An executive summary of the Professors' Report

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In October 2013, the Israeli government issued a tender to establish an ammonia production plant at Mishor Rotem in order to move the risky operation from Haifa Bay to the Negev. Unfortunately, in November 14, 2016, realizing that nobody has responded to the call, the Ministry of Environmental Protection (MEP) announced its failure. Frustrated by the government failure, Haifa Mayor Yona Yahav appointed a professional committee of scientists and engineers of diverse background to examine all aspects of the ammonia activities in Haifa Bay. The committee was requested to prepare a comprehensive expert report that included the ammonia ship, ammonia tank, land transportation of ammonia, ways to satisfy the essential needs of the domestic and export markets, etc. Mayor Yahav intended to use the report as a factual basis for legal proceedings and public discussions. To ensure objectivity and total independence, all ten committee members who are listed below (Figure 1) agreed to work voluntarily, receiving neither compensation nor any other benefit.

- Prof. Ehud Keinan, the Schulich Faculty of Chemistry, Technion (Chairman)
- Prof. Noam Eliaz, Dept. of Materials Science and Engineering, Tel Aviv University.
- Clinical Prof. Yedidia Bentur, the Rappaport Faculty of Medicine, Technion
- Dr. Alec Groysman, Faculty of Chemical Engineering, Technion
- Prof. Amos Notea, Faculty of Technology Management, Technion
- Prof. Asher Tishler, the Coller School of Management, Tel Aviv University

Figure 1. Members of the Ammonia Committee.

- Prof. Amnon Stanger, the Schulich Faculty of Chemistry, Technion
- Distinguished Prof. Dan Shechtman, Dept. of Materials Science and Engineering, Technion
- Prof. Israel Schechter, the Schulich Faculty of Chemistry, Technion
- Prof. Yoel Sasson, Institute of Chemistry, the Hebrew University of Jerusalem

The report is organized in ten chapters, which are summarized below.

Chapter 1. Ammonia – properties and toxicity

Ammonia is a very toxic gas. Exposure to a concentration of 0.5% in air causes death within 5-10 minutes. Those who are exposed to lower concentrations may not die immediately but become paralyzed and, therefore, cannot rescue themselves. Rupture of the ammonia ship would create a deadly cloud of ammonia, which could reach the entire metropolitan area of Haifa and beyond. The event could create havoc of a magnitude that has never occurred in Israel's history, with hundreds of thousands of casualties. It would be impossible to reach the victims and rescue them because only rescuers equipped with autonomous breathing systems can safely enter a contaminated area. Furthermore, all the roads would be clogged with vehicles with asphyxiated or unconscious drivers. Those who would stay in closed buildings could possibly do better, but may not survive, and the event could last for more than 8 hours.

Unlike the experience gained in the Second Lebanon War, where rescue teams arrived at rocket-damaged areas immediately after the attack, in the case of ammonia contamination, rescuers would not be able to arrive in time to help the victims. Under such chaotic circumstances of unbelievable scale, people will have to take care of themselves. If the event lasts for many hours, the damage would be quite independent of the direction of the wind.

Chapter 2. The ammonia tank has never been a strategic asset of Israel

Authoritative, yet false, statements by senior officials have created the myth that the ammonia tank and related activities in Haifa represent a national strategic asset. These statements sought to support the claim of Haifa Chemicals Ltd. (HCL) that the ammonia tank is unique and irreplaceable, a vital national infrastructure. Furthermore, HCL managed to market itself as the guardian of this asset for the State of Israel in both routine and emergency situations. This position has won the overwhelming support of state officials, including the MEP, the Council of National Security (CNS), the army and even the State Comptroller, all accepting this myth as an absolute truth. However, this assumption has never been verified and is simply incorrect. The ammonia tank has never been a national strategic asset. Various business entities other than the fertilizer producers need tiny quantities, less than 3% of the excessive amounts of liquid ammonia entering the Kishon port every month. Approximately 97% of that is exported in the form of chemical fertilizers, mainly to customers in China and India. This is quite a profitable industry, but has nothing to do with national interests. Anyone interested can produce ammonia and fertilizers, preferably in the Negev. Importing huge quantities of liquid ammonia (120,000 tons per year), stockpiling it in a densely populated area, and transporting it across the country from Haifa to the Negev, a distance of 260 km, is a major strategic threat, certainly not a strategic asset.

The report commissioned by the MEP in 2011, which describes the Israeli ammonia market, is a poorly written document, riddled with erroneous data, poor analysis and, in particular, false conclusions. This is a historically important report because it was fully adopted by the MEP, as if it were a professional and objective document. Furthermore, the report and its conclusions were fully endorsed by the government and served as the basis for the problematic resolution 766 and the above-mentioned tender, which resulted in loss of valuable time and public resources and left a huge population of one million people at high risk.

Moreover, this report contradicts an earlier report by the Committee of the National Emergency Authority (NEA), which examined the need to maintain strategic stocks of hazardous materials. The NEA stated that the domestic Israeli economy does not need more than 2,250 tons per year, certainly not the current imports of 120,000 tons. Such small amounts can be imported and stored in the form of iso-tanks, which are well protected, or in other forms, such as urea, which can be distributed and stored in various sites around the country in safe sites, without risking the population. The NEA stated clearly that there is no reason to stockpile strategic inventory of ammonia and, therefore, no reason to maintain a large ammonia tank in either Haifa or anywhere else. It is a disturbing mystery why the commissioned report of the MEP, which contradicts the earlier report of NEA, has become the sole policy-determining document.

The government resolution 766 of October 6, 2013, declared the establishment of an ammonia production plant at Mishor Rotem as a national interest of vital importance and urgency, and instructed all ministries, government bodies and regulators, to promote and prioritize the project, including all aspects of infrastructure, regulation and supply of natural gas, in order to complete the project in the shortest possible time.

To date, nearly four years after that dramatic announcement, there is no facility in the Negev, no ammonia production plant in the Negev, no tender for establishing one, and no probability of having such a plant in the foreseeable future. It is likely that if any business would like to produce ammonia in the Negev, it will do so without resorting to the aid and initiatives of the government of Israel. In any case, it is not the task of the Israeli government to take care of supplying raw materials for an American private company that has chosen to produce fertilizers for export on Israeli territory.

Chapter 3. Refrigerated ammonia tanks - maintenance and inspection

Recognized international organizations, such as the European Fertilizer Manufacturers Association (EFMA), and the National Association of Corrosion Engineers (NACE), have formulated detailed guidelines and standards for the maintenance of storage tanks of refrigerated ammonia at atmospheric pressure. These documents testify to the great importance the chemical industry in Europe gives to safety issues. The guidelines detail how and why to perform periodic inspections of the tanks, what is the recommended frequency of testing, what test method should be used, and how continuous monitoring should be performed between inspections. All of these reflect the considerable probability of failure and the high risk to the population and environment.

Ammonia tanks are built according to international standards that require radiographic testing (RT) and magnetic testing (MT) methods to ensure the quality and integrity of welds, which are of critical importance throughout the life of the container. The main cause of metal aging is the phenomenon of stress corrosion cracking (SCC). Any material under a corrosive environment develops cracks that can cause sudden and unexpected failure. These microscopic cracks undergo gradual branching and eventually unite to form macroscopic cracks, which may lead to sudden collapse of the metal structure with catastrophic results. Metal surfaces may look fine and shiny and, yet, may contain multiple microscopic cracks. The SCC phenomena vary greatly with the toughness and strength of the metal plates, quality of welds, internal stress, external pressures and function of the tank. Thus, decisions on the planning and execution of internal inspection programs are of crucial importance.

Another risk factor is metal fatigue, which stems from periodical fluctuations in stress of temperature and pressure over time. This phenomenon is manifested by tiny microscopic cracks, which penetrate deep into the material, weakening its ability to resist the load until it breaks down abruptly. Metal fatigue is one reason why the average life span of a refrigerated ammonia tank is limited to about 40 years. Consequently, according to the European standards, the 31-year old tank in Haifa is rapidly approaching the end of its life.

The EFMA Guidelines repeatedly emphasize the requirements for very high levels of skill and experience in managing and conducting the periodic inspections. Reliability of data is critical for making decisions on how often the tank should be examined. Risk-based inspection frequency is linked to two factors: the probability of failure and the expected consequences. In light of these guidelines, the fact that the tank in the Haifa Bay has never been inspected internally over its 31 years of operation raises serious questions. Even if the tank were perfectly built using the best possible materials, and even if it were located in the heart of the Sahara Desert, hundreds of kilometers away from any settlement, the final inspection date already passed six years ago. Obviously, the construction technology of 30 years ago was not perfect, and the tank is not located in the Sahara desert. Using the risk matrix of the EFMA guidelines, the Haifa tank had to undergo an internal examination, at least three times during its lifetime. This negligence could result in a heavy toll of human life. The tank is already in the "red area" of the risk matrix, namely the highest possible risk, which requires immediate cessation of all activities, emptying the tank and immediate inspection from inside.

The most highly recommended technique for internal inspection is wet fluorescent magnetic testing (WFMT), which is the most sensitive way for detecting SCC. The test is also very useful for repeated testing after welding repair and after heat treatment. There are other methods, such as the introduction of dyes, radiography, ultrasound and acoustic emission, some of which can be done on the outside of the tank with no need to stop its activity, but these are less sensitive and cannot detect cracks below a certain threshold. For example, the method of acoustic emission is relatively easy to perform from outside, but its sensitivity is very low. EFMA guidelines stipulate that non-invasive tests can be conducted only if at least one internal testing and external testing have been performed where the internal inspection revealed no significant SCC, general corrosion or intrinsic inborn defects. In other words, the single test, which was carried out in the Haifa tank by the acoustic emission method in February 2015, is meaningless and unacceptable according to European standards.

Chapter 4. The inspection results of the ammonia tank in Haifa Bay

The statements made by HCL officials, claiming that the ammonia tank has been tested and that the test fully confirms its integrity and credibility, is false, has no factual basis, and

is misleading, irresponsible and dangerous. Furthermore, the statement made by HCL that the expected lifetime of the tank has been extended for additional 55 years, is unprecedented and outrageous. The test was carried out in an amateurish way, contrary to international standards and guidelines, ignoring the key principles of risk-based inspection. It is very disturbing that the severest environmental risks in the State of Israel, which may affect hundreds of thousands lives, is ignored by the regulator. The absence of the MEP at all phases of the fake inspection is glaring. HCL decided by itself when to test, what to test, how to test, who will perform the inspection, how to report, to whom to report, and the Ministry gave an automatic approval stamp after the fact. Since an internal inspection has never been performed over the entire 31 years of the tank, which is unprecedented by any international standard, and because the acoustic emission report indicates the possibility of the existence of serious cracks in the tank wall that could lead to collapse within a few months, it is essential to decommission the tank immediately and prepare it for a true inspection.

Chapter 5. Analysis of world accidents involving ammonia tanks

All accidents described in this chapter are relevant to the ammonia tank in Haifa Bay, especially the accident that occurred near the town of Jonova, Lithuania. The ammonia tank of Jonova was built under the supervision of a reliable Japanese company. That tank is highly relevant to the Haifa one because it was of a similar size and was constructed by a similar method. When that tank collapsed due to metal failure, which can occur anytime in Haifa, it was only 11 years old, i.e., 20 years younger than the Israeli tank. It was an insulated steel tank with external steel casing, tightly fasten to its concrete foundations by 36 massive steel strips. In addition, the tank was surrounded by a protective wall of 40 cm reinforced concrete, like the one in Haifa. All of these features did not prevent the tank from bursting powerfully and flying 40 meters away, uprooted from its foundation, tearing all the welded steel bands and taking the concrete wall on its flight. Although, fortunately, most of the gaseous ammonia cloud flared and burned, yet the clouds of ammonia reached 32 km and created a contaminated area of 400 square kilometers.

In Soviet times it was possible to quickly evacuate 32,000 people from the disaster area. In Israel today, nobody can evacuate 600,000 residents from the area near the tank or to offer them any kind of help. In addition, one should keep in mind that the Jonova area of Lithuania is not tectonically active and is not prone to earthquakes, as opposed to the Haifa Bay area. Furthermore, Jonova is not threatened by terrorist organizations like our region.

Chapter 6. Risks involving the ammonia ship

Hezbollah Secretary General declared that he considers the ammonia tank to be an "atomic bomb" at his disposal. This statement sounds boastful, unrealistic and baseless. The two atomic bombs that were dropped on Hiroshima and Nagasaki at the end of the Second World War claimed 246,000 human lives. A similar toll of 230,000 deaths resulted from the tsunami in the Indian Ocean in 2004. Both of these events are remembered as traumatic events worldwide, mainly because they occurred as a complete surprise, within a terribly short period of time, and because the victims were innocent and helpless against tremendously powerful phenomena. Hezbollah Secretary General was absolutely right about the destructive potential inherent in the tank, and even more importantly, in the ammonia ship.

Despite the fact that the threat posed by the ammonia ship is far larger and more significant than the one associated with the ammonia tank on the beach, it had never been part of the public agenda. The Shafir Committee, which was established after the Second Lebanon War, intended to examine all aspects of preparedness and defense with regard to hazardous materials in the Haifa Bay in both peaceful and war times. Their report, as well as the 2011 report of the MEP, never mentioned the risks posed by the ship. Only recently, after bringing this issue to the Supreme Court in July 2016, the MEP admitted that damage to the ship would actually create a cloud of ammonia gas with a lethal range of 6 km. These estimates were established with more details, although referring to the ammonia tank, by the Haz-Mat report of 2007.

Once a month, for already 30 years, the ammonia ship enters the Kishon port, carrying a tremendous amount of 16,700 tons of liquid ammonia within 5 containers. Usually, it stays at the port for two days, and during that time pushes about 10,000 tons of ammonia into the tank on the beach, to renew the maximum allowable capacity of 12,000 tons. A detailed study, published in 1974 by the US Coast Guard, assessed the risks of marine transportation of liquefied ammonia. It was found that the contact between liquid ammonia and seawater causes a spontaneous exothermic reaction that has catastrophic consequences. Their experiments demonstrated that approximately half of the liquid ammonia dissolves in water, but the other half evaporates immediately, creating a cloud of ammonia gas. One can compare this phenomenon to the familiar event of pouring water on hot metal surface or into a pot of boiling oil.

Rupture of the five tanks in the ship would result in a cloud of ammonia weighing over 8,000 tons and the initial height would be 600-800 meters. Although ammonia gas is lighter than air, it reacts with moisture in the air, forming an equilibrium with

water crystallites thereby keeping the ammonia near the surface for many hours. Videotaped leak events at various locations around the world show that the ammonia contamination looks like a thick white fog creeping close to the ground. In the accident occurred on the Jonova site in Lithuania, clouds of ammonia reached as far as 32-35 km, contaminating an area of 400 square kilometers. The free software ALOHA is widely used by the US Environmental Protection Agency (EPA) and by the MEP, Ministry of Defense and the chemical industry. The ALOHA predicts that on a fair weather, partly cloudy, when the wind speed is 10 miles per hour, which is very common in Haifa, the area of the deadly cloud of ammonia could reach a diameter of more than 20 kilometers, depending on the wind direction, and could travel a distance of tens of kilometers, until gradually dissipating and being absorbed in the ground. The event will last for at least 8 hours and, during this time, all those trapped within the danger zone and not equipped with autonomous breathing system with oxygen tanks, will choke to death within 5-60 minutes.

All the metropolitan areas of Haifa and its suburbs are within the range of this deadly cloud, even if the attack occurred when the ship was within the waiting area in the center of the bay, away from the port. Technion City is just 4 km away from the port and Haifa University, 5.5 km away. According to the known wind directions in the Haifa area, the chances of survival in these campuses would be very slim. The effect on the Haifa hospitals would also be a fatal blow. Even if someone would trigger an alert signal, it would not be possible to evacuate the hospitals and their medical teams in a timely manner. This would effectively neutralize the entire health system in the metropolitan area, including Rambam Hospital, the Italian Hospital, hospitals in the Carmel and Bnei Zion. Over 600,000 people would be at high risk. Such numbers are inconceivable in any apocalyptic scenario that has been considered by any security officials in Israel. This means hundreds of thousands of casualties, blocked roads and a chaotic situation that this country had never experienced. There is no rescue organization that can control disasters of this magnitude. Nobody can collect real data in real time, analyze, make decisions and initiate any action.

The ammonia ship cannot be protected against a terrorist act. Planning, scheduling and execution of a terrorist act on the ammonia ship entering Haifa is much simpler than many recent terrorist attacks in Israel and abroad. The arrival times of the ship are known for at least one week in advance with an accurate day and hour. Anyone can easily follow the ship route using any smartphone with the free app MarineTraffic. The ability to prevent an attack on the ship is essentially impossible. A multinational team of multiple citizenships operates the ship. These sailors are replaced frequently at various ports along the ship's route from Ukraine, through various ports, including the ports of the black sea, Turkey and North Africa.

It should be remembered that the ammonia ship has a standard steel envelope of 19 mm thickness, and this is also the thickness of the ammonia containers. The distance between the envelope of the ship and the containers is usually 20 cm. In military terms the ship and its containers are only slightly stronger than a tin can. Any terrorist can consider a wide range of weapons, devices and scenarios that could rupture the ship and containers. Even a machine gun positioned outside the port can do it. The damage can be done by various explosives placed inside the ship, shoulder-fired missiles, magnetic bombs, marine mines, as well as a direct hit by a surface-sea missile, such as the one that hit the IDF combat ship in 2006. Hezbollah may prefer the scenario of a hit by an accurate missile, because it would be very easy to target a large stationary ship. Moreover, it is possible to accurately plan the time of attack for optimal meteorological conditions in terms of damage efficiency.

Chapter 7. Risks of tanker trucks: analysis of accidents around the world

HCL consumes 85,000 tons of ammonia out of the annually imported 120,000 tons. The company operates two production sites, each consuming about 40,000 tons annually. Thus, 40,000 tons ammonia are transported using road tankers from Haifa to the Negev. The average transportation rate is 10 trips a day, through densely populated areas, from northern Haifa Bay to the southern site at Mishor Rotem, south of Arad, a distance of 260 km. Fortunately, during nearly three decades of activity there were only few of road accidents involving tankers ammonia, and none of them breached the tanker itself. Fortunately, to date, terrorists have not targeted these tankers, despite the fact that the release of 20 tons of ammonia gas in urban area can be disastrous. The potential damage following either a mechanical failure or a terrorist attack can be assessed on the basis of accidents involving road tankers, which occurred worldwide. In one case where an ordinary road tanker collapsed, it ended with 129 dead and 1,150 wounded. The level of risk that Israel imposes on its citizens to enable business activity of a private company is unreasonable and intolerable. The business model of importing liquid ammonia to Haifa, for use in Mishor Rotem, is not acceptable in a modern country.

Chapter 8. Risks associated with the regulator's weakness: Bhopal and Seveso

Industrial activity is very expensive in developed countries due to the intricate regulatory track and procedures in terms of time and money. Therefore, it is quite tempting for developed industries to conduct their dangerous activities in places where safety requirements and enforcement capabilities do not exist, or are relatively weak. In this way they can bypass the expensive

routes of licensing and continuous supervision and avoid the need for approval by the local population. This is a way to increase profits by saving on quality and security arrangements at the production facilities. Increased profitability comes at the expense of the local population, which cannot be protected by the political leadership. Since the activity usually involves cheap products and low technology and because safety standards and insurance coverage in developed countries are expensive, the advantages to the foreign company are obvious. International organizations, such as the United Nations, have already considered such scenarios and the risks posed to vulnerable populations whose politicians are unable or unwilling to protect them. Still, there is no mechanism in which international organizations can protect these populations.

Understanding the parameters that led to the disasters in the city of Bhopal, India, and in Seveso, Italy, can prevent a disaster of similar magnitude in Haifa Bay. In all cases, there was a company from a developed country, which would have good reasons to set up factories in a weaker country. The Swiss company Givaudan chose to build a plant in Italy, the American company Union Carbide chose to build a plant in India, and the American company HCL has chosen to operate in Israel. In all three cases, if the company would have been operating either in the US or in Switzerland, its profitability would be much lower because the product is cheap and the technology is relatively low, whereas safety standards in these countries are rigid and costly, and insurance coverage is very expensive for such activities. In all three cases, there is a company that takes advantage of cheap labor in another country, where safety barriers are low and the regulator is absent, careless and toothless. The big difference is that in India and Italy the disaster has already happened, whereas in Israel it has not yet.

Chapter 9. Risk management

According to the theory of risk management, the seriousness of a given risk is expressed mathematically as the product of two parameters: probability of the event and severity of the consequences. Security officials, not only in Israel, tend to ignore this basic principle, especially when exposed to public debate, or even when presenting an expert opinion in court. Phrases such as “an event of very low probability” are meaningless, and their use reflects irresponsibility. We all remember the complacency and smugness of security officials in the US with respect to feasibility of the attack on the Twin Towers in New York, not to mention the estimates of Israeli intelligence and the political leadership on the eve of the Yom Kippur War. Whoever treats only the likelihood parameter and ignores the severity of the incident, is wrong and misleading, because it converts a two-dimensional surface into a one-dimensional statement, which is meaningless. Converting a serious discussion that is based on quantitative logic into a populist debate, based on qualitative terms, is inexcusable, because it harms not only the subject of discussion, but also the level of discussion.

The ammonia risks may be discussed in the context of earthquakes. First, there is a very likely chance that an earthquake at the Yagur Fault would lead to fracture of the ammonia tank. The MEP has recently predicted that the lethal range of the ammonia cloud, which will be created by the collapse of the tank, would be 4 km, and a terrorist attack on the ammonia ship would create a lethal zone of 6 km. Our estimates, based on the ALOHA program, are larger than 10 km. Given the population density at these ranges, the number of casualties, especially fatalities, could reach hundreds of thousands.

Secondly, there is an unjustified difference between the way the State of Israel evaluates the risks of major earthquakes (probability is low, and the potential for damage is relatively low) and the way it manages the risks associated with the ammonia activities (probability is high, and the potential for damage is relatively high). The expected loss of lives is 10 times higher than the expected toll of a major earthquake. This difference may be attributed to incorrect risk management and the fact that earthquakes are familiar phenomena. The scenario of mass poisoning by an ammonia cloud is an unknown disaster and is therefore transparent to the public and political eyes, resulting in ignorance and complacency.

The public commission report of Major-General Herzl Shafir considered only risk scenarios that were easy to handle but of marginal insignificance. They referred only to the ammonia tank, but not the ship. They referred only to top-attack of the tank, only by high-trajectory weapons, only to damage during a declared war, etc. This is, of course, only one disaster scenario out of countless scenarios, all being ignored, including the dire scenario that would involve the collapse of the tank as a result of metal fatigue, earthquake, terrorist attack, strike by flat track weapon, not to mention an attack on a ship of ammonia, which is the worst scenario. The Committee acknowledged that "in the routine, the situation of a hazardous event, fault, terrorist event, it is not the responsibility of the IDF, so we do not know how to deal with those... in principle, according to our instructions and in accordance with our mandate, the tank is protected to our satisfaction." And yet, the commission transmits a tranquilizing message for all other scenarios not even discussed by them. This complacency of the committee makes the lines of separation between risk factors vague. Because there is no entity willing to take a comprehensive responsibility, the situation is difficult and complex, allowing for continuing "business as usual" and ignoring the actual risks.

Chapter 10. Alternative ways to match the Israeli demand for ammonia

There is no need to import liquid ammonia to Israel by ship and there is no need to risk hundreds of thousands of people during this operation. There are several reasonable alternatives to this activity. None of these alternatives requires huge tanks of the kind found in Haifa Bay. Other industries that need small or medium size quantities can import ammonia using well-secured iso-tanks, which come in size of 20 feet long (12.5 tons of ammonia), 30 feet (18 tons) and 40 feet 23 tons). Such containers are locked up in a steel cage with dimensions identical to those of standard marine containers. Their transportation is safe and effective, is not expensive and handling is similar to that of regular containers. All needs of the Israeli economy, except for the fertilizer industry for export, is merely 3,000 tons of ammonia per year. This amount can be imported using 150 iso-tanks. There is no need to bring in all that amount at one time, and it can be imported sporadically through container ships transactions, which reach all Israel's ports, without special safety requirements.

Ammonia can also be produced on site from urea, a solid, granular material, which is easy and very safe to import and store indefinitely. There are effective technologies to hydrolyze urea to ammonia, so that all the ammonia produced is consumed immediately and therefore there is no need to store it in a container of any sort. The Israel Electric Company produces all the ammonia it needs for neutralization of nitrogen oxides in the Orot Rabin power station. They plan to reach an annual consumption of 200,000 tons of urea, which enables the production of 113,000 tons of ammonia, almost equivalent to the liquid ammonia imported to Israel by HCL. It is also possible to produce ammonia from natural gas in small quantities, as can be seen all around the world in the last 20 years.