Before the

SUBCOMMITTEE ON TRANSPORTATION SECURITY AND INFRASTRUCTURE PROTECTION
OF THE
COMMITTEE ON HOMELAND SECURITY
UNITED STATES HOUSE OF REPRESENTATIVES

Statement of

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On

U.S. Department of Homeland Security's Chemical Facility Anti-Terrorism Act of 2008

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Introduction

Chairwoman Jackson Lee, ranking member Lungren and members of the Subcommittee, my name is M. Sam Mannan and I hold a BS, MS, and PhD in chemical engineering. I am a registered professional engineer in the states of Louisiana and Texas and I am a certified safety professional. I am a Fellow of the American Institute of Chemical Engineers and a member of the American Society of Safety Engineers, the International Institute of Ammonia Refrigeration, and the National Fire Protection Association. I am Director of the Mary Kay O'Connor Process Safety Center, holder of the T. Michael O'Connor Chair I in Chemical Engineering, and Professor of Chemical Engineering at Texas A&M University. The Center seeks to develop safer processes, equipment, procedures, and management strategies that will minimize losses in the process industry. My area of expertise within the chemical engineering discipline is process safety. I teach process safety engineering both at the undergraduate and graduate level. I also teach continuing education courses on process safety and other specialty process safety courses in the United States and overseas. My research and practice is primarily in the area of process safety and related subjects. The opinions I present today both in my written statement and oral testimony represent my personal position on these issues. These opinions are based on my education, experience, and training.

First, I want to thank this Committee and the US Congress for addressing Chemical Facility Anti-Terrorism and giving the Department of Homeland Security the necessary authority to regulate security in the chemical industry. I applaud the Subcommittee for holding today's hearing on chemical security regulations and their impact on the public and private sector. This is a subject that is of extreme importance to our nation, and I am pleased to be able to share my experience and opinion as well as continue to serve as a resource to the federal government on this important issue.

Background

Hazardous materials can be grouped into three tiers of vulnerability categories. The first category includes the stationary facilities that are members of major industry associations. Even though these facilities have large inventories of hazardous materials and are quite visible, they are the best prepared against attack because of voluntary programs that have been developed and implemented. The second tier of vulnerability category includes smaller and medium-sized facilities that manufacture or use chemicals but may or may not be members of any industry associations. These facilities are less visible, but are also, in general, less prepared and more widely distributed. Finally, the third category of vulnerability includes all hazardous materials that are in transit (by whatever means) throughout the United States. In addition to being present almost anywhere in the United States at any given time, this category also represents high visibility and the highest vulnerability. It could also be argued that this category is the least prepared to deal with intentionally caused catastrophic scenarios.

Some pertinent subjects of interest with regard to attacks on the chemical infrastructure are: active protection measures; passive protection measures; vulnerability analyses, response and recovery plans; and long-term needs and priorities. Active protection measures include increased security, limited access to facilities, and background checks. Examples of passive protection measures include development of exclusion areas and process and engineering measures.

Vulnerability analysis, response, and recovery plans are needed not only to help devise the prevention and protection plans, but also to develop the response and recovery plans. In this respect, it must be mentioned that most of the large, multi-national facilities that are members of major industry associations have voluntarily conducted some form of vulnerability analysis. What is not clear is whether these analyses have been used to integrate planning for response and recovery efforts in coordination with local agencies and the public. One very stark lesson from the 9/11 events is that the “first” first-responders are usually members of the public. Additionally, area- and region-specific vulnerability analysis and assessment of infrastructure availability for response and recovery have not been conducted. Finally, a national vulnerability analysis and assessment of infrastructure availability for response and recovery is a critical need.

Whether natural or man-made, disasters will continue to happen. However, as we have seen with the 9/11 events, hurricanes Katrina and Rita, and chemical incidents such as the Bhopal disaster, planning and response is crucial in being able to reduce the consequences and to recover from the disaster more rapidly. In this regard, it is essential to conduct vulnerability analysis, response, and recovery planning at the following three levels:

- **Plant-specific vulnerability analysis** and assessment of infrastructure availability and preparedness for response and recovery is needed. As mentioned earlier, most of the large multi-national facilities that belong to prominent industry associations have voluntarily conducted some form of vulnerability analysis. What is not clear is whether these analyses have been used to integrate planning for response and recovery efforts in coordination with local agencies and the public.

- **Area- and region-specific vulnerability analysis** and assessment of infrastructure availability for response and recovery should be conducted. Each area- and region-specific analysis should include an assessment and planning for evacuation and shelters.

- **National vulnerability analysis** and assessment of infrastructure availability for response and recovery is critically needed. In doing this national analysis, impact on international issues and criteria should also be considered.

Long-term Goals and Priorities

Long-term goals and priorities to prevent and/or reduce the consequences of intentional catastrophic scenarios require clear thinking and hard work. While no one would argue that making hazardous materials less attractive as a target should be a goal that all stakeholders should accept, differences arise in how we realize that goal.

Inherent safety options can and should be considered; however, we must be aware of the differences in implementing inherent safety options for existing plants, as compared to new plants. Also, in some cases, a seemingly clear choice with regard to inherent safety may create some undesired and unintended consequences. Issues such as risk migration, reduction of overall risk, and practical risk reduction should be evaluated whenever an inherent safety option is considered.

Another long-term goal is to develop technology and know-how with regard to resilient engineered systems and terrorism-resistant plants. In this respect, research and technological advances are needed in many areas, such as bio-chemical detection, sensors, and self-healing materials. Protection of the chemical infrastructure, like many other challenges, requires the commitment and effort of all stakeholders.

I feel very strongly that science should precede regulations and standards. With regard to science and technology investments, many initiatives have been proposed and are being implemented. However, some important additional initiatives that should also be considered are given below:

1. The fact is that the chemical infrastructure and all components including the individual sites, supply, and delivery systems were never built with terrorism in mind. Research must be conducted to determine how we might have designed and built the chemical plants and the infrastructure had we considered these threats. The ultimate goal for such research would be two-pronged. First, determine options for what can be feasibly implemented for existing plants. Second, if necessary, prescribe new standards and procedures for new plants.

2. Research investments should be made on advanced transportation risk assessment methods. Before transportation of any hazardous materials, a transportation risk assessment should be conducted using available information and methodology, as well as time-specific data that may be available.

3. Additional science and technology investments that should be considered are:

    - Development of incident databases and lessons learned. This knowledge base could then be used to improve planning, response capability, and infrastructure changes. Recent experience in this regard is the improvement in planning and response for the hurricane Rita from lessons learned from the hurricane Katrina.

- Research should be conducted on decision-making, particularly under stress, and how management systems can be improved.

- Research on inherent safety options and technologies. This type of research should be combined with systems life cycle analysis and review of practical risk reduction. In other words, implementation of inherent safety options should not be allowed to create other unintended consequences, risk migration, or risk accumulation. While transportation is outside the scope of the ***Chemical Security Act of 2008***, it must be included in vulnerability assessments to avoid transfer of facility risks to transportation risks.

- Basic and fundamental research is also needed on design of resilient engineered systems. For example, if the collapse of the World Trade Center towers could have been extended by any amount of time, additional lives could likely have been saved.

- Basic and fundamental research is also needed on resilient and fail-safe control systems.

- Long-term research is also needed in the area of self-healing materials and biomimetics.

Specific Comments on the *Chemical Security Act of 2008*

With regard to the ***Chemical Security Act of 2008***, I have the following specific comments:

1. The US Congress must give the Department of Homeland Security permanent and continuing authority to regulate chemical security in the United States. While many facilities are voluntarily taking appropriate measures, I am concerned that many are not. A regulation that creates a minimum and level playing field is very important.

2. The inclusion of water processing facilities in the ***Act*** is important and necessary. As the 9/11 events have shown, terrorists are more likely to use easily available materials to strike at us.

3. The use of a risk-based approach and risk-tiering in evaluating the vulnerability of any facility is a good approach.

4. Although Section 2110 of the ***Chemical Security Act of 2008*** does not refer to the term “inherent safety” or “inherently safer technology,” compliance with Section 2110 deals exclusively with the implementation of inherently safer technologies and approaches. I have several comments with regard to the proposed language in the ***Act***.

a. It is not clear how the Secretary would determine what is an inherently safer technology or approach. More clarity is needed on this issue.

b. There are many methods available to the industry for potentially reducing risk and vulnerability. Vulnerability assessments should consider the feasibility of all methods for improving security to determine the method to achieve the optimum balance of cost effectiveness and vulnerability reduction.

c. As I stated earlier, science should precede regulations. I do not believe that the science currently exists to quantify inherent safety. This ***Act*** or any actions taken as a result of the ***Act*** should not create unintended and unwanted consequences. An example in this context is the substitution of hydrogen fluoride (HF) with sulfuric acid (H_2SO_4) for refinery alkylation processes. While it is true that HF is more toxic than H_2SO_4, the amount of H_2SO_4 needed to do the same amount of processing is 25 times or more than HF. Thus changing from HF to H_2SO_4 would require large storage facilities and more transportation. In fact, changing from HF to H_2SO_4 may provide more opportunities for a terrorist attack. On the other hand, a well-managed plant with a smaller amount of HF and appropriate safety protective systems may represent a lower overall risk.

d. While there is no question that options with regard to inherent safety should be considered, we must understand and account for the challenges and difficulties in implementing inherently safer technology and options. In this context, the Mary Kay O'Connor Process Safety Center published a White Paper outlining challenges faced in evaluating and implementing inherently safer designs (the White Paper is provided as an attachment). The first challenge is simply to measure the degree of inherent safety in a way that allows comparisons of alternative designs, which may or may not increase safety or may simply redistribute the risk. The second is that because inherent safety is an intrinsic feature of the design, it is best implemented early in the design of a process plant, while the US has a huge base of installed process plants and little new construction. Finally, in developing inherently safer technologies, there are significant technical challenges that require research and development efforts. These challenges make regulation of inherent safety very difficult. We believe that a coordinated long-term effort involving government, industry, and academia is essential to develop and implement inherently safer technologies. A similar collaborative approach has shown success in related areas such as green chemistry, energy conservation, and sustainable development.

e. Instead of prescriptive requirements for inherently safer technology and approaches, facilities should be allowed the flexibility of achieving a manageable level of risk using a combination of safety and security options. For example, nuclear facilities have very high hazard materials, but they protect their site and the public with a combination of multiple layers of security and safety protective features. The current language in the bill is far too prescriptive and focused much too heavily on only one method of reducing the consequences of a terrorist attack. All methods of reducing vulnerability should be considered on a case-by-case basis, and the implementation of any one particular method should not take or appear to take precedence over the others.

   f. Over the past 10-15 years, and more so after 9/11, consideration of Inherently Safer Technology (IST) options and approaches has effectively become part of industry standards, with the experts and persons with know-how assessing and implementing inherently safer options, without prescriptive regulations that carry risks (both as trumping other tools or potentially shifting risk). A better approach for applying IST in security is by allowing the companies to assess IST as part of their overall safety, security and environmental operations and therefore, cannot be prescriptive. The current DHS regulations allow for IST - but do not require it under the performance-based standards and the no "one-measure" language proposed in the ***Chemical Security Act of 2008***. Any new law should adopt the current comprehensive regulatory scheme and build upon the great effort and momentum already established.

5. The section of the ***Act*** dealing with the formation of the *Panel on Methods to Reduce the Consequences of a Terrorist Attack* is in principle a good idea. However, an issue that needs to be given some thought is trade secrets. Even though the ***Act*** contains requirements with regard to protection of information and confidentiality of documents, it stands to reason that companies may feel restricted in providing certain trade secret information when they know that such information may be viewed by panelists who are employees of other companies and competitors. Another issue is that the panel could well be faced with a huge volume of work. There are thousands of different chemical processes in use in the US. What works at one facility is not necessarily appropriate at another facility, even if they have the same feedstock and product.

6. The numerous uses of the word "any" could create a huge amount of workload associated with the evaluations and documentation of site vulnerability assessments (SVA) with little benefit. For example, page 12, "The identification of any hazard that could result from a chemical facility terrorist incident at the facility." Another example on page 12 is paragraph E, "Any vulnerability of the facility with respect to___."

7. Paragraph B on page 12 requiring the quantification of consequences ("The number of individuals at risk of death, injury, or severe adverse effects to human health as a result of a chemical facility terrorist incident at the facility.") should be removed or modified. As was the case with the RMP "Population at Risk" values, the data are often taken out of context or used inappropriately. Furthermore, there will be significant variability in how these estimates are calculated if performed by each company. It would be much better to have these estimates generated by DHS based

upon the inventories provided by the companies, as is the case with current DHS regulations.

8. Regarding SEC. 2110, section (a) METHODS TO REDUCE THE CONSEQUENCES OF A TERRORIST ATTACK, it is not clear how item (5) '*procedure simplification'*, or (10) '*reduction of the possibility and potential consequences of equipment failure and human error'*, would have an impact upon the consequences of a terrorist attack.

Concluding Thoughts

I applaud the US Congress for providing leadership in this important area of chemical security. It is clear that many companies are taking reasonable and responsible steps in chemical security. However, all facilities that handle, store, or transport hazardous materials should be required to take such steps. That is why government must develop and enforce good-science based regulations that set the minimum and necessary standards for chemical security. These regulations should be based upon good science aimed at making the industry secure, avoid over-regulation, and create a level playing field.

Terrorism should not only be expected from Al-Qaeda and its support organizations, but from other sources as well, both home-grown and foreign. In this respect, planning and response measures should be based upon considering not only the existing structure of Al-Qaeda and its support organizations, but also the looming threat of mutations of Al-Qaeda and other terrorist organizations. As the Oklahoma City bombing and the more recent London events have shown, the terrorists could very well be our own citizens. As the mutation keeps evolving, it is not unlikely that alliances would develop among Al-Qaeda type organizations and other organizations or individuals who are disaffected or anti-establishment for totally different reasons. In fact, these organizations may be at odds with each other ideologically, but may unite because they see the establishment as a common enemy.

Regardless of what steps are taken by government, industry and other stakeholders regarding chemical security, it stands to reason that a terrorist attack should be expected and will occur sooner or later. As we know now, the 9/11 attacks were in planning for several years. As the adage goes, the terrorists only have to be successful once. Thus, it is imperative that the approaches taken be based upon the triple-pronged philosophy: evaluation and assessment, prevention and planning, and response and recovery. Planning and preparedness is required for all three areas.

In closing, only through a comprehensive, uniform and risk-based approach can we protect the people and communities of our nation as well as protect our nation’s critical chemical infrastructure. I am encouraged by the leadership of Congress and the continued effort to seek expertise and opinion from all stakeholders.

Thank you for inviting me to present my opinions and I will be happy to answer any questions.

<u>Attachment to the</u>

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Challenges in Implementing Inherent Safety Principles in New and Existing Chemical Processes

White Paper

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Abstract

This paper defines inherent safety and contrasts it with more traditional approaches to safety. It illustrates through analogies with common household examples the challenges faced in evaluating and implementing inherently safer designs. The first challenge is simply to measure the degree of inherent safety in a way that allows comparisons of alternative designs, which may or may not increase safety or may simply redistribute the risk. The second is that because inherent safety is an intrinsic feature of the design, it is best implemented early in the design of a process plant, while the US has a huge base of installed process plants and little new construction. Thirdly, in developing inherently safer designs, there are significant technical challenges that require research and development efforts with limited economic incentives. These challenges make regulation of inherent safety very difficult. We believe that a coordinated long-term effort involving government, industry, and academia is essential to develop and implement inherently safer designs. A similar approach has shown success in related areas such as green chemistry, energy conservation, and sustainable development.

Challenges in Implementing Inherent Safety Principles in New and Existing Chemical Processes

What is Inherent Safety?

Inherent safety is based on the use of technologies and chemicals with intrinsic properties that reduce or eliminate hazards. Inherent safety is based on concepts known for more than 100 years (Kletz, 1998) and is an approach to chemical incident and pollution prevention that is in some ways contrary to traditional accident prevention and mitigation methods. Traditional safety practices typically reduce risk by lowering the probability of an incident and/or mitigating the consequences of an incident. This approach alone, although extremely important and generally effective, does not reduce the hazards of serious chemical incidents because it attempts to control hazards rather than eliminate them. Inherent safety is especially important in today's world where terrorists may cause a chemical release by methods that bypass or defeat normal safety systems.

The concepts of inherent safety as applied to chemical process plant design has been discussed elsewhere (Mannan et al., 2002) and are summarized below:

> **Intensification or minimization** consists of reduction of quantities of hazardous chemicals in the plant. "What you don't have can't leak".
>
> **Substitution** is the use of a safer material in place of a more hazardous one. It may be possible to replace flammable substances with non-flammable ones or toxic substances with non-toxic ones. However, it is necessary to evaluate not only the substance but also the volumes required.
>
> **Attenuation** or moderation is the use of a hazardous chemical under less severe conditions such as lower pressure or temperature. Thus chlorine and ammonia are stored as refrigerated liquids at atmospheric pressure rather than at high pressure at ambient temperature. The lower pressure results in lower leak rates and the lower temperature lowers the vaporization rate.
>
> **Limitation of effects**, by changing designs or process conditions rather than by adding on protective equipment that may fail. For example, it is better to prevent overheating by using by using a fluid at a lower temperature rather than use a hotter fluid and relying on a control system.
>
> **Simplicity**: Simpler plants are safer than complex plants as they provide fewer opportunities for error and contain less equipment that can fail.

Other principles such as, making assembly errors impossible, and avoiding knock-on effects are also inherently safer design concepts.

One of the most common accidents at home is falling on the stairs. A home without stairs, i.e. a one-story bungalow, is inherently safer with regard to falling on stairs than a two-story house. Even if the stairs are equipped with handrails, non-slip surfaces, good lighting, and gates for children, the hazard is still present (Kletz, 1998). Obviously the choice of an inherently safer house implies positive and negative consequences, which may include aesthetics, cost, and other types of hazards. An elevator could reduce the use of stairs but requires a large capital expense. During construction there would be significant hazards to the residents and construction workers and the stairs would still be necessary for emergency egress. Few families would conclude that installing an elevator is the best use of their resources.

Measuring Inherent Safety

While inherent safety is based on well-known principles, difficulties have been encountered in adopting the principles as a routine practice by industry. One of the first problems encountered during application of inherent safety principles is the subjectivity involved. The principles are descriptive rather that prescriptive, hence they are subject to interpretation based on previous experience, knowledge, and personal perception. A consequence of the subjectivity is that a systematic methodology to measure inherent safety does not exist, and it is not currently possible to know how inherently safe a plant or an equipment item is because it is not possible to evaluate how well the principles have been applied. If we cannot measure how inherently safer the one story condo is with respect the two-floor house, how can we choose the inherently safer option?

Several measurement and analysis tools have been proposed during the last few years, but in general they focus on specific aspects of the problem during a specific time in the plant lifecycle and are difficult to apply. Besides the lack of measurement methodology, inherent safety cannot be applied in the same way for existing productive plants as for new facilities during the design stage. Existing equipment and processes impose restrictions on changes towards inherently safer technologies that might be implemented in an operating facility. For instance it is not possible to turn a two-story house into a bungalow without an extremely expensive modification. However, other smaller changes can be implemented to obtain an inherently safer house even if not so safe as the bungalow. Some types of staircases are safer than others, e.g., short high steps are inherently more hazardous than long low steps. Very low single steps are easy to be undetected and cause accidents. Thus the possible solutions could be to avoid single small steps and to use staircases with low and long steps or (as suggested by Kletz) with frequent landings to reduce the distance and height of a possible fall.

Evaluating and Comparing Design Options

The cost of applying inherent safety to existing facilities may require significant financial resources but may also unintentionally cause an increase in risk if it is implemented without a holistic view of the plant. A chemical plant is a complex collection of intricate and interconnected equipment, pipes, vessels, and instruments containing a variety of chemicals. When a modification is made in one part of the plant, other areas will be affected, requiring other changes in other parts of the plant. If the safety impact of this cascade of changes into other areas is not understood during the evaluation of the original change toward an inherently safer plant, the final result could be a less safe plant! A common example is the possible substitution of a hazardous chemical substance, used in small amounts, by another one that is more benign but is required in much larger amounts. In this case it is difficult to evaluate which chemical is actually the inherently safer option, because aspects such as transportation, storage, and modification of the plant to work with the new chemical must be included in the evaluation. There must be a systematic assessment and minimization of all hazards together rather than one at a time to avoid the appearance of unidentified hazards. Application of inherent safety principles to operating plants is possible (Hendershot, 1997) but implementation is subject to constraints dictated by technical and economic factors.

The implementation of inherent safety for new plants is simpler and cheaper because the design exists only on paper since nothing has been built yet. However, since many inherently safer options may be available and because a systematic analytical methodology is not available, application of the inherent safety principles is still restricted. Also, inherent safety is not absolute, it is site and plant specific. For instance a two-story house may be safer than a bungalow when located in an area threatened by frequent flooding. Therefore, a solution that can be inherently safer for one plant may not be the best option for the same plant in another location with a different environment.

The application of inherent safety requires subjective judgment and tradeoffs among several factors. Furthermore, the selection and use of inherently safer technology does not guarantee by itself that a plant will result in safer operation among its complex and interrelated systems. For instance, a sick person with lung, heart, and digestive problems can take the best medicine for each sickness, however the interaction of those drugs may have catastrophic results rather than a positive therapeutic effect.

The objective of inherent safety is to remove or reduce hazards. The inherently safest case is the one with zero hazards, but this is a limiting and unachievable case. Everyday life is plagued with hazards that are intrinsic to our society. Removing all the hazards is not possible. The situation of a chemical plant is very similar, and therefore we can only aspire to design inherently safer plants. It will be necessary to apply other methods to control the remaining hazards. Therefore, it is still possible for incidents to occur but their consequences are reduced.

It may also be true that it is really not possible to judge which of two options is inherently safer. For instance solvent A is toxic but not flammable, solvent B is flammable but not toxic. There may be no “right” answer. Also, the answer may depend on one’s point of view. A plant can use chlorine from 1-ton cylinders or from a 90-ton rail car. To the operator who has to connect and disconnect cylinders several times a day the rail car is inherently safer. To a neighbor several miles away the cylinders are safer, they do not contain enough material to affect him.

When new knowledge about chemical hazards or new technology is available, our understanding of the inherent safety of a specific plant can change. An example of this change is the adoption of CFC refrigerant gases (Hendershot, 1995) that are not flammable or toxic compared with ammonia, which was previously used. It has been theorized (and widely accepted) that they destroy the earth’s ozone layer and our judgment of the inherent safety of CFC refrigerants relative to other materials are radically changed. Inherent safety is therefore a dynamic, subjective, and holistic concept that requires specific measurement and analytical tools to evaluate. However, these tools are under development and at present are not available for general use. Without these analytical tools it is very difficult if not impossible to impose restrictions, limits, and regulations to improve inherent safety.

Inherent Safety can also be misused when decisions are subjective and based on limited aspects without possibility of a methodical analysis. For instance, a plant requiring a specific raw material transported by rail can decide to improve the degree of inherent safety by reducing the inventory of that hazardous chemical. Changing the mode of transportation to truck results in a smaller shipment (and a smaller inventory) but it also triples the shipment frequency. Thus the total plant inventory is kept low but the remainder of the inventory is on wheels traveling from the supplier’s plant to the user’s plant. This example also shows an inherent safety complication that extends outside the plant boundaries and represents an incorrect application of inherent safety that cannot be detected without a measuring tool and without analyzing the plant as a global system. In this case it is inherently safer to maintain the large inventory inside the plant and, as suggested by Kletz (1998), keep it under control by using good design and operating practices that follow other concepts of inherent safety (e.g., keep the design simple to avoid errors).

Progress to Date

We believe that many chemical plants have adopted the easiest and most obvious improvements, such as reviewing chemical inventories and reducing them when it is practical. This improvement is a natural outcome of the Process Hazard Analysis that has been required of most major facilities for the last 10 years.

Less hazardous solvents have been developed and are in use in some processes (Crowl, 1996). Plants using hydrofluoric acid can now use an additive that reduces the dispersion of this chemical during a release. These developments however, required substantial time and cost to develop, test, and implement. Many significant advances are possible but they too will require research, development, and implementation over a long time period. As shown above, the development of methods to measure the inherent safety of various process options is an essential first step to the widespread implementation of inherently safer designs. The Mary Kay O'Connor Process Safety Center is currently developing a method to measure inherent safety using fuzzy logic mathematics.

Moving Forward

Regulation to improve inherent safety faces several difficulties. One, there is not presently a way to measure inherent safety. Two, the complexity of process plants essentially prevents any prescriptive rules that would be widely applicable. At most it would seem that legislation could explicitly require facilities to evaluate inherently safer design options as part of their process hazard analysis, but inherent safety would be almost impossible to enforce beyond evaluation because of unavoidable technical and economic issues.

Government programs now support the research and development of concepts such as "green chemistry", "solvent substitution", "waste reduction" and "sustainable growth", which are related to inherent safety. A similar approach involving industry, government, and academia can enhance the discovery, development, and implementation of inherently safer chemical processes.

References:

- Crowl, D, ed., *Inherently Safer Chemical Processes*, pp. 39-40, CCPS, New York (1996)
- Hendershot, D.C. "Conflicts and decisions in the search for inherently safer process options", Process Safety Progress, 1996, Vol. 14, 1, 52.
- Hendershot, D.C. "Inherently safer chemical process design", Journal of Loss Prevention, 1997, Vol. 14, 3, 151-157.
- Kletz, T.A., "Inherently Safer Design: The growth of an idea", Process Safety Progress, 1996, Vol. 15, 1, 5.
- Kletz, T., Process Plants: *A Handbook for Inherently Safer Design*, p. 193,Taylor & Francis, Philadelphia (1998)
- Mannan, M.S., D. Hendershot and T.A. Kletz, "Fundamentals of Process Safety and Risk Management," Encyclopedia of Chemical Processing and Design, ed. R.G. Anthony, vol. 69, Supplement 1, pp. 49-94, Marcel Dekker, Inc., New York, 2002.

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