

Summary

The Use and Storage of Methyl Isocyanate (MIC) at Bayer CropScience

The use of hazardous chemicals such as methyl isocyanate can be a significant concern to the residents of communities adjacent to chemical facilities, but is often an integral, necessary part of the chemical manufacturing process. In order to ensure that chemical manufacturing takes place in a manner that is safe for workers, members of the local community, and the environment, the philosophy of inherently safer processing can be used to identify opportunities to eliminate or reduce the hazards associated with chemical processing. However, the concepts of inherently safer process analysis have not yet been adopted in all chemical manufacturing plants. This report presents a possible framework to help plant managers choose between alternative processing options—considering factors such as environmental impact and product yield as well as safety—to develop a chemical manufacturing system.

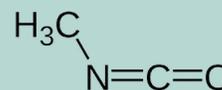
In 2008, an explosion at the Bayer CropScience chemical production plant in Institute, West Virginia, resulted in the deaths of two employees, a fire within the production unit, and extensive damage to nearby structures. The accident drew renewed attention to the fact that the Bayer facility manufactured and stored methyl isocyanate, or MIC—a volatile, highly toxic chemical used in the production of carbamate pesticides and the agent responsible for thousands of deaths in Bhopal, India, in 1984. In the Institute incident, debris from the blast hit the shield surrounding a MIC storage tank, and although the container was not damaged, an investigation by the U.S. Chemical Safety and Hazard Investigation Board found that the debris could have struck a relief valve vent pipe and caused the release of MIC to the atmosphere. The Board's investigation also highlighted a number of weaknesses in the Bayer facility's emergency response systems. In light of these concerns, the Board requested the National Research Council convene a committee of independent experts to write a report that examines the use and



Figure 1. The Bayer CropScience facility at Insitute, WV.
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Box 1. What is MIC?

MIC is a volatile, colorless liquid that is extremely flammable, and potentially explosive when mixed with air. MIC reacts with water, giving off heat and producing methylamine and carbon dioxide. The liquid and vapor are toxic when inhaled, ingested, or exposed to the eyes or skin. The release of a cloud of MIC gas caused the Bhopal disaster in 1984, killing close to 3800 people who lived near the Union Carbide India Limited plant in Bhopal, India.



storage of MIC at the Bayer facility, and to evaluate the analyses on alternative production methods for MIC and carbamate pesticides performed by Bayer and the previous owners of the facility.

Following the 2008 accident, Bayer halted MIC production while completing safety modifications, such as reducing on-site inventory of MIC and building underground storage facilities. Then, in 2011—with the National Research Council study already underway—the Environmental Protection Agency cancelled registration of aldicarb, a carbamate pesticide known commercially as TEMIK that is produced using MIC. Shortly afterwards, Bayer announced that production of certain carbamate pesticides was no longer economically viable for the company and would cease at the end of 2012. In the meantime, Bayer intended to finalize modifications to the MIC plant at Institute and restart manufacturing of aldicarb, carbaryl (another carbamate pesticide known commercially as SEVIN), and the intermediate materials required for their production (including MIC) in mid 2012.

In February 2011, amid concerns about the safety of restarting MIC processing at the Institute, West Virginia plant, a group of local residents filed suit against Bayer. On March 18 2011, Bayer announced that it no longer intended to restart production of MIC. In a press release, the company stated that “uncertainty over delays has led the company to the conclusion that a restart of production can no longer be expected in time for the 2011 growing season.”

In response to these developments, the National Research Council report’s authoring committee felt it necessary to change their approach to addressing the tasks they had been given. In particular, it became apparent that a full review of

technologies for carbamate pesticide manufacture was less relevant, as the pesticides would no longer be produced at the Institute plant. In addition, it became clear that a full analysis of manufacturing and energy costs would require greater time and resources than were available for the study. Instead, the committee focused on a limited number of possible alternative production processes, presenting tradeoffs with particular attention to safety considerations. Because deciding between alternative processes requires consideration and weighing of a number of different factors, including safety, one possible framework for evaluating these complex decisions is presented.

Making the Use of Hazardous Chemicals Safer

Within the chemical engineering community, the use of process safety management—a methodology for controlling hazards across a facility or organization to reduce the frequency or consequences of an accident—is a standard practice required by the Occupational Safety and Health Administration.

The goal of process safety is a systematic approach to safety that involves the proactive identification, evaluation, mitigation, or prevention of chemical releases that might occur as a result of failures in the process, procedures, or equipment. Process Safety Management ensures that facilities consider multiple options for achieving a safe process, and carefully weigh the possible outcomes of each decision, and the Process Safety Management Standard, promulgated by the Occupational Safety and Health Administration in 1992, lists 14 mandatory elements—ranging from employee training to process hazard analysis—to building a chemical processing system.

One approach for considering each of the options for safer processing is to consider a hierarchy of hazard control. The hierarchy contains four tiers: inherent, passive, active, and procedural, described below. Considering these possible hazard control methods in turn can help identify options for process design or modifications to improve process safety.

Inherent: The inherent approach to hazard control is to minimize or eliminate the hazard, for example by replacing a flammable solvent with water to eliminate a fire hazard, rather than accepting the existence of hazards and designing safety systems to control them. There are four

Box 2. MIC Storage and Use in the United States

The Bayer CropScience facility in Institute, West Virginia was the only site in the U.S. that stored large quantities of MIC. The chemical is generated during chemical manufacturing at another chemical facility in Texas, but at this facility the chemical is used up in the next stages of the reaction moments after being produced. MIC is still produced at several other chemical facilities worldwide.

strategies to consider when making any chemical process inherently safer:

- *Substitute*—Use materials, chemistry, or processes that are less hazardous
- *Minimize*—Use the smallest quantity of hazardous materials feasible for the process, reduce the size of equipment operating under hazardous conditions such as high temperature or pressure
- *Moderate*—Reduce hazards by dilution, refrigeration, or process alternatives which operate at less hazardous conditions reduce the potential impact of an accident by siting hazardous facilities in locations far from people or other property
- *Simplify*—Eliminate unnecessary complexity, and design “user-friendly” plants

Passive: Passive safety systems are those that control hazards with process or equipment design features without additional, active functioning of any device. For example, a containment dike around a hazardous material storage tank is a passive system to restrict a chemical spill to a limited area.

Active: Active safety systems control hazards through systems that monitor and maintain specific conditions, or are triggered by a specific event. Examples of active systems include a sprinkler system that is triggered by smoke or heat.

Procedural: Procedural safety systems control hazards through personnel education and management. Such systems include standard operating procedures, safety rules and procedures, operator training, emergency response procedures, and management systems.

Only the inherent tier of process safety management invites consideration of the elimination or

Box 3. Emergency Preparedness and Inherently Safer Processes

Inherently safer processes can help reduce demands on emergency services. Specifically, applying the inherently safer principle of substitution reduces vulnerability if a chemical release occurred; minimization reduces the quantity of chemical available for release; and moderation decreases the temperature and pressure of release.

However, the implementation of inherently safer processes can sometimes transfer risk to new sites. For example, reducing the storage of hazardous chemicals at a chemical facility may make it necessary to increase the number of shipments of chemicals to the site to meet process requirements, with the potential to increase the risk of a chemical release along the transportation route. While the emergency services in a community that houses a chemical processing facility would likely be prepared for the possibility of a chemical release, sites along the transportation route would likely have fewer resources to support an emergency response.

minimization of a given hazard; the other tiers are focused on control of an existing hazard. Although a valuable tool, consideration of inherently safer processes is not currently a required component of the Occupational Safety and Health Administration’s Process Safety Management Standard.

Implementing Inherently Safer Process Assessments

Inherently safer process assessments can be valuable components of process safety management that can help a facility consider the full range of options in process design. However, inherently safer process assessments will not always result in a clear, well-defined, and feasible path forward. Although one process alternative may be inherently safer with respect to one hazard—toxicity of byproducts, for example—the process may present other hazards, such as an increased risk of fire or more severe environmental impacts. Choosing between options for process design involves considering a series of tradeoffs and developing appropriate combinations of inherent, passive, active, and procedural safety systems to manage all hazards. Some hazards will be best managed using inherent methods, but others will inevitably remain and be effectively managed with other process safety management systems.

Although the philosophy of inherently safer processes applies at all stages of processing, the available options and the feasibility of implementing them can change over the course of a technology’s life cycle. For this reason, it is easiest to implement

Box 4. Inherently Safer Process Assessments at Bayer CropScience

Because the view of what constitutes an inherently safer process varies among professionals, the chemical industry lacks a common understanding and set of practice protocols for identifying safer processes. In its presentations to the report's authoring committee, Bayer stated that inherently safer processing is an integral part of its process safety management strategy. However, the committee found that inherent safety considerations were not explicitly stated in Bayer's process safety management records. Bayer performed hazard and safety assessments and made business decisions which resulted in MIC inventory reduction, elimination of aboveground MIC storage, and adoption of various passive, active, and procedural safety measures. However, these assessments did not explicitly incorporate the principles of minimization, substitution, moderation, and simplification that are the basis of inherently safer processes.

Without an emphasis on incorporating inherently safer processes into process safety management, it is unlikely that these concepts would become part of corporate memory, and therefore they could be forgotten or ignored over time. It would be beneficial for Bayer to formally incorporate inherently safer process assessments into the company's process safety management system and training, and to record such assessments as part of its audit and review processes.

Alternative Methods for Producing MIC and Carbamate Pesticides

The report's authoring committee reviewed Bayer's assessment of alternative processes for the manufacture of MIC and carbamate pesticides and considered the alternatives and tradeoffs. The alternative processes Bayer considered fall into the following broad categories:

1. Continue with the current process
2. Adopt an alternative process that does not involve MIC
3. Use an alternative process for MIC production that would consume MIC immediately, and therefore onsite storage of MIC would not be required
4. Reduce the volume of stored MIC, and the risks associated with transporting MIC from site to site, by re-arranging process equipment

Each possible approach presents its own costs and benefits. For example, a non-MIC based process for production of aldicarb (option 2) means that there is no risk of worker exposure to MIC. However, some non-MIC-based processes could result in lower purity in the aldicarb, which could negatively affect the characteristics of the final commercial product. Just-in-time production of gaseous MIC product (which falls under option 3) would eliminate the risk of catastrophic release of that material within the community, but it would require a significant re-design of the facility and would, in its current form, result in a final product with lower purity than the existing process.

In evaluating the alternatives, considering costs and benefits such as risk, cost, quality of final product, and community perception, no one method out-performed all others in every category. The process ultimately chosen by Bayer poses higher risks to the surrounding community due to the volume of MIC stored at the facility, but it also considerably decreases the amount of wastewater generated by the process, thereby reducing health risks to the community from damage to local surface water quality.

inherently safer process design before process technologies have been chosen, facilities built, or customers have made commitments based on products with particular characteristics. As a product moves through its life cycle, these and other factors may limit options, make changes more difficult,

or involve more people and organizations in the change.

In order to build an inherently safer system, each stage of the process life cycle should be considered:

- **Selection of basic technology:** Identify inherently safer options for chemical synthesis

- **Implementation of selected technology:** How will the chosen process chemistry be implemented? Can hazardous operating conditions be minimized? Can impurities and by-products be avoided to eliminate purification steps?
- **Plant design:** Considerations include plant proximity to the surrounding population, in-plant occupied areas, sensitive environmental areas, and the general layout of equipment on the plant site.
- **Detailed equipment design:** Minimize the inventory of hazardous material in specific pieces of process equipment. Consider the impact of equipment layout on the length and size of piping containing hazardous materials. Consider human factors in the design of equipment to minimize the potential for incorrect operation and human error.
- **Operation:** Use inherently safer processing principles in ongoing process safety management activities such as management of change, incident investigation, pre-startup safety reviews, operating procedures and training to identify new opportunities for inherently safer processes.

Challenges in Measuring Inherent Safety

There are tools to measure the degree of inherent safety of a given process or processing alternative, but there is no current consensus on the most reliable metrics. Some metrics consider the likelihood of different hazards such as fire, explosion, or toxicity using penalty factors assigned based on the severity of the hazard to calculate an overall hazard index. However, the origin and justification of this relative scale is unclear, and these indexes are not designed to be adjusted readily in order to reflect the variation in preferences among attributes or willingness to tolerate risk that different constituencies may exhibit. For example, a company owner may be willing to tolerate a small risk of a spill that could have health effects in the community if the alternative involved a much higher risk of a fire that would seriously damage the facility, whereas members of the community may not accept such a tradeoff, and

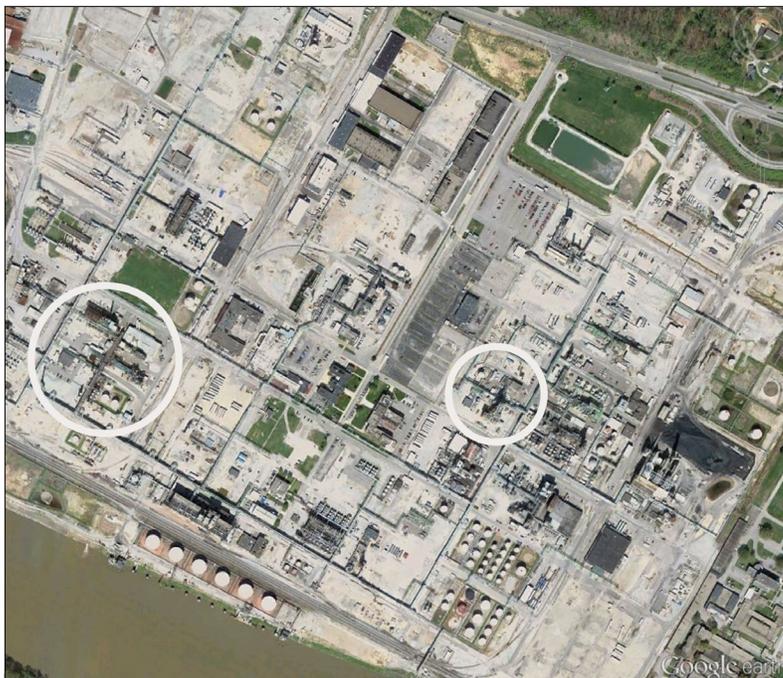


Figure 2. The Bayer CropScience Facility. The circle on the left marks the location of the MIC production unit, and the circle on the right marks the methomyl production unit, site of the MIC aboveground storage container.

Google Earth satellite image: © 2012 Google

employees of the firm (who place some value on keeping the facility intact in order to retain their jobs) might fall somewhere in between the owner and the community.

Choosing Between Alternative Processes: A Framework for Decision Making

Choosing between multiple process alternatives with conflicting tradeoffs is a concern faced by any chemical processing facility. When no option is clearly favorable to the others, the question arises as to what decision-making framework a company could use to consider the trade-offs of process choices from an inherently safer perspective.

Employing Decision in Inherent Safety Assessments

As currently performed, a potential concern with using inherently safer process analysis is that it may become focused too narrowly, and as a consequence may overlook certain outcomes. Even when multiple outcomes are recognized, they may be inappropriately weighted. For example, existing indexes for assessing inherently safer processes cannot capture the preferences of all decision makers, and the many trade-offs, uncertainties, and risk tolerances are hidden from view as implicit assumptions rather than explicit chosen parameters. One possible method for

incorporating these preferences is to draw upon multi-criteria decision analyses, which use mathematical constructs to assess and evaluate stakeholder input to play a role in developing weighted comparisons between options.

One example of decision theory analysis is multi-attribute utility theory. This is not a new idea to the chemical community—in 1995, the Center for Chemical Process Safety (CCPS) published a book that suggested this and other decision aids could be used to support process safety assessments. However, though employed regularly in other sectors, these decision aids have yet to take hold in the chemical process industry. Key obstacles to their use include lack of familiarity with the tools among chemical process industry decision makers and the fear that the methods are either too simplistic or too costly to use. Nonetheless, the report’s authoring committee found that decision analysis techniques could prove valuable for strengthening the integration of safety concerns into decision making in the chemical process industry. The use of these techniques could benefit not only the communities at risk from safety breaches, but also the industries themselves, as decision making techniques can help with the identification of profitable safety solutions that otherwise could be overlooked.

A formal plan from the Chemical Safety Board or other appropriate entity for incorporating decision theory frameworks into inherently safer process assessments could help chemical facilities adopt inherently safer processes. A working group

including experts in chemical engineering, inherently safer process design, decision sciences, and negotiation could identify obstacles and identify options for tailoring methods from the decision sciences to process safety assessments.

Post-Incident Process Assessment

Incident investigation is one of the mandatory elements of the Occupational Safety and Health Administration’s process safety management standard. Comprehensive protocols and advice are available for conducting investigations of chemical process incidents. These guidelines emphasize the need for a process safety management system to be simultaneously retrospective and prospective, with incident investigation providing the vital bridge between the lessons of the past and safer designs and operation in the future.

Incorporating the principles of inherently safer processes into incident investigations can help prevent future potential incidents that may have similar causes. Over time, findings from inherently safer process assessments performed in the wake of accidents may identify trends in process design that could be used to improve future systems. Findings from an investigation may also be of use when refining the models that support existing inherently safer process assessments. A post-accident inherently safer process assessment may also help identify unanticipated hazards within a process, which could help inform the redesign or rebuild of the facility.

Box 5. Summary of Findings, Conclusions, and a Recommendation

Although claimed to be an integral process safety management component, inherent safety considerations are incorporated into Bayer's process safety management efforts in an implicit manner that is dependent on the knowledge base of the individual facilitating the particular activity (e.g. process hazard analysis).

Bayer and its predecessors did seek to reduce risks associated with MIC, and those efforts did incorporate some aspects of risk reduction associated with inherently safer process principles. However, Bayer did not make statements or provide documentation indicating that it had engaged in a systematic effort to incorporate inherently safer processes into the decision making process.

Bayer and its predecessors evaluated trade-offs among the alternatives, but while analysis provides a very useful starting point for a comparison of technologies, it excludes factors that may be important in the decision, from the perspective of both the company and the community.

Bayer CropScience did perform Process Safety assessments, however, Bayer and the legacy companies did not perform systematic and complete inherently safer process assessments on the processes for manufacturing MIC or the carbamate pesticides at the Institute site. Bayer and the previous owners performed hazard and safety assessments and made business decisions that resulted in MIC inventory reduction, elimination of aboveground MIC storage, and adoption of various passive, active and procedural safety measures. However, these assessments did not incorporate in an explicit and structured manner, the principles of minimization, substitution, moderation and simplification. The legacy owners identified possible alternative methods that could have resulted in a reduction in MIC production and inventory, but determined that limitations of technology, product purity, cost, and other issues prohibited their implementation.

Inherently Safer Process Assessments and Decision-Making

Inherently safer process assessments can be a valuable component of process safety management. However, the view of what constitutes an inherently safer process varies among professionals, so the chemical industry lacks a common understanding and set of practice protocols for identifying safer processes.

Consistent application of inherently safer process strategies by a company has the potential to decrease the required scope of organizational emergency preparedness programs by reducing the size of the vulnerable zones around its facilities. Such reductions are achieved by reducing the toxicity of the chemicals being used or produced, the quantity of the chemicals being stored, and the conditions under which they are being stored.

As currently performed, a potential concern with using inherently safer process analysis is that it may become focused too narrowly, and as a consequence, may overlook certain outcomes. Even when multiple outcomes are recognized, they may be inappropriately weighted.

The committee recommends that the Chemical Safety Board or other appropriate entity convene a working group to chart a plan for incorporating decision theory frameworks into inherently safer process assessments. The working group should include experts in chemical engineering, inherently safer process design, decision sciences, negotiations, and other relevant disciplines. The working group should identify obstacles to employing methods from the decision sciences in process safety assessments. It should identify options for tailoring these methods to the chemical process industry and incentives that would encourage their use.

The Use of Inherently Safer Process Assessments in Post-Incident Investigations

The principles of inherently safer process assessment can be used to good effect in conducting an incident investigation when the objective is the prevention of potential incidents having similar fundamental, underlying (root) causes.

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The National Academies appointed the above committee of experts to address the specific task requested by the Chemical Safety Board. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.



For more information, contact the Board on Chemical Sciences and Technology at (202) 334-2156 or visit <http://dels.nas.edu/bcst>. Copies of *The Use and Storage of Methyl Isocyanate (MIC) at Bayer CropScience* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.

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