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Series on Chemical Accidents

OECD

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The Inter-Organisation Programme for the Sound Management of Chemicals (IOMC) was established in 1995 following recommendations made by the 1992 UN Conference on Environment and Development to strengthen co-operation and increase international co-ordination in the field of chemical safety. The Participating Organisations are FAO, ILO, UNDP, UNEP, UNIDO, UNITAR, WHO, World Bank, Basel, Rotterdam and Stockholm Conventions and OECD. The purpose of the IOMC is to promote co-ordination of the policies and activities pursued by the Participating Organisations, jointly or separately, to achieve the sound management of chemicals in relation to human health and the environment.

Foreword

The OECD Working Party on Chemical Accidents (WPCA) organised a half day thematic session at the occasion of its 32nd meeting on 26th October 2022. This thematic session was covering two themes:

- How to make lessons learning from accidents work? and
- Challenges and issues arising from decarbonisation and the energy transition.

The thematic session was organised as a brainstorming meeting with presentations from experts and discussion to exchange on challenges in these two particular areas. This report summarises the main conclusions from the thematic session. The conclusions will help support the development of future activities of the OECD WPCA. It does not necessarily represent the views of the OECD or a consensus among participants.

The report is published under the responsibility of the OECD Chemicals and Biotechnology Committee.

Table of contents

Boxes

1 Implementing lessons learned from chemical accidents

The fact that chemical accidents continue to happen that have great similarity to past events indicates that the necessary learning is not taking place. The thematic session looked at why stakeholders are not learning from accidents; what are some of the fundamental organisational root causes of accidents and barriers to organisational learning; and recommendations for improvement.

Why are we not learning from chemical accidents?

It is frequently observed that similar accidents keep repeating in the same company, and in other companies in the same industry. The workshop highlighted that the same safety failures have been identified over the years across accidents, with, in particular, continuous problems in managing and maintaining the integrity of the installation. There is a failure to learn from past accidents.

The workshop showed that there is a vast amount of incident data available. There are numerous academic publications on accident investigation and methods, there are reporting requirements in many national legislations and also many operating companies require their sites and installations to report specific types of events; there are numerous books, journals that serve as dissemination tools as well as investigation reports accessible from a number of national and international databases. The failure in learning does not seem to be linked to a shortage of data, so why are we not learning?

The workshop pointed out that lessons learning seems to mainly consist of reporting on the technical causes of an accident with a lack of discussion of organisational/systemic interaction of causal factors. It is not the amount of information that is the problem but the type of information that is researched, collected and then shared, and the possibility of implementing changes as a result. There is a need for more depth in the investigation and reporting, going beyond visible technical evidence, searching for the organisational root causes of accidents, and linking key organisational features with the occurrence of accidents. The workshop also identified difficulties in the sharing and implementation of lessons learnt because of “common” organisational practices that can inhibit learning and change.

What are some of the fundamental organisational root causes of accidents and barriers to organisational learning?

The workshop highlighted a number of barriers to the implementation of lessons learnt from past accidents, mainly associated with:

- a failure of the organisations to learn from past mistakes and as a result change practices, and
- fundamental features of organisations that stand in the way of effective learning.

The workshop highlighted an over-emphasis on “administrative practices” in organisations that inhibits flexibility, networks and sharing. “Administrative” practices include leadership means such as planning, directing, monitoring and controlling. This traditional “administrative” paradigm is still persistent and dominant in the chemical industry despite a growing research consensus on the importance for safety of also incorporating more “adaptive” and “enabling” practices. These “adaptative” and “enabling” practices include mindful compliance, being able to question existing processes, furthering dialogue, supporting formal and informal networks, creating an environment of trust with no fear of retribution or ridicule.[1]

The workshop then examined in more detail two particular features of organisations that make effective learning difficult[2]. The first one is a system of monetary reward focused on production levels and profits. Many corporations pay bonuses to people at all levels of the corporation. These bonuses often depend on the speed of production, and most generally on profit, which can be linked to cost cutting. The workshop presented accident cases, the causes of which implied bonuses linked to speed of production and a request for cutting cost across the organisation that resulted in managers cutting maintenance, staff and training. When bonus calculations also take account of safety, it is nearly always personal safety as measured by injury rates. However, the workshop highlighted that the hazards that are the cause of most injuries are not the same hazards that are the cause of major chemical accidents. The bonus system is focused on maximising profit and production and takes very little account of the capacity to manage chemical accident risk. Implementing the lessons learnt from accidents will very likely require the involvement of additional resources that will impact the overall profit. For bonuses that are dependent on share prices of a company there is a pressure to maximise shareholder returns and since major chemical accident that could impact share prices are rare, they can hardly counteract this pressure.

The second feature of organisations that was presented as an obstacle for lessons learning is the organisational location of technical specialists, such as chemical or drilling engineers. They understand the issues but often occupy lower positions in the organisational hierarchy. These technical specialists also are under pressure to meet business performance goals sometimes at the expense of technical or operational excellence. Regarding the implementation of lessons learnt from past accidents, they may not have the authority and be able to engage the resources needed for these lessons to be properly implemented. The workshop presented cases of accidents where the relatively powerless position of technical specialists has been identified as one cause of the accidents. These accidents had such a big impact on those companies that they had to react and develop systems that allowed technical specialists to be sufficiently empowered to ensure that good engineering practices are in place.

Conclusions and recommendations

Discussions at the workshop highlighted:

- the importance of not just studying a report of an accident but of looking at patterns. What are the patterns in processes that are leading to problems; what needs to be put in place to better understand these particular problems.
- the importance of information management and information communication. Many times accidents happen because the right information did not reach the employee who was doing the corresponding job and resulted in wrong decisions being made.

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[1] Maureen Heraty Wood, Konstantinos Koutelos, Mark Hailwood, Charles Cowley (2022), Learning lessons from chemical incidents – what's stopping us and how we can make it happen, Chemical Engineering Transactions, Vol.90, p 685-690, https://doi.org/10.3303/CET2290115]

[2] Andrew Hopkins, Sarah Maslen (2015), Risky Rewards: How Company Bonuses Affect Safety, CRC Press, London, ISBN 9781472449849

Andrew Hopkins, Organising for Safety. How structure creates culture, Sydney, Wolters Kluwer, 2019, ISBN: 9781925894158.

- the need to make sure learning is captured and learning is taking place on site. Accident reports need to be communicated to many different units within the company (e.g. front line, design, operational control) and a system should be developed to make sure learning is taking place.
- the need to have specific time dedicated for learning both within a company and government. It is critical for leadership to provide sufficient time and resources for people to learn, exchange, and gather information. This is also important for government policy personal. They should also have access to the learnings from accidents. The learnings often are the leading elements that go into policy thinking and policy formulation. They also are essential to communicate with senior officials and ministers for justifying policy and regulations.
- the need of ensuring both technical and non-technical competence for all employees.
- the importance to create knowledge-transfer systems to pass on knowledge to the next generation of employees when people retire or leave the organisation.

The workshop provided a number of recommendations to help overcome the challenges of implementing lessons learning:

- **Improving databases**

As part of the reporting of accidents in databases, the workshop proposed the possibility to include larger text content to the traditional formatted data fields. Also enhanced searchability and development of analytical methods and software tools to improve understandability were highlighted. This can be facilitated by increasing standardised ontology.

The workshop recommended that the use of chemical accident databases be developed to allow better recording of information that enables the identification of systemic causes that go beyond single-loop learning. This includes better information sharing to include not only dissemination of accident details but also lessons to be learned and recommended actions to be taken to apply those lessons. As an example, the Center for Chemical Process Safety (CCPS) will be leading a project to collaborate between incident data owners that will be aimed at a common data classification and more effective data analysis, focused on lessons to be learned and recommended actions to apply them

- **Fostering dissemination**

The workshop proposed to foster the role played by industry associations and professional organisations in the management of incident learning as some organisations may be reluctant to provide accident information. Networks should be developed within and between organisations to build expertise and share it widely.

- **Moving beyond reporting and dissemination: lessons learning led from the top**

Achieving effective organisational learning from incidents requires a cultural shift and a climate of psychological safety and mutual trust. The workshop strongly emphasized that learning from accidents must be led from the top. There needs to be a clear commitment by the CEO and senior executives to adopt the kinds of leadership practices that encourage learning. CEOs and senior executives should commit to adopting more adaptive and enabling leadership practices within their organisations to create the climate of psychological safety necessary for a learning culture, alongside traditional administrative ‘command and control’ leadership practices.

- **A change in the organisation focus**

The workshop highlighted two points as key features of organisations to encourage learning:

- The need to ensure that companies provide effective incentives to employees at all levels to manage major accident risk; and
- That they provide technical specialists with the authority and independence that will enable them to insist on good engineering practice.

Discussion at the workshop raised the possibility for the WPCA to:

- Review and update the OECD Guidance on Corporate Governance for Process Safety with the points highlighted during the thematic session. The project of update could include small studies looking at case studies from companies where leadership has allowed lessons learning and change;
- Develop a specific project that will continue discussions on how to improve the implementation of lessons learnt from past accidents (for example with the development of a catalogue of accident databases).

2 Challenges and issues arising from decarbonisation and the energy transition

The second part of the thematic session addressed risk of chemical accidents from the energy transition, focusing specifically on risk from hydrogen, ammonia as a green energy vector, lithium-ion batteries, solar power and carbon capture utilisation and storage (CCUS).

The thematic session did not attempt to discuss all the complexities of these new energy sources but rather to look at the big picture of some of the key safety problems that may need to be solved before they become mainstream energy alternatives. The workshop highlighted that discussing risks does not mean that these risks cannot be managed but that there is a need to make sure that effective management of the risk is a critical part of the transition to these new sources of energy.

Hydrogen - General considerations on accident risk

The workshop highlighted the properties of hydrogen and related chemical accident risk potential. Hydrogen has:

- A tendency to escape due to its low molecular weight;
- Wide flammability range;
- Low ignition energy demand; and
- The ability to detonate easily.

The typical considerations for hydrogen risk management were mentioned as:

- The fact that hydrogen rises rapidly but diffusion makes it disperse in all directions;
- Confined and semi-confined spaces can increase the risk of explosion;
- Cryogenic hydrogen, when released, is usually a mixture cloud of hydrogen, air, and water that can ignite with very low energy input;
- Hydrogen reacts spontaneously and violently at room temperature with chlorine or fluorine;
- Completely dust-free hydrogen released from a pipe or tank does not catch fire easily, but ignition can follow when escaping gas comes into contact with dust particles or water droplets;
- Hydrogen can be accidentally produced in various ways, e.g., from contact between water and molten metal.

The workshop presented an analysis of hydrogen related EU Seveso major accidents reported in the eMars database[3] in the last 20 years until 2019, with cases involving:

- Processes that involve pure hydrogen and air;
- Processes involving syngas with a significant percentage of hydrogen;
- Hydrogen created as a consequence of a reaction (e.g., with metal);
- Chain of events, not initiated by hydrogen, but where a hydrogen containment is ultimately affected and is responsible for the escalation of the incident;
- Equipment degradation caused by hydrogen embitterment, hydrogen stress cracking;
- Failure to anticipate the presence of hydrogen in mitigation measures;
- Build-up of hydrogen in confined spaces;
- Hydrogen releases causing jet flames, vapour cloud explosions and pressure bursts, and sometimes causing a wider conflagration when not contained.

Amongst the 32 cases of accidents reported, the industries the most impacted are chemical manufacturing, petroleum refineries and mining and metal processing. Explosions occurred in most of these accidents. Most accidents resulted in fatalities, injuries, property damages and had business impacts. Ten of these accidents included more than 2 million EUR in property damage and three over 10 million EUR.

The workshop highlighted a number of situations in which the use of hydrogen is raising questions around risk, including:

- Hydrogen storage;
- Electrolysis of water for the production of hydrogen;
- Hydrogen distribution through pipelines;
- Liquid hydrogen distribution via road, using pressurized or cryogenic storage;
- Transport of hydrogen in the form of ammonia;
- Compression and regasification of hydrogen associated with liquid hydrogen transport;
- Consumer fuelling stations;
- Hydrogen for heating: suitability of cast iron for hydrogen long term transportation of hydrogen, hydrogen gas explosions in buildings, delayed ignition of hydrogen gas releases from pipelines.

A number of initiatives developed in the UK associated to plans for the deployment of hydrogen in the country were presented at the workshop as an approach a specific country is taking (See Box 1).

3 See, https://emars.jrc.ec.europa.eu/en/emars/accident/search

Box 1. Hydrogen risk assessment in the UK

Initiatives developed in the UK associated to plans for the deployment of hydrogen in the country including the following examples.

There is an ongoing assessment of the impact of hydrogen on the British transmission and distribution pipeline network, including above ground installations. The assessment is examining:

- Materials performance: effect of hydrogen embrittlement and fatigue on design, construction, operation and maintenance
- Risk assessment: change in failure frequencies, leakage, gas migration, dispersion, accumulation, ignition potential, fire and explosion effects, hazardous area classification
- Operational procedures: pipeline purging, venting, inspection, maintenance, leak detection, repair
- Equipment: gas detectors, regulators, heat exchangers, meters, kiosks, PPE, software
- Training and Regulation

Two regional hydrogen and CCUS clusters funded by the UK government were presented: HyNet https://hynet.co.uk and the East Coast Cluster https://eastcoastcluster.co.uk .

Also, a number of projects on hydrogen for heating were presented with a neighbourhood trial in 2023 (https://www.h100fife.co.uk/), a village trial in 2025 and a town trial in 2030. Targets are set of 5 gigawatts of low carbon hydrogen production and 10 Mt of carbon capture by 2030.

Research projects were also highlighted:

- Hydeploy (https://hydeploy.co.uk): scientific analysis and experiments to support quantitative risk assessment for 20% blend of hydrogen in natural gas;
- H21 (https://h21.green): repurposing of existing natural gas distribution network for 100% hydrogen (leakage tests on recovered assets, gas migration through soil, dispersion, accumulation, ignition, fires, explosion severity, operational procedures);
- H100Fife (https://www.sgn.co.uk/H100Fife): application of 100% hydrogen in a new gas distribution network with community trials planned for 300 homes in Scotland in 2023 (testing of polyethylene pipes, experiment and analysis to support a quantitative risk assessment);
- FutureGrid (https://nationalgrid.com/FutureGrid): repurposing of existing national gas transmission network for hydrogen (analysis of 2% and 20 % hydrogen blends plus 100%);
- Hy4Heat (https://www.hy4heat.info/): hydrogen in residential and commercial buildings and gas appliances (focus on downstream of the emergency control valve, gas quality, metering, appliances, purging, tightness testing, trials);
- LTSFutures (https://wwwsgn.co.uk/about-us/future-of-gas/hydrogen.lts-futures): hydrogen in the local transmission system (7to 60 plus bar).

There were mentioned of a number of projects linked to cryogenic liquid hydrogen:

- PreslHy (www.preslhy.eu) 2018-2021: Prenormative research for safe use of liquid hydrogen
- SH2IFT (https://www.sintef.no/projectweb/sh2ift/) 2019-2022

And to transport related studies:

- HyTunnel (www.hytunnel.net) 2019-2022: hydrogen fires and explosions in tunnels from vehicle releases, explosion prevention and mitigation, emergency response actions;
- MultHyFuel (www.multhyfuel.eu) 2021-2023: Safety and permitting of hydrogen at multi-fuel retail sites, Review of permitting requirements and risk assessment, Experiments and modelling of high-pressure hydrogen releases.

The workshop also raised a number of additional risk considerations:

- Hydrogen is currently handled by a small set of companies with long experience and current incentives for a green energy transition are bringing many new players into the market that may not have the same level of expertise. Also, current experience may not be representative of the risks of new uses (e.g., electrolysis, compression, transport, distribution) especially with inexperienced users and untested systems;
- To assess the safety of hydrogen projects, realistic and useful scenarios and modelling are required for release, dispersion, explosion and fire events. These are not yet available for a number of new uses. There are difficulties at the moment to establish safety distances and land-use planning measures associated to new uses of hydrogen;
- There is a need for increase in knowledge and competency amongst engineering contractors, operators, government inspectors, including regular exchange of knowledge, and sharing accident information and data.

Lithium-ion batteries – Implications for major chemical accident risks

The demand for lithium-ion batteries is rapidly increasing. In the EU/EEA region lithium-ion batteries producers are identified as Seveso sites. They are identified under eSPIRS[4] as “electronics and electronic engineering”.

The workshop presented accidents that have happened during incineration, at a battery production site and at a power station. Also a study from the Bureau for Analysis of Industrial Risks and Pollutions in France (BARPI) on involvement of Lithium-ion batteries in accidents occurring in non-waste business sectors was presented.[5] In this study, BARPI has analysed all events involving Li-ion batteries since the 2000s in non-waste business sectors and excluding use by non-business customers (phones and laptops, electromobility, etc.). The study provides details of accidents occurring during the life cycle of these batteries: research, design, use and storage on site before sending to waste facilities. Most of the cases of accidents presented in the study involved batteries in use or storage, but a few are in production and generally seem to be caused by a short circuit or overheating resulting in an exothermic reaction.

4 Seveso Plants Information Retrieval System, https://espirs.jrc.ec.europa.eu/en/espirs/content

5 See, https://www.aria.developpement-durable.gouv.fr/synthese/involvement-of-lithium-ion-batteries-in-accidents-occurring-in-non-waste-business-sectors/?lang=en

The workshop posed a number of questions:

- What will be the future presence of major hazard sites that involve lithium-ion battery production in OECD countries?
- What efforts are underway to improve knowledge in government and industry about accident causality and typical scenarios?
- How does the presence of lithium-ion batteries complicate hazardous waste risks in major hazard sites that handle or treat hazardous waste?
- Failures in battery energy storage systems (BESS)[6] are also causing major fires, are they appropriately distant from major chemical hazards?

Solar power and chemical accident risk

Manufacturers of solar panels are listed as EU/EEA major hazard sites in eSPIRS. The workshop identified two solar panel producers in these regions, one in the Netherlands and one in Norway, as well as 34 solar thermal plants, all but one, in Spain. There are also thermal power plants found in other OECD countries such as Chile, Colombia, Mexico and the United States.

The workshop highlighted that there are not many chemical incidents involving these types of plants, but the following elements could be raised:

- At first glance, the chemical accident scenarios for solar panel production seem to have characteristics similar to other metal/machinery production industries;
- Solar thermal energy appears to have accident scenarios that share characteristics with power plants;
- There may be initiating conditions that are unique to solar power, but too few incidents to understand the potential sequences of events;
- It is likely that the needs for solar equipment waste management and recycling will very much increase in the future. Solar panels contain heavy metals such as cadmium and other rare earth metals. The workshop pointed to the need for clear risk management strategy.

Carbon capture utilisation and storage (CCUS)

The workshop highlighted a number of knowledge gaps for assessing the risks linked to the use of CCUS:

- Pipeline design: understanding of running ductile crack propagation along CO_2 pipelines that can be used to specify material toughness and/or crack arrester requirements;
- Pipeline risk assessment:
  - Pipeline failure rates: there is a need for modifications to fracture mechanics model in pipeline risk assessment models for CO_2 properties;
  - There is a need to develop a fast method for modelling CO_2 dense-gas dispersion, incorporating terrain effects along pipeline route.
- Ship transport of CO_2 and subsea CO_2 pipelines.

6 BESS are devices that enable energy from renewables, like solar and wind, to be stored and then released when customers need power most.

A CO_2 pipeline incident was presented that took place in February 2022 in Mississippi, USA. A landslide led to the rupture of a 24-inch diameter, 97 bar dense-phase CO_2 pipeline. The release was located at approximatively 1 mile from the village of Satartia. Local emergency responders were not informed by the pipeline operator of the pipeline rupture and release of CO_2. The operator's risk assessment had not identified that a release could affect the population of Satartia. Approximatively 200 residents were evacuated and there were 46 casualties.

Ammonia as a hydrogen energy carrier

The workshop highlighted that there are still knowledge gaps for the use of ammonia. The workshop presented a number of initiatives that were developed to try and fill those gaps:

- A collaborative effort by the US, UK and Europe in 2020 aimed to develop exercises on modelling of toxic industrial chemical releases. The exercises covered topics such as defining scenarios, source models, dispersion models (e.g. dense gas in low wind speeds, transition to passive dispersion, obstacles and terrain, meteorology, infiltration into buildings, dry deposition and chemical reactivity), health effects[7];
- The Jack Rabbit III project: international collaboration conducted in 2021-2022 with a modelling exercise with 21 participants from the US, UK and Europe. The exercise aimed to conduct large scale anhydrous ammonia release experiments to fill critical hazard prediction data gaps and inform emergency responders.[8]

The Norwegian roadmap for the green industrial initiative was presented at the workshop providing a comprehensive approach to the development of different technologies to support the energy transition (see Box 2).

7 Hanna S., Mazzola T., Chang J., Spicer T., Gant S.E. and Batt R. "Gaps in Toxic Industrial Chemical (TIC) model systems: improvements and changes over past ten years", Process Safety Progress, June 2021, http://dx.doi.org/10.1002/prs.12289

8 For further information, see: https://www.uvu.edu/es/jack-rabbit/

Box 2. Norwegian roadmap for the green industrial initiative

The Norwegian roadmap for the green industrial initiative was presented during the workshop and its link with policy and regulation for the management of hazardous substances. The roadmap was launched in June 2022. Seven priority areas are developed in the roadmap linked to: offshore wind, batteries, hydrogen, carbon capture and storage, the process industry, the maritime industry, forestry and the timber industry and other bioeconomy sectors. These sectors are key to delivering an emission free energy system and society and many of these activities involve the use of hazardous substances.

Norway has seen an increase in demand for the establishment of new facilities related to the green shift. These facilities include, for example, production plants for hydrogen and ammonia – both for gaseous hydrogen and liquid hydrogen, plants that plan to use hydrogen to produce ammonia, plants for bunkering of ammonia and hydrogen, battery factories for production of lithium-ion batteries. For the later ones, the presentation raised that there is still very little information on the type of hazardous substances that these facilities will handle as there is a wide variation in the chemistry and production methods that can be used in these factories. For example, it is still difficult to know whether these facilities will be covered under the Norwegian regulation that implement the Seveso III Directive. There are also demand for the creation of infrastructures for CO_2 transport and storage and production plants for e-fuel (fuel made from hydrogen and carbon dioxide) as well as biogas plants.

Successful introduction of these new technologies needs a regulatory framework that ensures that the risk introduced to society is acceptable. The competent national authority in Norway continuously evaluates the need for update of the regulation. For example, as a direct result of the green shift, Norway is in the process of adding new technical and operational requirements for the bunkering of flammable gas to the regulation relating to the handling of flammable, reactive and pressurized substances. It will also be requesting that all enterprises that plan to bunker flammable gas to ship must apply for a permit.

Norway is also paying particular attention to land-use planning measures for these new facilities. Norway has developed specific guidelines for land-use planning for Seveso plants based on a quantitative risk analysis "Guidelines for quantitative risk analysis of facilities handling hazardous substances". The presentation highlighted a lack of data from industries linked to the green shift to input into the quantitative risk assessment. There is an ongoing project taking place in Norway with industry aiming to improve data for hydrogen, ammonia and carbon dioxide. The results will be available in summer 2023 and will probably lead to an update of the guidelines on land-use planning.

Possible future work

Overall, workshop discussions and presentations showed that there is still a gap in available realistic scenarios to understand and plan for the risk from new fuels. The WPCA could develop a project on risks related to new fuels and renewables including the development of realistic scenarios and as such to contribute, by providing a safety perspective, to other ongoing OECD projects on the development of new energy sources.

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