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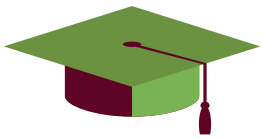
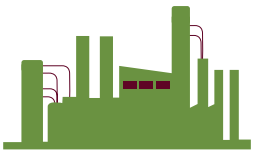
IChemE Safety Centre

# **Process Safety** for the 21st Century and Beyond





# 1 Introduction

Process safety has been practiced as a field of research and safety management in the oil and chemical industries since the 1960s. Over this period there have been many tragic incidents, which have resulted in fatalities as well as asset, environmental, and reputational damage. While standards have improved since then and much work has been done, particularly in inherently safer design and management systems, catastrophic incidents are still happening and will continue to do so until we tackle them head on. It appears as if we are not learning lessons from the past, because the causes of failures for current incidents are the same as past incidents, albeit in different environments. We must learn from these incidents. As an industry, our inability to learn from past incidents and demonstrate that process safety is improving has led to this project, *Process Safety in the 21st Century and Beyond*. The aim of this project is to envision better process safety by outlining efforts that each stakeholder can take.

The project has been informed by a number of sources and resources. In 2011, the Mary Kay O'Connor Process Safety Center (MKOPSC) published the *Process Safety Research Agenda for the 21st Century*[1]. This defined a number of key areas where ongoing research was necessary to continue building knowledge. In 2013, the Institution of Chemical Engineers (IChemE) published a policy paper called *Chemical Engineering Matters*[2], which focused on the four challenges of water, energy, food and nutrition, and health and wellbeing, and highlighted process safety as being a necessary enabler to overcome these challenges. In 2017, MKOPSC and the IChemE Safety Centre developed the next level of these visionary documents – *Process Safety in the 21st Century and Beyond*. It is, however, necessary to overlay other factors, such as industry, regulatory, and societal perspectives in addition to academic research and teaching.

Process safety needs to evolve with industry to stay current with the dynamic technological, societal, and economic standards of society. The main question we want to tackle is what are the actions that we can take to improve the operational safety of facilities? Process safety professionals, across industry, academia, and regulators, have an obligation to drive this improvement, because engineering and science are necessary to address the four challenges outlined in *Chemical Engineering Matters*, and overcoming these challenges is vital for the ongoing survival of the human race and Earth. The explosive growth rate in India and China will likewise increase demand for energy and chemical production. Even if incident rates do not increase, the total number of incidents would increase by a factor of ten or higher, given the projected growth rate in these countries[3]. Viewing the MKOPSC and IChemE documents together gives a picture of the research needed to address the challenges in new ways

## 1.1 Who was involved in this project?

This project was led by a steering committee convened to bring in academic, industrial, regulatory, and societal perspectives from around the world and across stakeholders. Trish Kerin, the director of the IChemE Safety Centre and Dr M Sam Mannan, the executive director of Mary Kay O'Connor Process Safety Center were the co-chairs of the steering committee. The team members are listed below, and biographical details can be found in Appendix A.

### Team members

- **Dr Paul Amyotte**
- **Dr Ian Cameron**
- **Dr Mike Considine**
- **Ms Cheryl Grounds**
- **Dr Jai Gupta**
- **Dame Judith Hackitt**
- **Mr Alan Hollonds**
- **Dr Christian Jochum**
- **Dr Atsumi Miyake**
- **Dr Christina Phang**
- **Dr Genserik Reniers**
- **Dr Juergen Schmidt**
- **Dr Hans Schwarz**
- **Dr Dongil Shin**
- **Mr Georg Suter**
- **The Honorable Vanessa Allen Sutherland**
- **Dr En Sup Yoon**
- **Dr Jinsong Zhao**

This work was also supported by the staff and graduate students of the Mary Kay O'Connor Process Safety Center:

- Valerie Green
- Zohra Halim
- Pritishma Lakhe
- Yueqi Shen
- Dr Bin Zhang

[1] Process Safety Research Agenda for the 21st century, October 2011, Mary Kay O'Connor Process Safety Center. Available at http://psc.tamu.edu/news/process-safety-research-agenda-for-the-21st-century

[2] Chemical Engineering Matters, September 2013, Institution of Chemical Engineers. Available at http://www.icheme.org/media_centre/technical_strategy/chemical_engineering_matters.aspx

[3] Economides, M. and Oligney, R. (2000) The Color of Oil: The history , the money, and the politics of the world's biggest business, USA, David Grant Publishing

## 1.2 How was the project undertaken?

Gaining a global perspective of the key challenges in process safety is the first important step. The challenges were considered across four stakeholders: industry, academia, regulators, and society. To determine the challenges, a series of workshops at international symposia were undertaken, including in the UK (with input from other European countries), North America, Asia, Australia/New Zealand, and the Middle East. Various methods of consultation were used, but the key questions remained consistent. In process safety:

* what are the key industry challenges?

* what are the key academic challenges?

* what are the key regulatory challenges?

* what are the key societal challenges?

These questions were answered by professionals from various levels in industry, academia, and regulatory bodies.

Once the challenges were identified, a top five list was drawn up for each stakeholder group. The steering committee held a series of meetings over 18 months, and used these lists to develop strategies to address the challenges. The strategies focused on ***new ways*** to address the challenges, rather than activities that are being broadly undertaken already.

Our goal with this document is to lay out a series of actions to be undertaken at various levels and across all stakeholders to improve process safety because people have a right to not get hurt. To enable this vision, this roadmap is a **call to action** to all stakeholders and not just process safety professionals.

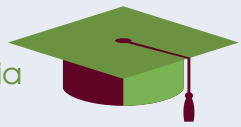
We invite you to look at the opportunities and think about how you can influence them and positively impact process safety. Every professional is obliged to improve process safety because engineering and science are essential to us all and it must be sustainable in all senses of the word, including process safety. If we, as engineers, do not develop new strategies for continuous improvement, the engineering profession will become irrelevant to society and the need for process safety will become extinct, thus increasing process safety incidents.

A question that needs to be answered is where this roadmap is intended to take us. The simple answer is that the roadmap and the associated journey are focused towards improvements in process safety performance, which will ultimately lead us to our vision of zero incidents.

# 2 Challenges in Process Safety

The challenges described in this section were distilled from consultations and discussions across the world. For the each of four areas, academia, regulators, industry, and society, the top five challenges were identified after reviewing all feedbacks from the consultation sessions and steering committee meetings. Note that overall, the feedback was very similar in each region for academia, industry, and society challenges. However, a standout difference in regulators aspect was found in the Middle East. This is a region that has few defined process safety laws, and the feedback from this region specifically was a desire for consistent science-based regulations to be implemented and enforced. Consistent science-based regulations give much-needed certainty to companies when they are operating. This message was not apparent in the other geographical regions where there were more legislation in place.

## 2.1 Academia



The top five challenges in order when all academic responses were consolidated were:

1 Collaboration

2 Funding and resources

3 Experience

4 Practical experience

5 Content

Two pillars of a good academic process safety program are teaching and research. The fact is that the academic community uses its expertise to provide competence to graduates at both undergraduate and graduate levels and create new technology and knowledge for a safer world, with the support from other stakeholders. All the challenges identified in the workshops are related to these two missions in some way.

The key challenge is collaboration among all stakeholders for the activities in the academic community, in terms of communicating needs and providing necessary support to academia. Improved dialogue between all stakeholders could guide academia to define the content of its curricula and research. It will make the research outcomes more likely to fit the industrial needs.

Funding and resources are very much needed to develop a successful process safety program in the universities, especially for research. Given the need for safe operation, industry should provide support directly to academia in terms of research funding and donating equipment. Also, industry should speak up for its need for safety research, and other organizations, including governmental agencies should make plans to fund safety research. With funding and resources, a successful safety research program can be established, that not only provides tremendous contributions to improve process safety, but also helps to sustain the process safety program in academia, given the fact that a tenure-track faculty member is extensively evaluated for their ability to secure funding and publish high-impact papers. This is very true, at least, in the US.

Therefore, a successful safety research program helps to keep faculty members in the universities, including relevant activities such as teaching. A key to increasing funding for process safety research and improving process safety courses in universities is collaboration among industry, regulators and academia to improve the quality and competency of engineering graduates.

Practical experience is very important for process safety, and is often missing in academia. The challenges are twofold (for students and faculties). Students need to understand why process safety is important, where process safety is needed in the real world, and how they can apply their knowledge to the industry. Internships will be a huge help to address this challenge. In addition, many university faculties and lecturers start their careers directly from graduate school or a post-doctoral position at national laboratories and not necessarily from an industrial position. Some constant exposure to the industry for current faculties in terms of workshops and project experiences will be very helpful to add practical experience to academia.

The content challenge refers to a process safety curriculum, which ensures proper material will be systematically taught to students. A good curriculum helps to produce graduates with ingrained knowledge and fundamentals of process safety. These graduates will assume the technical and managerial leadership in industry, academia, and government in the future years. At one time, one of the few textbooks available was *Chemical Process Safety: Fundamentals with Applications by Daniel A Crowl and Joseph F Louvar*[4]. However, in recent years a few others have become available, for example, the Chinese textbook *Chemical Process Safety*, published in 2015 by Jinsong Zhao, Wanghua Chen and Yi Lu[5]. The key challenges here are to understand if there are enough materials for process safety education in first place, and whether efforts are being made to develop a systematic curriculum.

## 2.2 Regulators

The top five challenges, in ranked order, when all regulatory responses were consolidated are:

1 Competency
2 Regulations
3 Politics
4 Complexity
5 Compliance

In the discussions on competency, the challenge is about how regulators become and remain competent so they can add value and improve safety outcomes. Competency was seen as an important topic across a range of fields and will be discussed further in this context below. One important aspect of competency is to understand the concept of risk. Understanding of risk is lacking in general across all stakeholders. Despite the development of international standards on risk management, there is still confusion in some areas between the fundamental difference of risk and hazard. This becomes more complicated when considering whether to take a hazard or a consequence-based approach towards management of risk. There can also be a tendency to assume that if the risk has been assessed, then it has been managed.

Regulations vary greatly between jurisdictions. This increases the regulatory burden for organizations operating over multiple regions. The resources for managing multiple regimes could be deployed in an effective way to perform tasks that actually enhance safety outcomes and avoid conflicting requirements, rather than a checkbox mentality. The inclusion of regulations in the top five challenges was driven by feedback for a strong desire to adopt a consistent science-based regime in the Middle East.

The political environment is different across countries and jurisdictions. Political responses to safety and in particular to incidents are typically immediate reactive responses to alleviate community pressure, not necessarily well-thought-out long-term proactive policy positions. This can leave organizations spending time trying to anticipate government positions, taking effort away from improving safety outcomes. This is linked to the societal stakeholder, where there is less understanding and trust, as discussed below.

Complexity in the regulatory space can result in duplication and conflicting requirements. Duplication wastes resources that could be used to improve safety outcomes, and conflicting requirements leave companies needing to develop a best-fit option. There are often differing laws across jurisdictions, so companies need to have complex systems to address multiple regulatory requirements. It is not as simple as just picking what appears to be the most stringent set of laws and applying them. Even the most conservative regulations would not always imply the highest reduction of risk, if they are not structured through appropriate scientific methods.

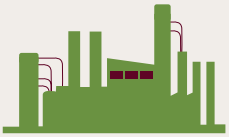
In some areas of the world, it's assumed that if you have complied with the law, then the facility is safe. Safety is not an outcome of compliance, as compliance is a minimum standard. However, compliance is often an outcome of good safety management. The challenge here is to shift away from a compliance mindset to a safety one. It must be remembered that "willful compliance"[6] – i.e., doing what you are told, or what the regulations say, even when you know it is wrong or there could be a better approach – does not aid safety outcomes.

[4] Crowl, D.A. and Louvar, J.F., (2011) *Chemical Process Safety: Fundamentals with Applications. 3 ed.*, Prentice Hall

[5] Zhao, J., Chen W. and Lu Y., (2015) *Chemical Process Safety (in Chinese).* Beijing, Chemical Industry Press

[6] Dame Judith Hackitt, 2016, *"Thinking outside the box – creating an environment where concerns can be raised and heard and contingencies planned for"*, Hazards Australasia 2016, Melbourne

## 2.3 Industry



The top five challenges, presented in ranked order, are as follows:

1 Funding and resources
2 Culture
3 Leadership
4 Competency
5 Understanding

In industry, the question of available financial resources is not the primary hurdle, based on experience. The challenge is to make a business case to invest in process safety. Company culture and leadership is at the heart of the matter. A leadership with good safety culture that values and promotes safety would positively endorse the investment on the safety research and management program within the company. Therefore, it is essential to use actual data to demonstrate the link between process safety and financial performance to help the argument to persuade leadership to invest in process safety and cultivate safety culture.

Leadership and culture are intrinsically linked, as the definition states *"shared attitudes, values, goals, and practices that characterize an institution or organization"*[7], which the leadership allows and promotes. Leadership characteristics related to process safety may trace back to early career experiences and education. This is an important connection where the link between industry and academia can have an impact. Academia should not only provide technical skills, but also ingrain the safety culture among its graduates. Engineering ethics is one of the courses that can help students build up safety culture in their mindsets. If a graduate learns to value process safety in their early academic work, they will take this attitude into the workplace. Instilling a strong safety culture among graduates provides a strong grounding in the values of safety as they seek to influence the future of safety throughout their careers.

Competency and understanding sit on a continuum ranging from basic awareness, through skillful application, to mastery. Competency starts with basic awareness, but how do we ensure a continuous and long-term effort to develop and maintain competency? Two challenges faced by industry are lack of competence and long-term experience. Because people are moving between roles quickly, it becomes difficult to build expertise over time. It is a challenge for industry to capture the expertise and corporate memory. To address this, the roles of Information Technology and Information Management Systems are crucial. There should also be a strong emphasis on supporting future professionals and people transitioning into safety in the industry today. Outsourcing and interfaces in industry compound these challenges, so how are their interfaces managed competently?

Human factors (HF) has been growing as a field of application in the process industries over the past decade. Prior to this, HF was well established in critical infrastructure such as air traffic control, aviation and railways. Industry can learn a great deal from the application of HF and should continue down this path.

## 2.4 Society

The top five challenges, ranked in order, are as follows:

1 Understanding
2 Trust
3 Risk
4 Communication
5 Competency

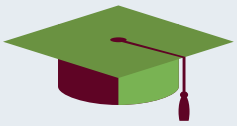
These five challenges can be grouped into two overarching issues. The first combines understanding, trust, competency, and communication, whereas the second issue focuses on the application of risk assessment by communities. Without understanding and a degree of competency within the community, there is unlikely to be trust of industry and regulators. A common understanding between industry and the community can build trust, provided there is transparency of information through proper communication and involvement of the community. There is a general lack of understanding on the fundamental differences between risk and hazard, but people use it interchangeably. The level of risk that the general population tolerates is often related to how much control it feels it has over the situation; as this changes its interpretation of the risk changes. For example, some people believe flying carries a high level of risk compared to driving, but in fact there is a higher risk of a fatal event in a road traffic accident. According to the National Safety Council's "odds-of-dying" table for 2008, the odds of a fatality in a motor vehicle accident were 1 in 98 for a lifetime, and for air and space transport (including air taxis and private flights) they were 1 in 7,178 for a lifetime[8]. Discussions regarding how to increase awareness of communities on safety and how to keep communities informed about hazard and risk without revealing confidential and/or trade secret information will be worthwhile to have in order to overcome the societal challenges. However, with the industry being more open to the communities, it has to have a higher level of risk management and control capability.

[7] *Merriam Webster dictionary.* Available at www.merriam-webster.com/dictionary/culture

[8] USA Today. *"Is Air Travel Safer than Car Travel"*. Available at http://traveltips.usatoday.com/air-travel-safer-car-travel-1581.html

# 3 Existing Initiatives

## 3.1 Academia



### North America

In 2012–2013, the Accreditation Board for Engineering and Technology (ABET) in the US listed safety as a criterion for chemical engineering program to receive accreditation. The ABET criteria are recognized in a number of countries. To meet this criterion, chemical engineering departments across the nation have been revising curricula to incorporate process safety[9]. A literature review and search through department websites show that 23 universities in the US offer dedicated courses in process safety . This data is, however, not exhaustive, and the study itself is limited only to chemical engineering departments; other engineering and non-engineering disciplines were not considered. These dedicated courses range from 1 to 3 course credits and include various topics such as toxicology, industrial hygiene, source-term and dispersion modeling, fire and explosions, hazard identification, risk assessment, case histories, and inherently safer design. Apart from the dedicated process safety courses, process safety topics are also integrated into existing courses such as unit operations, controls, and process design. For graduate students in most universities, most of the exposure to process safety comes through learning about laboratory safety, and not process safety.

The Canadian Engineering Accreditation Board (CEAB) accredits Canadian undergraduate engineering programs that meet or exceed educational standards acceptable for professional engineering registration in Canada. The CEAB has adopted a set of graduate attributes as one component of an outcome-based accreditation system; institutions are required to demonstrate that the graduates of a given engineering program possess these attributes at a level commensurate with the time of graduation. Several of these graduate attributes explicitly incorporate key concepts of safety and risk (which is the case of Canadian undergraduate chemical engineering fundamentals)[10].

There are centers and institutes in universities focused solely on providing process safety knowledge. MKOPSC at Texas A&M University has successfully incorporated process safety into the chemical engineering curriculum. Apart from providing graduate and undergraduate courses on process safety, MKOPSC also conducts research solely dedicated to enhancing safety in the industry. It offers a safety certificate to all engineering disciplines at the graduate and undergraduate level as a minor in safety engineering, given the coursework requirements are met. A certificate through continuing education is also available for industry professionals. Offering these programs through distance learning enables people all over the world to participate in the programs. Other examples include the Purdue Process Safety and Assurance Center at Purdue University, teaching safety courses and conducting safety-related research, and the David and Joan Lynch School of Engineering Safety and Risk Management at the University of Alberta in Canada, offering undergraduate (and occasional graduate) safety courses currently and moving forward to conduct research in the field of process safety in the near future. Process safety research in Atlantic Canada is emphasized at both Memorial University and Dalhousie University – the former with the recent establishment of the Centre for Risk, Integrity and Safety Engineering (C-RISE) and a Canada research chair in offshore safety and risk engineering, and the latter with the establishment of the endowed CD. Howe Chair in Process Safety. Dalhousie University was also the first Canadian university to introduce a mandatory process safety course for chemical engineering undergraduates (which has been taught for the past 15 years).

### Europe and Rest of World

ProcessNet, an initiative of DECHEMA in Germany, published in 2013 an update of a curriculum for Process and Plant Safety for undergraduate and graduate programs in process operation, chemistry and mechanical engineering.[11] The whole area of technical safety typical for the chemical and petrochemical Industry has been tackled. Until today only a few institutes and universities followed the recommendations to integrate the curriculum, mainly because of a lack of industrial experience of most of the teaching personnel and a drastic drop in public funding of safety-related research in Germany.

Additionally, the Institution of Chemical Engineers (IChemE) is an independent accrediting body for chemical engineers internationally. Since 1998, IChemE has required process safety to be a component of a chemical engineering degree. IChemE accredits almost 60 universities across 13 countries, including those in Europe, Asia, and Australasia. The IChemE Safety Centre is currently working with universities to provide resources to enhance this education.

An example of a successful integration of process and plant safety as a bridge between academia and industry is the CSE Center of Safety Excellence in Pfinztal (near Karlsruhe), Germany. For the past 15 years, process and plant safety is lectured at the Karlsruhe Institute of Technology. By means of the CSE, Center of Safety Excellence a new research opportunity was added and supported by more than 50 companies and organizations. A research focus lies in new safety technologies, e.g., the combination of economics in production and an increase in safety. Other topics are zero-emission strategies and security of PLC interlocks. These topics and the deep involvement of major industrial companies are recognized by students as very attractive and challenging. Beside education, the industry enforced the CSE to involve

[9] Dee, S. J., Cox, B.L. and Ogle, R.A. (2015) *"Process safety in the classroom: the current state of chemical engineering programs at US universities."* Process Safety Progress **34.**4: pp. 316-319

[10] Amyotte, P.R., (2013) *"Process Safety Educational Determinants"*, Process Safety Progress **32**, pp126-130

[11] ProcessNet, (2013),. Available at http://processnet.org/processnet_media/Lehrprofil_Prozess_Anlagensicherheit_engl-p-4196.pdf

deep training courses for young safety engineers in industry, consisting of 15 modules with 4 days training for each module. Each participant has the opportunity to get a high level degree in process and plant safety and if interested to obtain the CSE professional safety engineer certificate. The unique 360° safety offer – trend scouting, education and research and the transfer of knowledge into the industry is one option to gain funding and initiate research in process and plant safety.

In most European countries, there is at least one university with a risk management chair, which is often encompassing process safety. For example, ETH Zurich has a chair of integrative risk management and economics under the Department of Management, Technology and Economics, which along with economic, financial, political and social risks, also conducts research on technical, operational and environmental risks. In the UK the University of Sheffield has a chair in process safety and loss prevention hosted in the Department of Chemical and Biological Engineering. The Universities of Sheffield and Aberdeen provide post-graduate degrees in process safety. In Germany the Center of Safety Excellence Institute offers curricula in process safety. All these universities have faculties which conduct safety-related research and are involved in development of a safety curriculum at those universities. Countries in which the effort extends to more than one university are for example the UK, Italy, Norway, Belgium, Germany, the Czech Republic and France. Generally, there is a strong tradition of process safety education at university level in the European countries.

There is still a need for research funding to be more readily accessible and funding agencies in general still have a lot more to do to stimulate innovative process safety research. The DECHEMA/GVC position paper of 2004 showed how, in Germany, the expiration of funded research projects significantly decreased the number of submission and posters at DECHEMA's annual conferences (40 in 1995 to 15 in 2004)[12]. The number of universities in Germany conducting safety-related research had gone down from 26 to only 8 in 2013. In the Netherlands, the Dutch government was repeatedly advised to invest in academic process safety education. Such investment has however remained quite marginal. Norway may be an exception, with plenty of research funding for process safety. In this aspect, industry should have responsibility and foresight to support academic research activities because it will ultimately benefit.

## 3.2 Regulators

### North America

There have been a number of initiatives undertaken by the US government in the past few decades to improve process safety. Some of these initiatives are at federal level and others are at state level. The major regulatory bodies overlooking process safety are the Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA). OSHA first introduced the Process Safety Management (PSM) program in 1992[13]. The program was introduced as a tool to manage and prevent any release of "highly hazardous chemicals", as defined by OSHA. The PSM program has 14 interdependent elements:

- Employee participation
- Process safety information
- Process hazard analysis
- Operating procedures
- Training
- Contractors
- Mechanical integrity
- Hot work
- Management of change
- Pre-startup safety review
- Emergency planning and response
- Incident investigation
- Compliance audits
- Trade secrets

In addition to this, OSHA released a series of programs under OSHA's National Emphasis Program (NEP) to protect health and safety of workers in industries determined to have higher risks to people and the environment. The NEP introduced regulation on flammable and combustible liquids to improve safety of workers. EPA has also introduced a Risk Management Program (RMP)[14], which requires industries storing/using more than threshold quantities of regulated substances to submit a detailed description of hazard assessment, prevention program, and emergency response program to the EPA.

In addition to these federal initiatives, industry-specific agencies have also been created. The US Chemical Safety and Hazard Investigation Board (CSB), an independent non-regulatory agency, was authorized by the Clean Air Act Amendments of 1990 and became operational in 1998 to investigate industrial chemical incidents[15]. CSB is known for conducting comprehensive incident investigations and sharing the information and lessons learned with the public. In 2004, the US Department of Transportation (DOT) created an agency to develop and enforce safe and reliable transportation of hazardous materials called Pipeline and Hazardous Materials Safety Administration (PHMSA). PHMSA oversees transportation of hazardous materials by land, sea,

[12] Pfeil, N., Jochum, C., Mitropetros, K. and Schmelzer, P.G., 2013, *Keeping and Improving Process and Plant Safety Competence – What Is Needed, What Should Be Done?*, Chemical Engineering Transactions, 31, pp. 373-378
[13] Occupational Safety and Health Administration (2012), *Process Safety Management*. Available at https://www.osha.gov/SLTC/processsafetymanagement/
[14] US Environmental Protection Agency. Available at www.epa.gov/rmp
[15] US Chemical Safety Board. Available at www.csb.gov/about-the-csb/

and air along with pipeline transportation[16]. Similarly, the US Bureau of Safety and Environmental Enforcement (BSEE) was created as a regulatory body for offshore energy following the Deepwater Horizon incident in 2010[17]. Since its establishment, the agency has worked on expanding safety and environmental management systems, creating a near-miss reporting system, and launching joint inspections with US Coast Guard among others. BSEE contracted with the MKOPSC to establish the Ocean Energy Safety Institute (OESI). MKOPSC is leading the joint efforts of Texas A&M University, University of Texas at Austin and University of Houston to support the OESI, aiming to provide a forum for dialogue, shared learning, and cooperative research among academia, government, industry, and other non-governmental organizations, in offshore energy-related technologies and activities that ensure safer and environmentally responsible offshore operations[18].

There have been a number of efforts undertaken on a state level as well, such as the creation of programs and acts like California Accidental Release Program, Contra Costa County Industrial Safety Ordinance, Delaware Extremely Hazardous Substances Risk Management Act, Nevada Chemical Accident Prevention Program, New Jersey Toxic Catastrophe Prevention Act.

In contrast to the PSM regulatory approach in the US and most other industrialized countries, Canada relies mostly on voluntary compliance and initiatives led largely by industry and industry/technical associations (e.g., the Canadian Society for Chemical Engineering, CSChE). This voluntary compliance may be more perception than reality, given the bits and pieces of PSM-type requirements in existing legislation; one such example is the emergency response planning requirements for chemical accidents as specified in the Canadian Environmental Protection Act. Nevertheless, the vast majority of safety regulation at the provincial/territorial level in Canada deals explicitly only with occupational safety[19].

## Europe

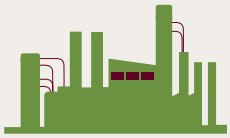
Industrial countries around the world have recognized the need for process safety. After an incident in the Italian town of Seveso in 1976, the European Commission created the Seveso Directive[20]. The Directive was introduced to avoid major chemical incidents in industries storing and using large quantities of highly hazardous materials. The UK established the Control of Major Accident Hazards (COMAH) framework following the Seveso Directive and the Flixborough disaster in 1974. The Seveso Directive, now in its third revision has been adopted internationally since its development. For example Australia and New Zealand have adopted process safety legislation based on the Seveso Directive.

## Asia Pacific

Australia and New Zealand have a legislative system based on the UK's COMAH framework, as does Singapore. Malaysia, Brunei and Thailand have established models based on these requirements while China follows the OSHA's PSM framework. Broadly the COMAH framework requires facilities to identify hazards that could lead to major incident events, assess the risk of those hazards introduce, and implement controls to prevent or mitigate the major incident event. This introduces the concept of managing risks to "as low as reasonably practicable" (ALARP). ALARP is a performance-based standard, used for determining whether the risk has been managed to an appropriate level. "Reasonably practicable" takes into account the magnitude of the consequence, the likelihood of that consequence eventuating, what the person in control knows or reasonably ought to know about the risk and reducing it, availability and suitability of ways to eliminate the risk, and after reviewing the cost assessing whether implementing the additional barriers is grossly disproportionate to the risk. This drives ongoing assessment and continuous improvement in controls.

[16] Pipeline and Hazardous Materials Safety Administration. Available at www.phmsa.dot.gov/about
[17] US Bureau of Safety and Environmental Enforcement. Available at www.bsee.gov/who-we-are/history
[18] Ocean Energy Safety Institute. Available at http://oesi.tamu.edu/about-the-center/mission-and-objectives/
[19] Amyotte, P.R. and Lupien, C.S., 92017) "Elements of Process Safety Management", "Methods in Chemical Process Safety", 1, Ch. 3, pp. 87-148, Elsevier/Academic Press, Cambridge, MA
[20] European Commission. *The Seveso Directive – Technological Disaster Risk Reduction*. Available at http://ec.europa.eu/environment/seveso/

## 3.3 Industry



### North America

The American Institute of Chemical Engineers (AIChE), in collaboration with companies like Dow and Eastman[21], started an Undergraduate Process Safety Learning Initiative which focuses on improving knowledge of chemical engineers regarding process safety in three primary areas: (1) online curricula through Safety and Chemical Engineering Education (SAChE) Program, (2) faculty competence through workshops, and (3) student competence through undergraduate process safety bootcamps. AIChE's SACHE, initiated in 1992, has a Student Safety Certificate Program whereby students can complete multi-level online courses to obtain certificates in 8 different safety topics: (i) Process Safety Lessons Taught From Experience, (ii) Process Safety 101, (iii) Dust Explosion Control, (iv) Inherently Safer Design, (v) Safety in the Process Industries, (vi) Risk Assessment, (vii) Runaway Reactions, and (viii) Chemical Reactivity Hazards[22].

BP has committed US$500m over 10 years to fund independent scientific research through the Gulf of Mexico Research Initiative. The goal of the initiative is to improve society's ability to understand, respond to and mitigate the potential impacts of oil spills to marine and coastal ecosystems[23].

In 2009, Phillip Townsend Associates and the Center for Chemical Process Safety agreed to jointly develop a benchmarking program for process safety management systems[24]. Their initial benchmarking initiative covered the following areas: process safety culture, compliance with standards, hazard identification and risk analysis, asset integrity and reliability, management of change, performance measurement, and metrics.

Industry serves on work groups and initiatives focused on improving safety, such as XTO Energy[25]. They are actively engaged in the Advancing Process Safety Initiative, a collaborative effort between the American Fuel and Petrochemical Manufacturers and the API, representing nearly all of the US refining capacity. This initiative is focused on improving process safety performance across the industry by sharing experiences and knowledge about process safety events, hazard identification and performance metrics, and industry-proven practices. This effort recognizes that when a significant process safety event occurs at any site, it affects everyone in the industry by eroding stakeholder trust.

The Baker Panel was commissioned by BP to investigate process safety management and safety culture in all of its US refineries[26]. The panel carried out a thorough assessment and in its report (Baker Panel, 2007) it made a set of 10 recommendations to enhance process safety, which are being used by many US companies as the basis for process safety improvement. The Baker Panel recommendations are widely accepted in the US and they are forming a crucial agenda for improvement in process safety performance for the next several years.

Several voluntary industry initiatives, such as American Chemistry Council's (ACC) Responsible Care and National Association of Chemical Distributors' (NACD) Responsible Distribution Process (RDP), provide guidance on process safety management for chemical manufacturers and distributors[27].

The Responsible Care initiative in Canada is led by the Chemistry Industry Association of Canada (CIAC), with member companies adopting the ethics and principles of sustainability as well as the operations, stewardship and accountability codes of Responsible Care (which, again, incorporate process safety management principles). Industry involvement in the PSM Division of the CSChE has facilitated developments such as the 2017 CSA Standard on Process Safety Management. Earlier collaboration of the CSChE PSM Division with Minerva Canada Safety Management Education Inc. has resulted in an ongoing and successful series of summer schools (training sessions) for process safety educators in academia.

### Europe

The European Process Safety Centre (EPSC) is an industry-funded network, which exists to provide an independent forum for the leadership and support of process safety within Europe[28]. EPSC was founded in 1992 by the European Federation of Chemical Engineering (EFCE), with the encouragement of CEFIC (Conseil Européen des Fédérations de l'Industrie Chimique). The Centre's membership including manufacturers, contractors, consultants and academic institutions represents a significant part of the process safety community in Europe. The European Federation of Chemical Engineering (EFCE) also organizes an annual symposium on Safety and Loss Prevention in the Process Industries to discuss and address important process safety issues among engineers. This is led by the Working Party on Loss Prevention.

In the past, there has been a strong awareness of process safety in the UK. Given the pioneering work of Trevor Kletz and Frank Lees, the UK has been promoting process safety from very early on. Much work has been done by IChemE), including the development of process safety programs. The European Federation of Chemical Engineering (EFCE) has its secretariat distributed over the UK (IChemE), Germany (DECHEMA) and France. Today IChemE delivers both open and in-company process safety training courses globally every year. It offers a range of process safety courses providing fundamental knowledge on process safety, hazard identification, layer of protection analysis, leadership and culture etc. IChemE has undertaken multiple initiatives in collaboration with industry and academia to enhance process safety education. One initiative includes developing a masterclass for training fresh recruits whereby they will be introduced to the various topics related to safety. Another initiative includes developing a curriculum for undergraduate process safety education. In 2014, the IChemE Safety Centre established operations and is led internationally from Australia. The ISC is an industry-led consortium focused on working with companies, regulators and

[21] AIChE, 2016. Eastman advances AIChE Process Safety Education Initiative. [press release] 10 November 2016. Available at https://www.aiche.org/giving/about/press/releases/11-10-2016/eastman-advances-aiche-process-safety-education-initiative

[22] Murhammer, D.W., (2014) *"Thoughts About Meeting the ABET Safety Requirements For Chemical Engineering Programmes."*

[23] BP, 2012. Sustainability Review 2012. Available at http://www.bp.com/content/dam/bp/pdf/sustainability/group-reports/BP_Sustainability_Review_2012.pdf

[24] Phillip Townsend Associates. *"Benchmarking Process Safety."* Available at http://www.ptai.com/processsafety.html

[25] XTO Energy. *"Safety and Security"*. Available at http://www.xtoenergy.com/en-us/responsibility/safety-and-health/safety-and-security/safety-and-security

[26] Pitblado, R. (2011). "Global process industry initiatives to reduce major accident hazards." *Journal of Loss Prevention in the Process Industries*, **24**.1, pp. 57-62.

[27] US Chemical Safety Board (2002). *"Hazard Investigation: Improving Reactive Hazard Management"*. Available at http://www.csb.gov/improving-reactive-hazard-management/

[28] European Process Safety Centre. Available at http://www.epsc.org/content.aspx?Group=about&Page=history

academia to advance process safety worldwide[29]. The ISC has also published a number of guidance documents for industry to advance process safety.

In Germany (after a conference in Berlin during ECCE-8 in 2012), several major companies, including BASF and Bayer, supported programs to develop a process safety curriculum and were also supporting the CSE. The adoption of a program like the IChemE university accreditation process is voluntary and given academic freedoms in continental Europe, it is not widely adopted, though some universities have done so. Beside academic education, the German chemical industry created intensive internal training programs for safety engineers. Nowadays, the training is completed by external professional safety institutes.

The United Kingdom Petroleum Industry Association (UKPIA) signed a "Commitment to Process Safety" in 2008, which cemented the industry's commitment to the health and safety of its workforce and the public[30]. The Commitment aims to recognize that a robust process safety performance is key to protecting people and environment and that a spirit of cooperation amongst members, through UKPIA's Council, is pivotal in pursuing process safety excellence. UKPIA has a number of initiatives in place in order to achieve the objectives set out in its Commitment Statement and that of the Process Safety Leadership Group. Together, these form the Assuring Safety initiative. Assuring Safety comprises three key principles: working together, encouraging excellence, and sharing and learning. Each of these principles is delivered through a network of initiatives, committees and forums.

During 2007 and 2008, Chemical Industries Association (CIA) staff carried out a series of visits to member companies designed to establish what process safety management and leadership practices were in place with stakeholders and which ones appeared to be effective in giving good control of process safety hazards[31]. The aim of the initiative was to capture best practice in process safety leadership from within our industry and then to share these lessons widely so that awareness of the issues could be raised on a broad front, and action stimulated to improve safety in the stakeholders as a whole.

### Asia Pacific

Stand Together for Safety (STFS) is an Australian oil and gas industry safety leadership initiative dedicated to promoting the highest standards of safety. STSF recognizes that success in safety relies on everyone – managers, supervisors, employees, contractors and regulators – working together to bring about significant and sustained improvement. New materials, resources and toolkits are being developed under the STFS leadership banner. These practical solutions will have industry-wide applications[32].

## 3.4 Society

### North America

Federal Emergency Management Agency (FEMA) has the Community Emergency Response Team (CERT) program aiming to train civilians to meet their immediate needs after a major disaster[33]. The Community Emergency Response Team (CERT) concept was developed and implemented by the Los Angeles City Fire Department (LAFD) in 1985. The Federal Emergency Management Agency (FEMA) recognizes the importance of preparing citizens ahead of a major incident. The Emergency Management Institute (EMI) and the National Fire Academy adopted and expanded the CERT materials, believing them applicable to all hazards. Since 1993 when this training was made available nationally by FEMA, communities in 28 states and Puerto Rico have conducted CERT training. The CERT training for community groups include seven sessions, which are 1) disaster preparedness, 2) disaster fire suppression, 3) disaster medical operations part I, 4) disaster medical operations part II, 5) light search and rescue operations, 6) disaster psychology and team organization, 7) course review and disaster simulation.

A relevant societal example in Canada is the Transportation Community Awareness and Emergency Response (TRANSCAER) initiative, which is led by CIAC and the Railway Association of Canada (RAC). As explained on the TRANSCAER web site, the aim of the initiative is to ensure communities are informed about the products being moved through their area by road and rail, as well as the measures in place to ensure safe transportation.

### Europe and Asia Pacific

As part of Seveso and COMAH-style legislation, facilities are required to consult with their communities and share relevant information regarding emergency response. There is also a requirement to engage with the emergency services to ensure they are educated in the facility hazards and response requirements. This takes a proactive approach to societal engagement.

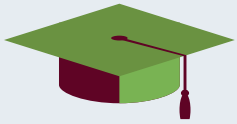
The initiatives mentioned in the sections above are not all inclusive, but has been chalked out to provide a general idea about what is being done currently by academia, industry, regulators and societies around the world to address the issues of process safety in present day.

[29] IChemE Safety Centre (2015). Available at www.ichemesafetycentre.org/
[30] United Kingdom Petroleum Industry Association. *Assuring Safety.* Available at www.ukpia.com/docs/defaultsource/download/Assuring_Safety.pdf?sfvrsn=0
[31] Chemical Industries Association (2008). *Best Practice Guide.* Available at www.cefic.org/Documents/IndustrySupport/CIA%20Process%20Safety%20%20Best%20Practice%20Guide.pdf
[32] Stand together for safety. Available at www.stfs.com.au/about/
[33] Federal Emergency Management Agency. *"Community Emergency Response Team"*. Available at www.fema.gov/about-community-emergency-response-team

# 4 What should we all do individually and collectively to advance process safety in the 21st century?

This work provides a roadmap to move process safety forward and to make a meaningful step change in the field. Through our work with the steering committee experts and the workshops worldwide, we have identified a number of opportunities we must act upon. It is up to all stakeholders to address these opportunities — industry, government, academia, and the public. We all have to work together on the ideas presented here and other ideas that are developed as we start executing this roadmap.

## 4.1 Academia



1 Explore the content included in university engineering bachelor's degree programs regarding process safety and understand how this aligns with the overall curricula. This then should lead to inclusion of missing elements to enhance initial education. There is no lack of information for process safety curricula. Organizations, such as AIChE and IChemE, CSE (Center of Safety Excellence) have made available process safety courses and materials, which academia can take advantage of to develop a standard curriculum. In addition, these courses and materials should be integrated within overall risk management frameworks to make it relevant.

2 Process safety education should overlap multiple disciplines, to include both engineering and non-engineering disciplines, such as chemistry.

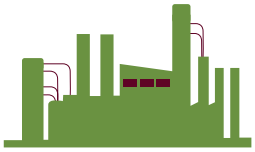
3 Process safety education should also include research. A successful safety research program contributes to maintain faculty members dedicating time to process safety. The research experience deepens the students' understanding of process safety topics.

4 Academia should work with industry to support and enhance opportunities for internships and work experience as part of the process safety education program. This could include defining clear outcomes for experience so all parties involved are clear on the process safety objectives, which should form part of the placement assessment

5 Collaboration with industry should be sought to enhance application of research in industry. The major issue is to get the funding necessary for process safety research even though it may not appear as the 'attractive' research area. The importance of process safety research needs to be emphasized to attract resources needed for research.

6 University laboratories could be considered to be a smaller version of real process facilities and therefore could have elements of process safety management applied. Application of standard operations process safety requirements would enhance learning and prepare students better for entry to an operation world on graduation. This would support a 'learning by doing' aspect to operational process safety management.

7 Academia should offer some opportunities for industry and regulators to involve post-graduate experience for continuous improvement, such as a safety certificate (e.g., CSE Professional Safety Engineer).

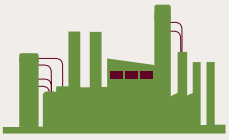


## 4.2 Regulators

1 Regulatory bodies should strive to improve competence to enable them to play a more proactive and trusted role in improving process safety outcomes. When the regulator is seen as more competent by society they will be more trusted, which should address the issues of regulation and enforcement, as well as tolerable risk.

2 While legislative requirements will vary across jurisdictions for many reasons, all regulators must support the development of clear and consistent risk assessment information that is founded in science. This may mean cross-jurisdictional engagement and learning to develop improvement opportunities. And finally, all regulations should be based on science, and science should precede regulations, not the other way around.

## 4.3 Industry



1 Industry and safety professionals need to switch from discussing the cost of safety and incidents to discussing the value of safety-focus on business justification for process safety improvements. Tools should be developed to help safety professionals have these conversations and to assist decision makers to understand clearly the ramifications of their decisions on process safety outcomes. It needs to be recognized that safety is not achieved by just complying with the letter of the law; safety is about long-term sustainable performance, including profitability.

2 Industry and process safety professionals need to build more competence in human factors to achieve better design and operation of facilities. We must create human-centric design and operational environment in our process plants.

3 As a key beneficiary of the education and academic process, industry has a role in supporting the development of future engineers and technicians, as well as people transitioning into safety in industry today. Industry needs to collaborate with educational institutions, be it for undergraduate or trade qualifications to provide practical experience and learning. It is also necessary for industry to assist in development of further competence of the academics who teach these programs. The academics are engaged in research but may not be up-to-date with operational aspects. Working together should enhance this transfer of knowledge and experience.

4 Industry should support internships and work experiences to enable students to learn process safety in the workplace as part of their degree or trade qualification. This would enhance the learning during their training.

5 Industry should maintain the competence and long-term risk management experience in order to overcome the problems caused by people moving between roles quickly.

6 Industry needs to put emphasis on research, such as inherently safer technology and abnormal situation management technology. Important concepts can develop from industrial research, which can inform and focus the direction of academic research.

## 4.4 Society

1 Industry, academia and regulators need to engage with stakeholders in a transparent manner to enhance safety management. To enhance the value of engagement there needs to be more understanding of the difference between risk and hazard and how we make decisions to accept or not accept risk. Most importantly, this engagement needs to be multi-directional, society has a part to play as the beneficiary of the products of industry. This may require education programs at the Kindergarten through to grade 12 level to build fundamental knowledge.

2 Industry, academia, and regulators should understand and accept the concerns of the general public even if they are based on a lack of competence. Therefore, there is a need to include the general public into being active participants in safety. Public awareness and involvement in process safety is important.


Academia
Society
Regulators
Industry

# 5 Opportunities for joint efforts of all stakeholders

In the discussions on how to organize the themes that have arisen through the workshop exercises and the steering committee meetings, we discovered two key threads, competency and making a business case for process safety, common across all areas — academia, industry, regulatory and societal. These present the best opportunities to improve process safety for the 21st century.

## 5.1 Competency

A fundamental underpinning requirement in process safety is to have appropriate levels of competence. Depending on the role this could vary from a basic awareness to advanced expertise, including understanding and application of principals to prevent incidents. This also requires us to be able to learn from the past, as the root causes of incidents continually repeat albeit under slightly different circumstances. This means we need to adopt new and different learning techniques, as the current methods we are using are not delivering the desired results. We need to consider how different people best learn and develop tools and strategies to address that. There is not a lack of information and learnings available, but there is a gap in embedding learnings.

To support learning, consistency needs to be achieved in what competency in process safety actually is and structured methods to achieve this. Commonly accepted standards will result in better safety outcomes across multiple areas.

## 5.2 Making a good business case for process safety

Investment applies to both financial and human resources. Importantly spending capital on safety-related items and activities should be seen as investment and not a cost, as good process safety management results in reliable operations and therefore positive financial outcomes for organizations. Often we see reduced spending on maintenance and reliability-related activities and this eventually impacts the integrity of the facility and therefore process safety. Adequate resources are also needed to update technology and management systems, including risk assessments and safe work practices. Investment in people to recognize hazards and take appropriate action as required is also vital.

## 5.3 Collaboration

The most important opportunity is for all four stakeholders to work together, because each has their strengths and needs, and working together collaboratively makes best use of all resources to fulfill the goal of process safety excellence and create the most value from the investment. The strengths and needs for each stakeholder are listed here, and illustrate how they can collaborate to further enhance process safety.

Academia provides process safety education and cultivates process safety competence at a very early stage in the careers of next generation of process safety professionals. The education in academia includes process safety curricula for all relevant majors, short courses or certificate programs for professionals and process safety research training through graduate programs. Academia also has the advantage to reach out to the general public to enhance awareness of process safety. Academia needs to work with industry to include practical experience in their curricula, such as internships and co-ops. Academia needs to continue to show the value of process safety research in order to receive funding from industry and government.

Regulatory bodies can steer process safety efforts thorough legislation and research funds. The regulations define the minimum requirements and set the direction of efforts. A research fund promotes process safety innovation and helps to sustain the process safety program in academia. Regulatory bodies need to continuously improve the competence level in order to have science-based regulation and build trust with industry and community.

Industry has the operational experience and resources to invest on process safety. The operational experience is essential to advance the competence started from college education to expert level. By providing this kind of experience, the competence grows and maintains in industry. Industry has most resources to invest on process safety research, safer techniques, and people to continuously improve their competence level. Industry needs clear and science-based regulations so that effective process safety management programs can be developed. Industry needs competent graduates from universities to sustain the competence in the company to implement safety management programs.

Society provides the supervision effect through involvement in the process. Community needs to increase competence levels to identify hazards, and understand risk and its acceptable level.

# 6 A Call to Action

The sustainability of the human race and our earth will be determined by how well we adapt to the changes in our environment, e.g., increasing the requirements of safety. These adaptations rely on our ability to engineer our future. We cannot do this without our solutions being sustainable, and this fundamentally requires us to effectively manage process safety.

It is up to all of us to contribute to this improvement in process safety, regardless of whether you are industry, academia, a regulatory authority or a member of our community. Below are some actions that we can work on to progress process safety. We may not be able to complete an entire action but we all have a role to play in achieving the outcome. What can you contribute to the overall solution?

We welcome your feedback on this document as well as the ideas and actions. We all need to take ownership of Process Safety in the 21st Century and Beyond.

## 1 Develop, enhance and maintain competency

a) **Build an international surveillance system to develop a database for incident data repository.** The ultimate goal of process safety is zero incident, and safety cannot be improved if it cannot be measured. An international surveillance system contributes to gather incident data information. With proper data structure, this data repository system will tell us where we are and how we can continue to improve.

b) **Build a common understanding of risk among all stakeholders to make risk and safety management a core value.** Despite all efforts to promote process safety, problems still persist with regard to understanding the difference between hazard and risk, which is the beginning of safety competency. A joint effort, both participation and promotion, from all parties is needed to elucidate the definition of hazard and risk. Once there is good understanding of risk, people will know that the key to process safety is to eliminate hazards and manage the residual risk, which should be the core value to legislate regulations for the government and operations in the industry. The efforts may include workshops and forums for all stakeholders and community service to increase the awareness of process safety. Media can also help spread the knowledge on process safety to the general public who may not be aware of it.

c) **Develop a standard process safety curriculum.** There is a demand for process safety curricula in academia especially from industry and to address this, ABET already requires education on process safety for the US universities. However, most of the universities do not even provide a 1-credit hour of coursework on safety. To address this, academia can take advantage of existing materials made available by AIChE and IChemE, to develop a standard process safety curriculum. The course can be improved further by consulting with industry to address its needs as well. As a minimum, the undergraduate curriculum should focus on the process safety fundamentals, applicable to all engineering disciplines and other relevant majors, such as chemistry. The post-graduate curriculum should provide advanced skills, allowing graduates to perform effective jobs for risk assessment and management.

d) **Provide opportunities for practical experience through internship or work experience in industry.** Process safety can be learned more effectively with practical experience in the industrial setting. The experience allows students to understand where process safety is needed and how it can be applied. It provides feedback on what to study and strengthens the knowledge in class. Also, industry internships put future process safety engineers into the pipeline, which eventually benefits industry due to continuous supply of competency. Real, industry-based projects within courses could also help emphasize the need for process safety knowledge to students.

e) **Provide funding streams for process safety research across academia, government and industry.** Academia contributes to process safety not only through teaching, but also conducting innovative research to make the process inherently safer, enhance the understanding of hazards, and identify novel methods of risk management, etc. Research programs deepen the understanding on safety and provide a synergistic effect on teaching.

f) **Influence regulators and governments to ensure regulations are consistent and science-based.** Science-based regulations are effective to manage risk, and the consistency ensures efficient implementation and compliance. Academia and industry have the responsibility to develop the competence for regulators so that they can see the necessity to legislate consistent and science-based regulations. The improved competency in the government will lead to easy compliance for industry and opportunities for academia to provide expertise.

g) **Contribute to the development of an education program to reach out to the community to increase awareness on process safety by all other stakeholders.** This could start in from kindergarten through year 12 schooling, as well as communities. Involving media will also help distribute the information to communities effectively.

h) Engage with leadership of organizations and help them understand how they contribute to process safety outcomes. Leadership drives the establishment of safety culture and allocates the resources of safety investment. It is crucial to develop process safety competency for leadership through workshops so that they will get on board to support process safety.

i) Support continuing professional development (CPD). Academia and industry should develop a CPD program, such as safety certificate. It helps to sustain the competency level of professionals and regulators. Also, the CPD program allows professionals to transition into process safety roles in the middle of their career.

## 2 Making a good business case

a) Discuss process safety in terms of business performance. Process safety not only prevents losses, but also promotes and sustains business performance. The discussion of process safety should focus on the impact on business performance in terms of good public image, high profit margin, and reliable operations leading to sustained operations..

## 3) Collaboration

a) Look for opportunities to work with others to advance process safety. Collaboration across stakeholders brings needs, expertise and resources together, creating opportunities to enhance safety. Each stakeholder needs to take the initiative to form fruitful collaborations.

b) Reward positive collaboration in process safety rather than competition. Proper recognition of collaborative work is the best encouragement for future collaboration. The success of collaboration is the best reward, but the rewards may include other forms, such as certificates, promotion and financial incentives.

c) Promote successful collaboration in your workplace or community. Success and helping others to succeed helps to build leadership for more collaboration.

d) Enhance communication through workshops and forums and promote the role of safety engineers. These events facilitate the discussion of problems and strategies, as well as successful stories to engage people.

# About ISC and MKOPSC

## IChemE Safety Centre (ISC)

ISC is a not-for-profit multi-company, subscription-based, industry consortium, focused on improving process safety. We share, analyse and apply safety-related thinking. Governed by an advisory board structure, we have membership from industry to partner with on safety-related matters. The three categories of membership are Operating Partners, Industry Partners and Supporting Partners.

- Operating Partners consist of operating or producing companies, and they set the direction of works via an advisory board structure and contribute to the work stream activities.
- Industry Partners consist of consultants or engineering companies who work for operating partners. They participate in work stream activities.
- Supporting Partners consist of regulatory authorities and academic institutions. This category of membership is complimentary and by invitation.

MKOPSC is a collaborative partner of the ISC.

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## Mary Kay O'Connor Process Safety Center (MKOPSC)

The Mary Kay O'Connor Process Safety Center is the world's foremost university-based process safety center. It serves industry, government, academia, and the public. A resource for education and research, it is guided by a Steering Committee of consortium member companies and a Technical Advisory Committee of industry experts.

The Center MS/PhD alumni are approaching 200 in number, with current MS and PhD students nearing 100. The Center administers the Safety Engineering academic program, a multi-disciplinary endeavor consisting of a Master's program as well as certificates for undergraduate and graduate students. From this program, a Process Safety Practice certificate program was developed for industry practitioners. To further networking and exchange of ideas, the Center hosts an Annual International Symposium, attracting over 600 individuals from industry, government, and academia annually.

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# APPENDIX A - STEERING COMMITTEE BIOGRAPHIES

Paul Amyotte – Dr. Paul Amyotte is a Professor of Chemical Engineering in the Department of Process Engineering and Applied Science at Dalhousie University (Halifax, Canada) where he holds the C.D. Howe Chair in Process Safety. He is a graduate of the Royal Military College of Canada (Bachelor's), Queen's University (Master's), and the Technical University of Nova Scotia (PhD). Dr. Amyotte has an extensive record of authorship, with three books, six book chapters and over 300 papers published in peer-reviewed journals or presented at national and international conferences. He is the current editor of the *Journal of Loss Prevention in the Process Industries*, and a past-president of the Canadian Society for Chemical Engineering, Engineers Nova Scotia, and Engineers Canada. He has also served as chair of the Canadian Engineering Qualifications Board, member of the Canadian Engineering Accreditation Board, and co-chair of the Materials and Chemical Engineering Evaluation Group of the Natural Sciences and Engineering Research Council of Canada. He is a recipient of the Cybulski Medal from the Polish Academy of Sciences for significant and sustained contributions to the field of dust explosion research, as well as the Trevor Kletz Merit Award from the Mary Kay O'Connor Process Safety Center, Texas A&M University.

Ian Cameron – Dr. Cameron a professor at the School of Chemical Engineering, The University of Queensland. He is a director and principal consultant at Daesim Technologies, Brisbane as well as a Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE). He completed Chemical Engineering degrees at the University of NSW, and the University of Washington. He spent 10 years with the CSR Group in diverse industry stakeholders such as sugar, building materials and industrial chemicals, having roles in process and control system design, plant construction and commissioning, production management and environmental protection.

Having obtained his PhD and DIC from Imperial College London in the area of Process Systems Engineering (PSE), he worked full-time for 3 years as a United Nations (UNIDO) process-engineering consultant in Argentina and a further 6 years in Turkey on a part-time basis. For the past 25 years at The University of Queensland he has carried out research, consulting and learning innovation, having received numerous awards including the J.A. Brodie Medal of the Institution of Engineers Australia.

He is a joint author of the book "Process Systems Risk Management" (PSE Series, Elsevier) and has applied systems thinking to a range of risk management areas, particularly the application of intelligent, knowledge based approaches to understanding function and failure in socio-technical systems. His recent work is focused on innovation in process hazard identification and the role of human factors in engineered systems. He consults widely to industry and government in areas of quantified risk assessment and land use planning. Over the years he has held visiting appointments at Imperial College London, University College London, the Technical University of Denmark, the Hungarian Academy of Sciences and the University of Edinburgh.

Mike Considine – Dr. Considine is a world recognised expert in process safety and loss prevention with 40-years' experience in this area. He is an organizer and presenter at numerous seminars & conferences and recipient of a number of professional awards.

On leaving industry he ran his own process safety consultancy and for the last 5 years he has been Professor of Process Safety and Loss Prevention at the University of Sheffield and course director for the MSc course in Process Safety and Loss Prevention.

Professor Considine is well connected within the process safety and loss prevention community; linkages with academia, industry and regulators via professional institutions & industry bodies and has international experience of leading and working with professional and industry bodies. He also has experience of developing and working with internal networks within large global organizations. He has regular contact with and numerous opportunities to work with academics from education institutions across Europe via the EFCE Loss Prevention Working Party and has extensive experience of developing and delivering process safety training courses around the world.

He has a broad international experience, covering most parts of the world and working with professional engineers from many different backgrounds and cultures, he has experience of working in the chemical, nuclear, regulatory, insurance and oil and gas industries. As a former head of a corporate team in a major oil company he was responsible for setting major hazards policy and therefore has a broad knowledge of the organizational and operational aspects of major companies and experience of dealing with people at all levels up to CEO.

He is a Fellow of IChemE, a Chartered Engineer and an accredited Professional Process Safety Engineer. For the last 6 years, he has been Executive Vice President of the European Federation of Chemical Engineers.

Cheryl Grounds – Ms Grounds has 34 years of process safety, risk management, and fire protection engineering experience in the oil and gas industry.

Cheryl retired as the VP Process Safety in BP's Group Safety & Operational Risk team. In this role she advocated process safety across BP working in the areas of practice, capability, and provision of deep technical support. Previously she was the Chief Engineer for Process and Process Safety Engineering in BP Upstream.

Prior to BP, Cheryl worked with Mobil and ExxonMobil Corporation for 17 years. She held a number of Process Safety Engineering positions in Refining & Marketing and International Exploration & Production where she provided process safety engineering and risk management support to existing facilities and major capital projects, worldwide. After ExxonMobil, Ms. Grounds worked with Baker Engineering and Risk Consultants - again focusing on process safety and risk management.

Cheryl is a Certified Safety Professional and a licensed Professional Engineer. She is a Fellow of both the CCPS and AIChE. She is also Chartered, a Fellow, and registered as a Professional Process Safety Engineer by the IChemE. She has been actively involved in the Center for Chemical Process Safety (CCPS) for many years.

Jai Gupta – Dr Gupta got involved into Process Safety after the Bhopal Gas Tragedy. He started teaching and researching in PS in 1988. Apart from a course to Chemical Engineering Students at IIT Kanpur, he has run short courses for over 500 engineers in India and lectured on the subject at Loughborough University, SQ University Oman and Texas A&M University. He has several times offered a course on Inherently Safer Design at Helsinki University of Technology. He is on the Editorial Board of PSEP and JLPPI. He was bestowed with the Trevor Kletz Merit Award at Texas A&M University; The Hutchinson Medal by IChemE (jointly with Dr. David Edwards); IPCL Process Safety Award by the IIChE and the Distinguished Alumni Award by the University of Pennsylvania. Dr Gupta has been a Diplomat for Science and Technology at the Embassy of India, Washington DC and India's Delegate to the UN. He has worked for UOP Des Plaines, IL and EER Corp, VA. He was a UNIDO Advisor to PLAPIQUI, Argentina. He has been a Visiting Professor at UNAM, Mexico City; Texas A&M University, University of Michigan Ann Arbor; NYUST Taiwan; Loughborough University UK; and EMA, France. He was a Professor at I.I.T. Kanpur (1973-2010) where he also served as Head, Chemical Engineering and Member Board of Governors. He is the Founder Director General of Pandit Deendayal Petroleum University, India and Founder Director of Rajiv Gandhi Institute of Petroleum Technology India (2008-16). He is currently Dean Graduate Studies and Distinguished Professor in Chemical Engineering at Shiv Nadar University, Greater Noida near New Delhi and an Adjunct Professor at Texas A&M University. He received Bachelor of Technology degree from I.I.T. Kanpur, MSE from the University of Michigan and PhD from the University of Pennsylvania, all in Chemical Engineering.

Dame Judith Hackitt – Dame Hackitt was first appointed in 1 October 2007 for a term of 5 years and was reappointed as Chair of HSE for a further 3 years from October 2012. She previously served as a Commissioner between 2002 and 2005. She was awarded her CBE for services to health and safety. Ms. Hackitt began her working career in 1975 with Exxon Chemicals where she spent 15 years in various process management roles. She was subsequently European Operations Director of a speciality pigments business before becoming Group Risk Manager with worldwide responsibility for health and safety, insurance and litigation. She then moved to the Chemical Industries Association where she became Director General (from 2002-2005) and then worked in Brussels for the European Chemical Industry Association (CEFIC).

Ms. Hackitt trained as a Chemical Engineer at Imperial College, London and is a Fellow of the Institution of Chemical Engineers and a member of council. She became President of IChemE in May 2013. She was elected as a Fellow of the Royal Academy of Engineering in July 2010. Judith is senior non-executive director of the Energy Saving Trust and was previously a non-executive director of Oxfordshire Health Authority.

Alan Hollonds – Mr. Hollands is an advisor for RasGas in Qatar. His career experiences include supervisory, management, advisory roles with senior management in the production and processing of oil, gas, LNG. He has worked in twenty countries on six continents throughout his career.

Christian Jochum - Dr. Jochum is currently the Deputy Chairman of German Commission on Process Safety. He was the Director of European Process Safety Center and Chairman of German Commission on Process Safety. He has 28 years of experience working in a large chemical/pharmaceutical company (Hoechst AG)where he served as the Site and Corporate Safety Director and Major Accident Officer for almost 10 years. He has also been involved in EHS and crisis management consulting for different types of business and administration since 1997. He was awarded with the German Medal of Honour (First Class) for his contributions for process safety and is also an Honorary Professor at Frankfurt University. Born in Frankfurt, Germany in 1943, Dr. Jochum obtained his PhD in Chemistry from Goethe University in 1969.

Trish Kerin, co-chair of the committee – Ms. Kerin is the Director of Institution of Chemical Engineers Safety Centre (ISC). After graduating from RMIT University with honors in mechanical engineering, Trish spent several years working in design, project management, operational, safety and executive roles for the oil, gas and chemical industries. Her passion for process safety saw her take on several advisory committee roles. This included representing the Plastics and Chemical

Industries Association (PACIA) on drafting the 2007 OHS regulations for major hazards in Victoria – Occupational Health and Safety Regulations 2007. She has also represented the Australian Chamber of Commerce and Industry (ACCI) on the Safe Work Australia temporary advisory group for drafting the major hazard facility model law. Trish has also represented PACIA to the WorkSafe Victoria Major Hazards Advisory Committee and been an invited speaker for various local and international conferences.

She currently sits on the board of the Australian National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) and is a member of the Mary Kay O'Connor Process Safety Center steering committee. Additional appointments have included positions as a director and vice president for a not-for-profit community radio station.

Ms. Kerin is a Chartered Engineer, a registered Professional Process Safety Engineer and Fellow of IChemE and Engineers Australia. She also holds a diploma of OHS and is a graduate of the Australian Institute of Company Directors (GAICD).

M. Sam Mannan, co-chair of the committee – Dr. M. Sam Mannan is a Regents Professor at Texas A&M University (TAMU) and Director of the Mary Kay O'Connor Process Safety Center at the Texas A&M Engineering Experiment Station (TEES). Dr. Mannan obtained his Ph.D. in 1986 in chemical engineering from the University of Oklahoma.

Dr. Mannan co-authored the Guidelines for Safe Process Operations and Maintenance published by the American Institute of Chemical Engineers (AIChE). He is editor of the 3rd and 4th edition of the authoritative reference, Lees' Loss Prevention in the Process Industries. He is the recipient of the AIChE Service to Society Award; the TAMU Association of Former Students' Distinguished Achievement Award for Teaching; the TEES Research Fellow; and the Dwight Look College of Engineering George Armistead, Jr. '23 Fellow. In 2003, he served as a consultant to Columbia Accident Investigation Board. In 2006, he was named the inaugural holder of the T. Michael O'Connor Chair I. In 2007, he was elected Fellow of AIChE. In December 2008, the Board of Regents of TAMU recognised Dr. Mannan and named him Regents Professor. Dr. Mannan is a Guest Professor at the Nanjing University of Technology, China University of Petroleum, Tianjin University, SINOPEC Research Institute of Safety Engineering, and Rajiv Gandhi Institute of Petroleum Technology. In September 2011, the Technical University of Łódźconferred the Doctoris Honoris Causa on Dr. Mannan. In 2012, Dr. Mannan was awarded the Bush Excellence Award for Faculty in Public Service and in 2013, the Charles W. Crawford Service Award. In 2014, Dr. Mannan was made a TEES Senior Fellow and awarded the TEES Engineering Genesis Award. In 2015, he was made a Fellow of the Institution of Chemical Engineers. Dr. Mannan has published 300 peer-reviewed journal publications and 212 proceedings papers, and provided 240 technical meeting presentations.

Atsumi Miyake – Dr. Miyake is a Professor of Safety Engineering and Risk Management and Vice Director of Institute of Advanced Sciences of Yokohama National University, Japan. His research fields include: Social systems engineering/Safety system, Reaction engineering/Process system, Energy engineering, Safety Engineering, Explosion and Detonation, Physical Risk Analysis of Chemical Processes, Risk Management of Technological Systems. Dr.Miyake completed his Bachelor, Master and PhD in Yokohama National University. Dr.Miyake has consulted to industry, government and academia in these and related areas, has published or presented over 300 papers in the field of industrial safety, and has been involved in the supervision of thirty graduate students whose research has been funded by various agencies and companies. He has served as President of Japan Explosives Society and Director of Japan Society of Safety Engineering. Dr.Miyake has been the Associate Editor of the Journal of Loss Prevention in the Process Industries.

Christina Phang - Dr. Phang is a Chartered Chemical Engineer and a Fellow of the Institute of Chemical Engineers (IChemE), UK. She has 25 years' experience in safety engineering and risk management, predominantly in providing advice to the oil and gas stakeholder and is the Managing Partner of ERM's Global Risk practice in Asia Pacific. Phang graduated from University of Sheffield with a degree in Chemical Engineering before receiving her doctorate from University of Sheffield in Safety and loss prevention. Dr. Phang is also an active member of the Society of Petroleum Engineers (SPE) in Malaysia and is heavily involved with IChemE activities.

Genserik Reniers – Dr. Reniers, holds a Master of Science in chemical engineering, is Full Professor at the Safety and Security Science Group of the Delft University of Technology, in the Netherlands, where he teaches Risk Analysis and Risk Management. At the University of Antwerp in Belgium, he is a Full professor lecturing amongst others in chemistry, organic chemistry, and Technological Risk Management. At the Brussels campus of the KU Leuven, Belgium, he lectures as a Professor, amongst others, in Engineering Risk Management. Furthermore, he is Scientific Director of the Leiden-Delft-Erasmus Centre for Safety and Security in the Netherlands. His main research interests concern the collaboration surrounding safety and security topics and socio-economic optimisation within the chemical industry. Amongst many other academic achievements and output, he has published 120+ scientific papers in high-quality academic journals, and has (co-)authored and (co-)edited some 35 books. He serves as an Editor of the Journal of Loss Prevention in the Process Industries and as an Associate Editor of the Journal 'Safety Science'. "

Jürgen Schmidt – Prof. Dr.-Ing. Jürgen Schmidt has been with the CSE-Center of Safety Excellence since 2015, serving as the CEO of the CSE-Institute, Director of the CSE-Society and Executive CEO of the CSE-Engineering. He was awarded the EPSC Award for his outstanding activities in process and plant safety in 2000. Dr. Schmidt worked as Principle Safety Specialist at BASF SE and as Safety Engineer at Hoechst AG. He has also been involved in teaching at the Technical University of Kaiserslautern and Karlsruhe Institute for Technology. Dr. Schmidt obtained his Masters in Mechanical Engineering from University of Applied Science, Krefeld, in Process Engineering from Ruhr-University of Bochum and Masters Thesis from Texas A&M University before obtaining his Doctorate Degree from Ruhr-University of Bochum. His other honorary activities involve the following: Chairman of International Ad-hoc WG: Pressure Relief, Chairman of the WG: Safety related siting of chemical plants and Member of the board of German ProcessNet section at GVC/Dechema; Convener of Technical Committee and Representative of ISO 4126/10 at ISO-TC 185; Member of board of Germany of European DIERS User Group and Member of the Scientific Advisory Council of BAM.

Hans Schwarz – Dr. Schwarz is a Vice President with group wide responsibility for process safety at BASF, the world's largest diversified chemical company with more than 100,000 employees in over 80 countries, and global sales exceeding $80bn in 2010. Dr. Schwarz started his career at BASF in 1986 and he has progressed through the organization with senior roles in Europe and North America, including plant management, project management, technology director and project director with responsibility for supply chain optimisation. He assumed his current role in 2010. Dr. Schwarz graduated as a chemist at the Technical University of Darmstadt in Germany before obtaining his doctorate at the Ruprecht-Karls University in Heidelberg, also in Germany. He is a co-owner of a new startup company, which builds and operates solar power installations, using cost effective and innovative components.

Dongil Shin – Dr. Shin is a Full Professor at the Department of Chemical Engineering, Myongji University. His main research topics include process systems engineering, abnormal situation management, fire and explosion safety, and disaster mitigation in chemical and energy industries, with strong emphasis on the application of high-performance computing, computational intelligence and complex system modeling. He is actively involved in the committees of: Korea Gas Safety Corp. (KGS); National Emergency Management Agency (NEMA); and Korea Fire Industry Technology Institute (KFI). He is also serving as NOC member of WCOGI 2012 (World Conference of Safety of Oil and Gas Industry), Seoul and as IPC member of PSE 2012, Singapore. Dongil Shin received his BS and MS at the School of Chemical and Biological Engineering, Seoul National University, and his PhD in Chemical Engineering from Purdue University.

Georg Suter – Dr. Suter graduated in Physical Chemistry at the Federal Institute of Technology Zurich and started his career in the Safety Testing Laboratory of SANDOZ. After some years working as Corporate Safety Officer of Clariant he became Board Member the Swissi Institute for Safety and Security and worked as an international safety consultant in thermal process safety and explosion protection. Currently he is member of the international consulting staff of TÜV SÜD Process Safety. He was a member of the EFCE Loss Prevention Party 1989 - 2016 and board member of the European Process Safety Center EPSC 2003 – 2006.

The Honorable Vanessa Allen Sutherland – Ms Sutherland was nominated by President Barack Obama to the U.S. Chemical Safety and Hazard Investigation in March of 2015 and confirmed by the Senate in August of 2015. Prior to her appointment Ms. Sutherland served as the Chief Counsel for the Pipeline and Hazardous Materials Safety Administration at the U.S. Department of Transportation, whose mission is to protect people and the environment from the risks associated with hazardous materials transportation.

Prior to PHMSA, Ms. Sutherland spent seven years at Fortune 25 Philip Morris/ Altria Client Services in Richmond, Virginia. She managed technology transactions, procurement matters, data security and privacy, competitive intelligence, U.S. Customs issues, state and federal audits, and issues related to reorganization, dissolution and spin-off of international entities. Prior to her role at Altria, Ms. Sutherland spent six years in various legal roles at MCI/WorldCom, including Vice President and Deputy General Counsel for its webhosting and outsourcing subsidiary, eventually helping the subsidiary through legal matters that followed WorldCom's admission of accounting fraud and irregularities and bankruptcy. During that time, Sutherland was profiled in the Legal Times for being a top, senior, minority, in-house lawyer. She also has worked briefly for the Federal Deposit Insurance Corporation, the U.S. Department of Energy – Office of Inspector General and a law firm. In 2012, she was the Recipient of a U.S. Secretary of Transportation Award at the 45th Annual Secretary's Awards after only a year in her new position, and two Secretary's awards in 2014. In 2010, she was the only in-house counsel recipient of thirty-one lawyers honored as "Leaders in the Law – 2010" for advancing the law, serving the community and improving the justice system in Virginia. She has been selected as a Fellow in both the Maryland State Bar (2005) and the Leadership Council on Legal Diversity (2011). She has been on the board or advisory committees of legal associations such as the Washington Metropolitan – Association of Corporate Counsel, Corporate Counsel Women of Color, Maryland State Bar, and the Virginia Bar Association.

Her non-legal contributions include having been the Vice Chairman of the Board for Peter Paul Development Center, whose mission is to help kids 7-18 by building a community of learners by engaging and challenging children, families and seniors in Richmond, Virginia's East End neighborhood. She

has been Vice President, President and a regional chair in Jack and Jill of America, Inc. – James River Chapter, Mid-Atlantic Region, has been top fundraiser annually for the March of Dimes–Central Virginia and has been a member of the fundraising arm of the Richmond Symphony Orchestra.

After graduating high school at 16, Sutherland went on to obtain a B.A. from Drew University in New Jersey in Political Science and Art History after studying in London, England, to a J.D. and an M.B.A. from American University and a Certified Information Privacy Professional standing from the IAPP. She speaks French and is proficient in Spanish.

En Sup Yoon – Prof Yoon received his PhD from MIT in 1982. He had served as a professor of School of Chemical and Biochemical Engineering in SNU for more than 30 years. He has taught and researched in the field of process systems engineering, process safety, energy industry, and policies. He has also published more than 200 papers and articles in the international journals in those areas and worked as an advisor, consultant, task-force leader to government, companies and non-profit organizations.

He has actively worked as an editor, reviewer, and organizer for domestic and international journals, conferences, and organizations. He has been also a chairman of PSA (Korea Association of Professional Safety Engineers) since 2008. He is currently serving as the supervisory professor for coordinating the professional education program on leadership in process industries at Engineering Development Research Center (EDRC) at Seoul National University.

He is currently responsible for planning and organizing curriculums in the area of industrial process safety specially emphasizing on the change by the 4th industrial revolution (e.g., artificial intelligence & big data analysis). The objective of the program is bridging the gap between graduate studies and industrial practices and providing the professional technology for the future leaders of process safety for participating students from industries, universities, and non-profit organizations.

Jinsong Zhao – Dr. Zhao is a Full Professor and the Department Chair of the Department of Chemical Engineering, Tsinghua University where he teaches both Chemical Process Safety and Chemical Engineering Ethics. Dr. Zhao's main research topics include: 1) Safety risk management technologies: HAZOP, LOPA, Inherently Process Design, Abnormal Situation Management, Alarm Management, 2) Artificial intelligence technologies (Case Based Reasoning, Artificial Neural Networks, Artificial Immune Systems), 3) Big data technologies for process safety and quality control. He received an Outstanding Employee Award from Tsinghua University and a First Prize for Progress of Science and Technology from the China Petroleum and Chemical Industry Federation in 2013. Dr. Zhao completed his BS, MS and PhD in Chemical Engineering from Tsinghua University. He did postdoctoral research at the Department of Chemical Engineering, Purdue University for three years. Before he moved back to China, he worked as a Senior Engineer in the industry for more than four years in the United States. He currently serves in editorial boards of two international journals Process Safety and Environmental Protection, and Computers & Chemical Engineering. He has given invited lectures to more than 10,000 audiences from industry, government and academia in China about process safety and engineering ethics.

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