas Gudavičius, Vladimir Savin, Ivan Tichonenko, Sergej Tichonov, Rimatas Venskus, Henrik Narkevič.