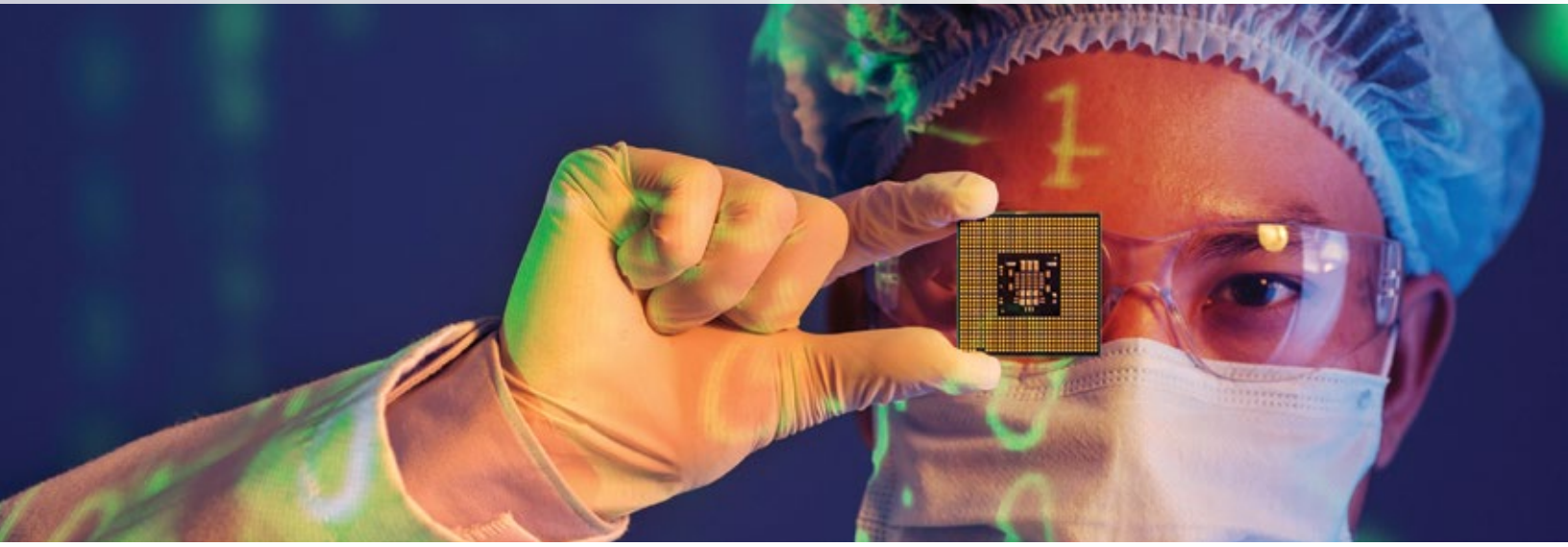

FOCUS ARTICLE

Safety Requirements for Energetic Materials in the Semiconductor Industry

The semiconductor industry is a fast-evolving sector that requires special standards and guidelines to ensure health and safety. The planned SEMI safety guideline could provide a framework to promote safety and reduce the occurrence of unwanted incidents.

SEMI Standard S30 was adopted in 2019. The new safety guideline aims to establish a minimum set of safety criteria for the procurement, storage, handling, and use of energetic materials in semiconductor R&D and manufacturing processes in all phases of use. It is intended to reflect industry best practices at the time of its publication.

The primary objective of the SEMI safety guideline is to eliminate or control hazards that include the use of energetic materials during R&D and manufacturing processes. To this end, the guideline defines what it considers "energetic material," specifying the testing and criteria required to identify a substance as such. In addition, it establishes the minimum characterization data to be provided at the time the energetic material is to be tested in research and development, pilot line or high-volume semiconductor manufacturing equipment. Recognizing the importance of design in contributing to positive safety outcomes, the guideline lists safety design criteria for equipment used in every phase of semiconductor manufacturing, referring to relevant international codes, regulations, standards and specifications.

Underpinning the safe use of energetic materials, the guideline emphasizes two overarching principles:

1. The quantity of energetic material used should be limited to the smallest amount necessary for effective production.
2. The customary levels of employee safety, fire and explosion prevention, environmental impact and asset protection, including uninterrupted production, should be maintained.

While the guideline strives to promote safe practices by compiling expert information on the responsible use of energetic materials in the semiconductor industry, it recognizes its own limitations: it cannot address every safety issue that may arise from the use of these hazardous substances. Users of the document are urged to look carefully at their specific operations and to adopt appropriate

practices and conform to applicable regulations that may go beyond the scope of the guideline.

Hazard Elimination Checklist

The SEMI guideline recommends a hierarchical approach to combating potential danger. It ranks suggested safety measures in order of precedence, i.e., the primary protective step is safe design. The complete list, as recommended to suppliers of equipment and process chemicals as well as to users, is as follows:

1. Design to eliminate hazards
2. Use the safest materials suitable to the application
3. Incorporate safety devices
4. Provide warning devices
5. Provide hazard alerts
6. Develop administrative procedures and training
7. Use personal protective equipment (PPE)

Suppliers and users are encouraged to employ all or a combination of these measures, depending on their specific operations and conditions.

In line with its emphasis on design safety, the guideline addresses the general criteria which equipment using energetic materials should meet:

> Regulatory requirements

> Industry standards

> This safety guideline

> Good engineering and manufacturing practices

Following these steps, a set of hazard analyses are required.

Hazard Analyses

An essential tool for creating safe industrial processes, **hazard analyses** occupy a central role in the new SEMI guideline. To successfully identify and evaluate hazards, the guideline recommends an analysis be performed early in the equipment design phase (SEMI S2 evaluation) and again in the overall equipment phase, encompassing supply, processing and waste treatment equipment. Authors of the guideline underscore the importance of consistent oversight when it comes to foreseeing and managing hazards. The document advises users to validate the safe installation of research, pilot line and high-volume manufacturing equipment to ensure applicable Environmental Health and Safety (EHS) regulations and best industry practices are satisfied prior to equipment start-up. Understanding the rapid rate of innovation in the industry, the guideline also urges users to maintain a management of change (MOC) program that includes guidance on how to evaluate existing processes for the addition of new chemistries or new use of chemistries by R&D and high-volume manufacturing business groups.

Hazard analyses are comprised of different methodologies including checklists, "What If?" analysis, **Hazard and Operability Studies (HAZOP)**, Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), **Layers of Protection Analysis (LOPA)** and more.

There are multiple hazards analyses that should be completed to ensure energetic materials can be safely used within a facility. Standalone and integrated hazard analyses are two main categories identified by the SEMI guideline.

	Application				
Method	**Design Review**	**Incident Investigation**	**Change Control Management**	**Process Safety**	**Equipment Evaluation**
Fault Tree Analysis		x	x		
FMEA	x		x	x	x
HAZOP	x			x	x
Hazard Survey	x	x			x
Process Safety Checklist				x	
"What If?" Analysis	x	x	x		x

Table 4 Hazards Analysis Techniques and Associated Applications

Equipment suppliers (of material delivery systems, process equipment, vacuum pumps and abatement systems) need to complete a standalone hazard analysis according to SEMI S2. In the case of collaboration among suppliers on a process application for an end user, suppliers should complete a joint hazard analysis, also in accordance with SEMI S2. In both cases these standalone hazard analyses precede the user's integrated analysis and may need to be revised to accommodate the addition of an energetic material or piece of equipment.

The guideline calls on users to initiate an integrated hazard analysis to identify and evaluate hazards associated with the complete energetic material's path from production to disposal. This integrated hazard analysis should take place as early as feasible and include appropriate representatives from the energetic process chemical supplier, material delivery system, process equipment, vacuum pump and abatement equipment suppliers, and the user's staff. As hazards may differ with different energetic materials, combinations of materials, configurations of supply, processing and waste treatment, this analysis should be performed for each equipment use, installation, or configuration. The minimum documentation required of an integrated hazard analysis, according to the SEMI guideline, includes:

> The physical, chemical, and toxicological properties of the energetic material to be processed

> The potential process byproducts and their physical, chemical, and toxicological properties and the locations of deposits

> The application or process at the maximum flow setpoints of the equipment, which are typically higher than the targeted process recipe values

> The hazards associated with each task

> Anticipated failure modes

> An analysis of interconnection hazards, based on proposed piping and instrumentation diagram (P&ID) and piping layout

> The anticipated level of expertise of exposed personnel and their frequency of exposure to the hazard

> The frequency and complexity (e.g., number of steps, required expertise) of operating, servicing and maintenance tasks

> Identification of safety critical parts

> PPE requirements

> Ranking, in accordance with SEMI S10 – Safety Guideline for Risk Assessment and Risk Evaluation Process, of the risks identified in the integrated hazard analysis

Information to Be Provided by Energetic Process Chemical Suppliers

According to the new standard, energetic process chemical suppliers are responsible for providing users with specific information about their products. The document lists the following as information to be shared between suppliers and users:

> Classification of substances

> Byproduct information

> PPE recommendations

> Any extra information agreed upon by the supplier and user

Classification refers to the identification of a substance as "pyrophoric," "water reactive," or "hazardously exothermic," all of which are defined in the document. The guideline requires extensive supporting information regarding classification. For instance, the test data and calculations or rationale for reaching a given classification conclusion must be included. In addition, suppliers must furnish a completed Material Characterization form, stoichiometry and thermodynamics of water and oxygen reactivity results, calorimetry results and a video illustrating potential exothermic reactions. This video is intended to educate anyone coming into contact with the substance, from maintenance workers to first responders, not only what safety measures are necessary, but why, by showing the results of the material's contact with moisture in the air; with a water-moistened cleanroom-compatible absorbent wipe; and with liquid water.

Byproduct information includes the chemical identity of known and anticipated products and byproducts based on the user's process conditions. It includes:

> States of matter

> Difficulty of removal of byproducts

> Any safety determinations made from byproduct quantitative or predictive model evaluation(s) or during the integrated process hazard analysis

The PPE recommendations relate to safe practices at on-site receipt, during transportation, installation and deinstallation activities. Permeation, penetration, degradation and fire hazards should be taken into consideration when advising on suitable PPE. In addition to the stated requirements, the guideline lists specific safety design criteria for equipment used in every phase of semiconductor manufacturing, such as liquid and vapor delivery

systems, gas boxes and process chambers as well as container delivery systems.

Partnering with Process Safety Experts

Adhering to the specifications stated in the guideline can lead to a reduction or elimination of unwanted incidents that put life and property at risk, but there are many factors to consider. Choosing a reliable process safety expert can ease the process and boost your confidence in your organization's safety practices. We are wellequipped to support you with the implementation of the new standard, including hazard analyses and testing to supply the data for the Material Characterization forms. Contact us to learn more about our one stop- shop solution for energetic materials in the semiconductor industry!

DEKRA Process Safety

The breadth and depth of expertise in process safety makes us globally recognized specialists and trusted advisors. We help our clients to understand and evaluate their risks, and work together to develop pragmatic solutions. Our value-adding and practical approach integrates specialist process safety management, engineering and testing. We seek to educate and grow client competence to provide sustainable performance improvement. Partnering with our clients we combine technical expertise with a passion for life preservation, harm reduction and asset protection. As a part of the world's leading expert organization DEKRA, we are the global partner for a safe world.

Process Safety Management (PSM) Programs

> Design and creation of relevant PSM programs
> Support the implementation, monitoring, and sustainability of PSM programs
> Audit existing PSM programs, comparing with best practices around the world
> Correct and improve deficient programs

Process Safety Information/Data (Laboratory Testing)

> Flammability/combustibility properties of dusts, gases, vapors, mists, and hybrid atmospheres
> Chemical reaction hazards and chemical process optimization (reaction and adiabatic calorimetry RC1, ARC, VSP, Dewar)
> Thermal instability (DSC, DTA, and powder specific tests)
> Energetic materials, explosives, propellants, pyrotechnics to DOT, UN, etc. protocols
> Regulatory testing: REACH, UN, CLP, ADR, OSHA, DOT
> Electrostatic testing for powders, liquids, process equipment, liners, shoes, FIBCs

Specialist Consulting (Technical/Engineering)

> Dust, gas, and vapor flash fire and explosion hazards
> Electrostatic hazards, problems, and applications
> Reactive chemical, self-heating, and thermal instability hazards
> Hazardous area classification
> Mechanical equipment ignition risk assessment
> Transport & classification of dangerous goods

We have offices throughout North America, Europe, and Asia.
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