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Safety, Risk & Operational Resilience

The Invisible Systems That Keep Operations Running

Trinity Consultants

ABOUT THE PUBLICATION

EHS Quarterly provides its readers with information on EHS regulatory developments and their implications, management standards, sustainability, and relevant technology considerations. Articles are written by our own expert consultants, leveraging their specialized experience in various key topics and industries.

ABOUT US

Trinity Consultants, a leading global environmental consulting firm, provides services and solutions in the EHS Regulatory Compliance, Built Environment, Life Sciences, and Water & Ecology markets. Founded in 1974, Trinity has the technical expertise, industry depth, and capabilities to help clients achieve their goals across the natural and built environments.

We help clients achieve compliance with applicable regulations, international standards, and company specifications, enabling them to avoid business disruption, speed products to market, address stakeholder concerns, and achieve business objectives. For more information about how we can help your organization, please call us at +1 800.229.6655 or +1 972.661.8100.

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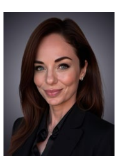

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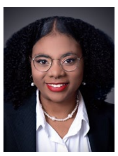

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DATA THAT MATTERS: LEADING AND LAGGING INDICATORS AS TOOLS TO IMPROVE SAFETY PROGRAMS

Andrea Simmons, *Managing Consultant, Sustainability & Assurance* — Albany, NY

What safety metrics is your organization tracking? Are they focused primarily on OSHA injury statistics and other lagging indicators, or has your program matured to the point where you are measuring activities, behaviors, and controls that help prevent incidents?

Lagging indicators such as Total Recordable Incident Rate (TRIR), Days Away, Restricted, or Transferred (DART) rate, lost-time injuries, and workers' compensation costs provide valuable insight into historical performance. However, they offer limited visibility into the effectiveness of risk management activities or the potential risk for future incidents.

As safety programs mature, they increasingly adopt leading indicators to evaluate whether risk controls, management systems, and employee engagement activities are functioning as intended. This shift reflects a broader focus on risk reduction, operational resilience, and continual improvement.

The need for this broader perspective has become more pronounced as organizations navigate workforce shortages, aging infrastructure, increasingly complex operations, and heightened stakeholder expectations. These challenges can introduce new risks and place greater demands on existing safety programs, increasing the importance of performance measures that provide insight beyond injury statistics alone.

Another factor driving interest in leading indicators is the increasing scrutiny of OHS programs during mergers and acquisitions, corporate transactions, and due diligence reviews. Buyers, investors, and other stakeholders are often interested in both historical safety performance data and in the strength of the management systems, risk controls, and processes used to identify and mitigate hazards. Due diligence reviews increasingly seek evidence that these elements are established, implemented, and effective.

This trend is reflected in industry guidance, insurer expectations, and standards such as ISO 45001, which emphasize risk-based thinking, worker participation, hazard identification, and continual improvement. By combining leading and lagging indicators, organizations can develop OHS objectives that measure the performance of the controls and processes that reduce risk.

OHS Performance Data

Data such as Total Recordable Incident Rate (TRIR), Lost-Time Injury Rate (LTIR), DART rate, workers' compensation costs, and regulatory violations provide important Occupational Health and Safety (OHS) performance baselines. These metrics help organizations understand whether safety performance is improving, remaining stable, or declining over time. They support benchmarking against industry peers, evaluation of safety initiatives, allocation of resources, and communication of program performance to leadership, employees, regulators, insurers, customers, and other stakeholders. They also remain important measures of compliance, accountability, and overall program effectiveness.

These metrics present a familiar scoreboard for safety performance. Injury and illness rates are widely recognized, consistently measured, and useful for identifying long-term trends. They can help validate whether investments in training, equipment, engineering controls, or safety programs are producing measurable results.

The challenge is not that lagging indicators lack value; rather, they primarily measure outcomes that have already occurred. A recordable injury, regulatory violation, or workers' compensation claim can highlight weaknesses in a safety program, but these metrics alone provide limited insight into whether current risk controls are functioning effectively or where the next incident may occur.

Leading indicators help fill that gap. They measure the activities, behaviors, and controls that influence safety performance and provide insight into the effectiveness of risk controls, management system processes, and employee engagement efforts. Examples include corrective action closure rates, preventive maintenance completion, safety observations, hazard reporting participation, and verification of critical risk controls.

Together, leading and lagging indicators provide a more complete view of safety performance and risk management. Lagging indicators measure results; leading indicators evaluate the processes and activities intended to produce those results.

This evolution reflects a shift in safety management from measuring incidents after they occur to managing the conditions that contribute to them. Strong safety performance depends not only on tracking outcomes, but also on understanding and influencing the activities, behaviors, and controls that drive those outcomes.

Business Implications of the Data

Safety performance is often viewed through the lens of injury statistics. While these metrics remain important, they represent only one outcome of an organization's ability to identify hazards, manage risk, execute work safely, and maintain effective controls. Safety performance does not exist in isolation. The conditions that contribute to workplace injuries can also affect equipment reliability, product quality, environmental performance, production efficiency, and overall operational resilience. Deferred maintenance can increase both injury risk and reliability concerns. Workforce turnover can affect training effectiveness, institutional knowledge, and operational consistency. Ineffective management of change can introduce safety, compliance, and operational risks simultaneously.

Safety performance also influences workforce engagement and organizational culture. Employees are more likely to participate in hazard reporting, safety observations, and improvement initiatives when they believe concerns are recognized and addressed. Conversely, recurring incidents, unresolved hazards, and ineffective corrective actions can erode trust, reduce morale, and create the perception that production priorities outweigh worker safety.

Leading indicators provide visibility into these underlying conditions. Measures such as corrective action closure rates, preventive maintenance completion, hazard reporting participation, safety observation quality, and verification of critical risk controls help organizations evaluate whether the systems intended to manage risk are functioning effectively.

When aligned with significant operational risks, leading indicators can identify emerging issues before they result in injuries, equipment failures, regulatory violations, or business interruptions. This allows management to focus resources on preventing problems rather than responding to them. The same information can also demonstrate to investors, insurers, customers, and stakeholders evaluating the organization as part of a transaction that the organization has effective processes in place to identify, evaluate, and manage risk. During due diligence reviews, these underlying indicators are assessed to provide valuable insight into how effectively an organization manages risk and maintains operational performance.

Effective OHS objectives build on the connection between safety and operational performance. The same controls, processes, and behaviors that reduce injury risk can also influence reliability, productivity, quality, and workforce engagement. By focusing attention on these underlying drivers of performance, organizations can strengthen safety culture, improve employee morale, and support more reliable business operations.

In this context, OHS objectives become tools for strengthening operational resilience, supporting a positive safety culture, protecting employees, and maintaining business continuity.

Data in Action

For decades, safety professionals have used data to prevent injuries. Early safety programs relied heavily on injury statistics because they were among the few readily available measures of performance. As safety management evolved, organizations recognized that injury rates alone provided limited insight into the effectiveness of the activities, behaviors, and controls intended to protect employees.

That realization has driven the development of new tools, technologies, and management systems designed to provide greater visibility into the factors that influence safety performance. Hazard assessments help identify where risk exists. Near-miss reporting highlights situations where controls failed but consequences were avoided. Behavior-based safety programs seek to understand work practices and decision-making. Corrective action management systems help organizations track issues to resolution and verify that improvements remain effective over time. Management systems such as ISO 45001 bring these elements together within a structured framework focused on hazard identification, worker participation, risk management, and continual improvement.

Across industries, the most effective programs tend to focus on a common objective: using data to understand how well systems intended to prevent injuries are functioning. While hazards differ at chemical facilities, manufacturing plants, warehouses, construction sites, or office environments, the underlying questions are often remarkably similar. Are hazards being identified? Are employees raising concerns? Are corrective actions being completed? Are controls working as intended? Are improvements being sustained? Leading indicators move the conversation beyond injury statistics and toward understanding the conditions that influence performance. Hazard reports, near misses, corrective action closure rates, safety observations, training effectiveness, and leadership engagement activities all provide information that can be used to strengthen controls before an injury occurs.

The goal is not to collect more data. The goal is to use data more effectively. The best safety programs use performance measures to inform decisions, reinforce desired behaviors, improve accountability, and continuously strengthen the systems that protect employees.

Questions that Matter

How many days has it been since the last injury? That is a lagging indicator. Lagging indicators are important measures of performance, accountability, and business outcomes. Leading indicators provide insight into how effectively risks are being managed.

The most effective safety metrics do more than track results. They drive conversations, influence decisions, and focus attention on hazard identification, employee engagement, corrective action management, and the effectiveness of risk controls. When used effectively, safety data becomes more than a scorecard. It helps to establish OHS objectives that focus on a more important question: Are the systems, controls, and behaviors working effectively to prevent injuries and support reliable business performance?

HEAT STRESS COMPLIANCE IN THE GAP: MANAGING RISK WHILE FEDERAL RULEMAKING LAGS

Whitney A. Smith, *Certified Hazardous Materials Manager, Senior Consultant* — Little Rock, AR

Federal heat stress rulemaking may be lagging, but enforcement is not. The Occupational Safety and Health Administration (OSHA) continues to expand heat-related inspections through its National Emphasis Program (NEP) and General Duty Clause authority, while states are moving ahead with their own OSHA-approved State Plans and, in some cases, separate labor-law frameworks. Employers that rely on the absence of a federal standard as a reason to delay action face growing compliance, operational, and liability risks. Organizations that implement structured heat illness prevention programs now will be better positioned to protect workers and demonstrate due diligence regardless of future rulemaking outcomes.

Enforcement Is Moving Ahead of Rulemaking

OSHA has not finalized a federal heat standard. The agency published the proposed rule in 2024, held public hearings in 2025, and continues to move through the rulemaking process. Additional steps may occur before OSHA issues any final standard, and the final requirements may differ from the proposal. Enforcement activity, however, continues to advance. OSHA's revised NEP for Outdoor and Indoor Heat-Related Hazards, issued April 10, 2026, renews the agency's focus on heat-related inspections for an additional five years. The program targets 55 high-risk industries,

2022

2022 Initial Heat NEP

OSHA's original National Emphasis Program – Outdoor and Indoor Heat-Related Hazards was effective April 8, 2022. OSHA CPL 03-00-024 confirms the 2022 directive and its focus on water, rest, shade, training, and acclimatization.

2024

2024 Proposed Federal Heat Standard

OSHA published the proposed Heat Injury and Illness Prevention in Outdoor and Indoor Work Settings rule in the Federal Register on August 30, 2024.

2025

2025 Public Hearings

OSHA's public hearing on the proposed rule was held June 16 through July 2, 2025, and the post-hearing comment period ended October 30, 2025.

2026

2026 Revised Heat NEP

OSHA updated the Heat NEP effective April 10, 2026, focusing inspections and outreach on 55 high-risk industries and extending the program for five years.

including construction, agriculture, manufacturing, warehousing, transportation, retail, and food service. OSHA states that the NEP is intended to address heat-related workplace hazards through targeted inspections, program evaluations, and enforcement activities, while continuing to authorize programmed inspections in designated industries during periods covered by National Weather Service heat advisories and warnings (OSHA, 2026). Rather than emphasizing inspection volume targets, the revised directive focuses on evaluating employer heat illness prevention programs, clarifying enforcement criteria, and continuing targeted inspections during heat advisories and warnings (OSHA, 2026).

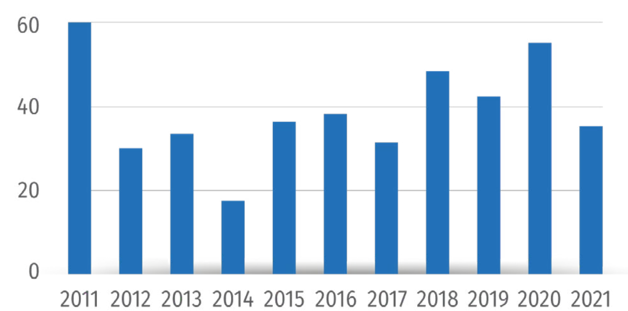
The enforcement mechanism itself has not changed. Without a heat-specific federal standard in effect, OSHA continues to cite heat-related hazards under Section 5(a)(1) of the Occupational Safety and Health Act, commonly known as the General Duty Clause. Heat-related inspections have accounted for approximately six percent of all federal OSHA inspections over the past five years, including both unprogrammed and programmed inspections (OSHA, 2026). Employers face an increasingly difficult challenge: OSHA continues to enforce heat-related hazards aggressively, but no federal heat standard establishes exactly what compliance looks like.

Several OSHA-approved State Plans, and some states acting through separate labor-law frameworks, have adopted heat-related requirements that impose prescriptive obligations beyond those currently enforced at the federal level. For employers, the message is clear: waiting for a final federal rule before implementing a comprehensive heat stress management program is a risky strategy. Enforcement is already here.

The Real Cost of Heat Stress

Heat-related incidents can result in lost productivity, increased workers' compensation costs, operational disruptions, employee turnover, litigation exposure, and reputational damage. The financial exposure begins before an incident becomes catastrophic: heat-related productivity losses in the United States have been estimated at nearly $100 billion per year, and a single heat-related illness can cost an employer approximately $80,000 when medical treatment, workers' compensation, lost time, and productivity impacts are considered. Regulatory penalties can compound those costs. In one December 2024 enforcement action, Cal/OSHA issued more than $276,000 in penalties for alleged heat illness prevention violations even though the matter did not involve a catastrophic injury. Functional heat illness prevention programs better position organizations to maintain workforce reliability, reduce incident rates, control avoidable costs, and demonstrate due diligence during regulatory inspections.

Figure 1. Number of work-related deaths from exposure to environmental heat, 2011-21



Source: U.S. Bureau of Labor Statistics

U.S. Bureau of Labor Statistics (BLS) data attribute 48 worker deaths to environmental heat exposure in 2024 and approximately 7,100 nonfatal cases involving days away from work, job restriction, or transfer across 2023 and 2024 (BLS, 2026). Those figures tell two important stories. Fatalities show that heat exposure remains a severe occupational hazard, while nonfatal cases show the broader operational burden employers face when heat illness leads to lost work time, restricted duty, or job transfer. Even these figures likely understate the true burden because heat exposure can contribute to injuries, cardiovascular events, and other workplace incidents classified under separate causes (Gubernot, Anderson, and Hunting, 2015).

While environmental conditions often receive the greatest attention, the factors that determine whether a worker experiences discomfort, illness, or a medical emergency frequently extend beyond temperature and humidity. Work pace, compensation structures that discourage breaks, staffing models that interrupt acclimatization, recent absences from hot work, and lone-worker assignments that delay intervention can all increase risk. Organizations that evaluate heat risk solely through environmental measurements may overlook important operational factors that affect how workers experience heat exposure.

Because unacclimatized workers appear to be at higher risk, employers should establish intentional acclimatization practices rather than relying on informal adjustment to hot conditions. A U.S. Centers for Disease Control and Prevention (CDC) review of OSHA heat-related fatality investigations found that many deaths involved workers who had not been acclimatized and that many employers lacked formal acclimatization programs (Tustin et al., 2018). This does not mean acclimatization is the only factor in preventing heat illness, but it is one of the most practical and defensible controls available to employers. Its prominence in OSHA's proposed heat standard, the revised NEP's program evaluation criteria, and existing state heat regulations reflects the growing expectation that employers address acclimatization as part of a broader heat illness prevention program.

Proposed Rule Requirements

Although federal rulemaking continues, the 2024 proposal remains the clearest public indication of the program elements OSHA may expect in a future heat standard. More importantly, many of those elements already align with how compliance officers evaluate employer programs under the NEP and the General Duty Clause. For employers looking to gauge likely expectations, the proposal offers more than a regulatory preview. It provides a practical framework for strengthening heat illness prevention programs today while final requirements remain unsettled.

The 2024 proposal would apply across general industry, construction, maritime, and agriculture, covering both indoor and outdoor work environments, subject to specified exceptions (OSHA, August 2024). Its structure is built around two environmental action levels. The initial heat trigger would begin at a heat index of 80°F or a wet bulb globe temperature (WBGT) equivalent to the National Institute for Occupational Safety and Health (NIOSH) Recommended Alert Limit. The high-heat trigger would begin at a heat index of 90°F or a WBGT equivalent to the NIOSH Recommended Exposure Limit (OSHA, August 2024). At the initial trigger, the proposal would require foundational elements of a heat illness prevention program, including access to cool drinking water, shaded or air-conditioned recovery areas, cooling measures for indoor workspaces, paid rest breaks as needed to prevent overheating, and acclimatization procedures for new employees and employees returning from extended absences (OSHA, August 2024). These are not novel concepts. They reflect controls that occupational health professionals have recognized for years as essential to preventing heat-related illness.

Figure 2

Trigger	Requirements
80°F Heat Index	Water, shade, acclimatization, breaks
90°F Heat Index	15-minute rest every 2 hours, monitoring, communication systems

Under the proposal, the high-heat trigger would shift the focus from prevention to active risk management. Employers would be required to provide paid rest breaks of at least 15 minutes every two hours, establish observation or communication systems for certain workers, issue daily hazard notifications, and apply heightened supervisory oversight for signs and symptoms of heat-related illness (OSHA, August 2024). Collectively, these measures recognize a reality often overlooked in workplace safety programs: when environmental conditions become severe, administrative controls must become more structured and deliberate.

The proposed operational requirements also include a Heat Injury and Illness Prevention Plan, which could be communicated verbally for employers with 10 or fewer employees. The proposal would call for employee involvement in program development, designation of a heat safety coordinator, site-specific control measures, emergency response procedures emphasizing rapid cooling, and enhanced training for workers and supervisors. For indoor environments expected to reach action levels, employers would also be required to establish a monitoring plan capable of identifying and measuring affected work areas (OSHA, August 2024).

The proposal is also instructive in identifying situations OSHA believes may not warrant extensive program requirements. Proposed exemptions include climate-controlled indoor environments, work activities with no reasonable expectation of trigger-level exposure, exposures lasting 15 minutes or less within a one-hour period, certain emergency response operations, and telework (OSHA, August 2024). For facilities that consistently maintain indoor temperatures below action levels through mechanical cooling, the proposal would provide a pathway to document those conditions rather than implement a full monitoring program. That distinction may prove particularly relevant for sectors such as data centers, advanced manufacturing, and other operations where environmental controls are integral to operations.

While the final form and timing of a federal standard remain pending, employers should not treat the 2024 proposal as a distant compliance exercise. Its core elements, including environmental triggers, acclimatization practices, written program structure, training expectations, and emergency response protocols, are rooted in longstanding occupational health guidance rather than novel regulatory theory. Specific provisions may change before any final rule is issued, but the underlying framework is unlikely to disappear. Employers that use the proposal as a roadmap for managing heat risk today will be better positioned regardless of when, or in what form, a final rule ultimately appears.

Heat Exposure Assessments: Moving Beyond the Weather Forecast

Heat stress is fundamentally an exposure assessment challenge before it becomes a compliance challenge, and this is where employer programs may fall short. Regulatory triggers and weather forecasts provide useful screening tools for outdoor activities, but neither captures the full complexity of occupational heat exposure. The heat index, for example, combines temperature and humidity but does not account for radiant heat, air movement, workload, or the impact of protective clothing. A weather app may indicate that outdoor conditions are uncomfortably hot. Determining whether those conditions are hazardous for a specific task requires a more sophisticated assessment (NIOSH, 2016).

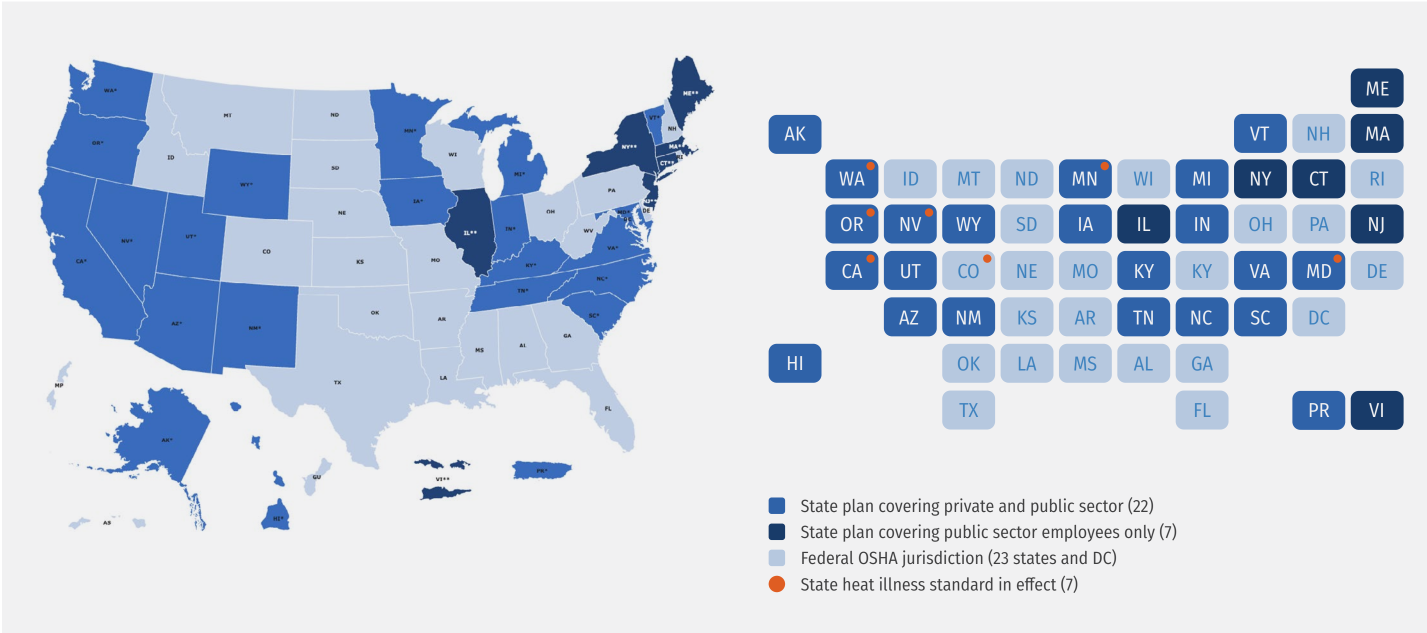
This is why industrial hygienists continue to rely on WBGT as the preferred evaluation metric. Unlike the heat index, WBGT incorporates the combined effects of temperature, humidity, solar radiation, and air movement, allowing exposure to be evaluated in the context of actual working conditions (NIOSH, 2016). The distinction is critical. A task that appears manageable based on ambient conditions alone may present a significant heat burden once physical exertion, radiant heat sources, or restrictive clothing are considered.

Both NIOSH and the American Conference of Governmental Industrial Hygienists (ACGIH) base their heat stress frameworks on this principle. The NIOSH Criteria Document, Occupational Exposure to Heat and Hot Environments, establishes Recommended Alert Limits and Recommended Exposure Limits that become more protective as workload increases (NIOSH, 2016).

A defensible exposure assessment therefore requires more than measuring air temperature. At a minimum, employers should evaluate four factors: task-specific WBGT, metabolic workload, clothing-related heat burden, and consider the acclimatization status of exposed employees. Where screening criteria are exceeded, physiological indicators such as heart rate recovery, hydration status, and other measures of heat strain help distinguish environmental exposure-driven heat stress from an individual's physiological response (NIOSH, 2016; ACGIH, 2026).

The fatality data reinforce the importance of disciplined heat stress management, but heat tolerance is not uniform across a workforce. Personal physiology, medications, age, fitness, acclimatization status,

Figures 3 & 4. OSHA State Plan Maps Showing Jurisdictions With OSHA-Approved State Plans



Source: osha.gov/stateplans

underlying health conditions, clothing, and workload can all affect how an individual responds to the same environmental conditions. For that reason, a defensible program cannot rely on action levels alone. Employers still need processes that allow employees to report symptoms, request additional recovery time, and receive reasonable accommodations based on individual tolerance, even when regulatory thresholds have not clearly been exceeded. Organizations rarely fail because they do not understand the concept of heat illness protection. They fail because the process is informal, inconsistent, and undocumented. From both a risk management and enforcement perspective, a formal, and ideally documented, heat illness protection program may represent the clearest line between a defensible heat stress management program and an informal approach that cannot be verified during an inspection.

The Expanding Patchwork of State Heat Regulations

While the federal standard remains unresolved, state heat requirements continue to expand. For multi-state employers, the challenge is no longer preparing for a future federal rule alone; it is managing a patchwork of existing requirements that differ in scope, trigger points, and program expectations (OSHA, 2026).

California has been the pacesetter for two decades. Its outdoor heat illness prevention standard (Title 8, Section 3395) has been in effect since 2005, requiring controls beginning at 80°F and enhanced high-heat procedures at 95°F. In July 2024, California extended that approach indoors, establishing trigger temperatures of 82°F and escalating requirements at 87°F (California Code of Regulations, §§ 3395, 3396). Other OSHA-approved State Plans, including Maryland, Minnesota, and Nevada, have adopted heat-related requirements that vary by scope, trigger point, and program structure. Maryland's standard, effective September 2024, applies to both indoor and outdoor workplaces beginning at a heat index of 80°F (Maryland Occupational Safety and Health, COMAR 09.12.32); Minnesota regulates indoor heat through workload-based temperature limits; and Nevada's 2025 regulation requires written heat illness prevention programs and job hazard analyses where employees are exposed to heat illness hazards (OSHA, 2026).

Together these standards reveal a broader trend. Although specific trigger values and program details vary, regulators are increasingly aligning around a common framework built on environmental monitoring, acclimatization, access to water and recovery areas, employee training, emergency response planning, and documented prevention programs. The debate is increasingly about implementation details rather than whether heat illness prevention programs are necessary.

The revised NEP introduces an additional compliance consideration. OSHA-approved State Plans were required to notify federal OSHA by June 2026 whether they would adopt the revised directive, maintain an equivalent enforcement policy, or decline participation (OSHA, 2026). For employers operating across multiple jurisdictions, this creates the potential for further variation in both enforcement priorities and compliance expectations.

The practical solution for employers is to create a corporate standard, not build separate programs for every state. Organizations generally achieve better outcomes by developing a corporate

heat illness prevention program aligned with the most stringent applicable requirements and then supplementing it with jurisdiction-specific provisions where necessary. In practice, the organizations most prepared for a future federal standard are often the ones already managing to the highest existing state requirements. Regardless of what eventually emerges from the federal rulemaking process, that strategy is unlikely to require substantial revision.

A Defensible Heat Illness Prevention Framework

A heat program that can withstand OSHA scrutiny today and align with future federal expectations should include:

- Formal Heat Illness Prevention Plan with site-specific procedures and a designated program administrator
- Environmental Monitoring tied to defined action levels, using WBGT where feasible and heat index as a screening tool
- Accessible Drinking Water available near work areas, with active hydration practices and sufficient supply for exposed workers
- Recovery Areas that are shaded or air-conditioned, easily accessible, and available without discouraging employee use
- Acclimatization Procedures for new hires, temporary workers, contractors, and employees returning from extended absences
- Emergency Response Protocols focused on rapid cooling and timely medical intervention for suspected heat-related illnesses
- Employee and Supervisor Training covering heat illness symptoms, risk factors, prevention measures, and emergency response procedures
- Program Documentation including monitoring data, training records, acclimatization schedules, corrective actions, and incident investigations

Where Heat Programs Commonly Break Down

A heat illness prevention program is most defensible when it works the same way in practice that it is described on paper. Two areas often determine whether that happens:

- **Defined Triggers and Clear Accountability:** Identify who monitors heat conditions, what measurement method will be used, when controls must be activated, and how those decisions will be documented. This keeps the program from depending on informal judgment during high-risk conditions.
- **Consistent Coverage for All Exposed Workers:** Confirm that temporary workers, contractors, new hires, reassigned employees, and employees returning from extended absences are covered by the same heat stress controls, acclimatization practices, training, and emergency response procedures as regular employees.

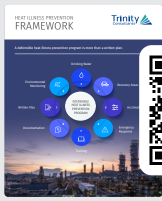
Why These Elements Matter

These program components closely align with OSHA's current NEP, the 2024 proposed federal heat standard, NIOSH recommendations, and the ACGIH heat stress framework. Together, they provide employers with a practical roadmap for demonstrating due diligence, managing heat-related risks, and defending their programs during regulatory inspections.

How Trinity Can Help

Heat stress compliance is no longer a future rulemaking issue. OSHA's current enforcement approach, the proposed federal standard, longstanding NIOSH recommendations, ACGIH heat stress guidance, and existing state heat standards all point to the same basic expectation: employers need a structured, documented program that works in practice.

Scan the QR Code for a printable Heat Illness Prevention Framework poster!



Navigating the gap between active enforcement, evolving regulation and risk mitigation requires more than compliance tracking. It requires a defensible, risk-based approach grounded in occupational health science and practical operational realities. Trinity Consultants helps organizations evaluate current heat stress risks, identify gaps in existing programs, and develop practical heat illness prevention strategies that fit real operating conditions.

Trinity has supported clients through numerous regulatory transitions, helping organizations interpret emerging requirements, conduct exposure assessments, implement prevention programs, and develop defensible compliance strategies. Our multidisciplinary team combines industrial hygiene, occupational health, engineering, and regulatory expertise to deliver practical solutions tailored to operational realities.

Trinity Consultants supports organizations with:

- Heat stress exposure assessments using WBGT monitoring and workload evaluation
- Heat illness prevention program development and benchmarking
- Acclimatization program design and implementation support
- Multi-state regulatory compliance evaluations
- Industrial hygiene monitoring and data interpretation
- Employee and supervisor heat stress training
- Incident investigations and regulatory response support

Trinity's industrial hygiene, occupational health, and environmental, health, and safety professionals have assisted clients across manufacturing, construction, energy, chemical processing, warehousing, transportation, and other heat-exposed industries in developing practical programs that reduce risk and keep employees safe while supporting operational objectives.

Organizations that invest today in exposure assessment, acclimatization, training, emergency response planning, and program documentation will be better positioned to protect workers, reduce liability, and demonstrate compliance regardless of when a final federal standard is published.

Whether your organization is evaluating current heat stress risks, developing a new heat illness prevention program, or preparing for future regulatory changes, Trinity Consultants can help. Our occupational health and industrial hygiene professionals provide practical, science-based solutions that support compliance, reduce risk, and improve worker protection.

HUMAN FACTORS AND THEIR OPTIMIZATION – REDUCING HUMAN ERROR

William Bridges, *Technical Director, Process Improvement Institute* — Knoxville, TN

Introduction

All accidents (except some from natural phenomena) result from human error. This is because humans govern and accomplish all of the activities necessary to control the risk of accidents. Not only do humans cause accidents (unintentionally) by making errors directly related to the process itself, but they also cause errors by creating deficiencies in the design and the implementation of management systems (we make errors in authorities, feedback, proof documents, and continual improvement provisions, etc.) Ultimately, these management systems govern the human error rate directly contacting or directly influencing the process.

The U.S. Chemical Safety Board (CSB) cites human factor deficiencies as one of the main contributors of all catastrophic accidents. Nearly all the causes and root causes of major accidents in the past 40 years have been the result of poor control of human factors.

OSHA's Process Safety Management (PSM) system lacks fundamental human factor elements and implementation guides. The Risk Based Process Safety industry guideline from CCPS/AIChE (2007) contains nearly all of these human factor requirements.

Definitions for use in this article:

- **Human Error** are those made during direct interface or direct influence of the process
- **Human Factors** are those aspects of the process and related systems that make it more or less likely for humans to make a mistake
- **Management systems** are the administrative controls an organization puts in place to manage the people and workflow related to the process under consideration, and so these inherently attempt to control human factors

Note that there is confusion in terms across the industry. In occupational safety, the terms unsafe act and unsafe condition are commonly used; these terms have been in use for more than 80 years. It is best to drop these terms in favor of the terms human error, component failures, and natural phenomena; doing so will allow all problems within an organization to be grouped together.

Some believe a “lack of awareness of the risk” causes these errors, but in actual practice the worker who commits an intentional error is normally well aware of the risk. They instead believe they know a better way to accomplish a task, or they believe there are already too many layers of protection (so bypassing one layer will not cause any harm).

Errors can be unintentional or intentional (errors in judgment). Regardless of type or category of human error, the organization can and should exert considerable control of the errors.

Statistical Limits of Control of Human Error Rates

Not all errors can be prevented. It is important to understand that with excellent control of all of the human factors a company can begin to approach the lower limits that have been observed for human error.

Error Probability for Initiating Actions: The values below are the lower limits for human error rates, a*ssuming excellent control of human factors*; these are expressed as the probability of making a mistake on any step:

- 1/100: process industry; routine tasks performed 1/week to 1/day.
- 1/200: pilots in the airline industry; routine tasks performed multiple times a day with excellent control of human factors. T*his average has been measured by a few airlines, but for obvious reasons they do not like to report this statistic.*
- 1/1000: for a reflex (hard-wired) action. *This is about the rate of running a stop sign or stop light, given no one is in front of you at the intersection.*

Coupled Error Rates: This is the probability of repeating an error, i.e., performing a second task wrong after the first task (the same task or one with the same goal) was done wrong:

- 1/20 to 1/10: if the same tasks are separated in time and if visual cues are not present to re-enforce the mistake path
- 9/10: if same tasks performed back-to-back by the same person and strong visual cue is present
- Two or more people become the same as one person (with respect to counting errors from the group), if people are working together for more than three days; this is due to the trust that can rapidly build

Response actions (time driven): This is the probability that the correct action will Not be completed within the time necessary (and after that time, the correction action will not help).

- 1/10: if practiced/drilled once per year and if there is always sufficient time, theoretically, to accomplish the response task
- 1/100: if practiced/drilled once per week and there is sufficient time to accomplish response task

Adjusting the lower limit rates to estimate a baseline rate at a site: As mentioned earlier, the lower limit rates assume excellent (but not perfect) control of human factors in the industry mentioned. Excellent control of human factors is not achieved in most organizations. Human error rates will be higher than the lower limit, perhaps as much as 20 times higher. Table 1 on the next page list the human factors, except for dependent or coupled errors mentioned above.

Table 1. Summary Table of Human Factor Categories (copyright PII/TC, 2003-2026)

Based in part on: Gertman, D.; Blackman, H.; Marble, J.; Byers, J. and Smith, C., The SPAR-H Human Reliability Analysis Method, NUREG/CR-6883, U.S. Nuclear Regulatory Commission, August 2005. PII/TC has modified the list slightly to account for general industry data and terminology and to incorporate PII internal data. Note that the right column is Not %, but rather is the multiplier of the baseline human error rate or probability, given the Human Factor issue/level in the middle column.

Human Factor Category	Human Factor Issue/Level	Multiplier Error Rates
Available Time (includes staffing issues) - for responses only	Inadequate time	$P_{failure}$=100%
	Barely adequate time (≈2/3 x nominal)	10
	Nominal time (1x what is expected)	1
	Extra time (> 2 x nominal and > 20 min)	0.5 to 0.1
Stress/Stressors (includes staffing issues)	Extreme stress (threat stress; unloading ship with crane non-stop for more than 2 hours; imminent hazard nearby)	5
	High stress (time pressures such as during a maintenance outage: issues at home)	2
	Nominal	1
Complexity & Task Design	Highly complex task. Or very low complexity/boring task that requires 100% attention for more than 45 min	5
	Moderately complex (requires more than one staff)	2
	Nominal	1
	Obvious diagnosis	0.2
Experience/Training (practice rate is key)	Low experience relative to complexity of task; or poor/no training	10
	Nominal	1
	High	0.5
Procedures	Not available in the field as a reference but should be. Or 75% accuracy or less (normal value for process industry)	20
	Incomplete; missing this task or these steps; or < 85% accuracy	8
	Available and >90% accurate, but does not follow format rules	3
	Good, 95% accurate, follows >90% of format rules	1
Human-Machine Interface (includes tools)	Missing/Misleading (violates populational stereotype; such as round valve handle is facing away from worker)	20
	Poor or hard to find the right device; in the head calculation	10
	Some unclear labels or displays	2
	Good	1
Fitness for Duty	Unfit (extreme fatigue level at >80 hrs/wk, or >17 hr/day, no day off in 7-day period; or illness, intoxicated, etc.)	20
	Highly degraded fitness (high fatigue such as >15 hr/day or >72 hr/wk, or more than 4 consecutive shifts of 12 hours or more; illness, injury, etc.)	10
	Moderately degraded fitness (≥12 hr day or ≥60 hours/wk; but at least 1 day off [break] per week)	5
	Slight fatigue (more than 8 hr per day, up to 48 hrs per work week, but at least 1 day off [break] after 48 hours of work (normal value for process industry)	2
	Nominal	1
Work Processes & Supervision	Poor	2
	Nominal	1
	Good	0.8
Work Environment	Extreme (in temp, humidity, noise, lighting, vibration, etc.)	5
	Good	1
Communication	Communication system/interference or damaged; poor communication environment	10
	No standard for verbal communication rules (normal value for process industry); use this value if coordinated task for response	3
	Well implemented and practiced standard	1

Optimizing Human Factors

At last count there were more than 300 non-governmental standards (such as from ANSI, ISO, IEEE, etc.) for the control of human factors, and there are more than 100 government regulations and standards and guidelines. Some human factors are more important than others:

- 90% of accidents had at least one root cause related to deficiencies in written work instructions
- 50% of accidents had at least one root cause related to miscommunication between workers or between workers and supervisors
- 50% of accidents had at least one root cause related to excessive fatigue of the worker

Available Time for the Task

The available time for the task refers to the time the task is expected to be completed. For mistakes related to responses to alarm, the time is the most critical parameter, since failure to complete the response in time can lead to some consequence, such as a process shutdown or worse.

The worst enemy for quality of performance is hurry. Operating under tight deadlines and trying to achieve unrealistic metrics increases the *level of pressure to complete work*.

Task design is directly linked with this category. Process design, procedure development and worker scheduling need to take into consideration not only the time it takes to complete each task but also the time it takes to manage usual as well as potentially unusual or unexpected situations.

Stress/Stressors

Work Stress refers to the emotional response that arises when work demands exceed the person's capacity and capability to cope. Staffing levels directly impact this human factor. An adequately staffed organization ensures that personnel are available with the proper qualifications for both planned and foreseeable unplanned activities.

Complexity and Task Design

The risk of errors due to poor task design relates to the definition of tasks and the interactions among multiple work members, between the work members and equipment and systems, and between different work groups.

As the volume of systems, variety, integration and coupling increases, so does the inherent complexity of the environment and tasks. Tasks should be designed considering human limits, since it is more likely to be accomplished that way than if one assumes humans can and will "always" do what is supposed to be done correctly. For instance, a worker cannot be expected to do a boring task more than 30-45 minutes at a time; after that, statistics show that worker error rates increase rapidly due to daydreaming.

Experience/Training

Training refers to the process of workers developing an accurate mental model of the process system so they can perform the assigned tasks correctly, diagnose process upsets properly and quickly, and understand the consequences of their actions. The only way such mental models can be built is for operators to be thoroughly trained not only in *what/how* to do something but also in why to do it. Hands-on training is key. Workers should be required to demonstrate their proficiency (via tests, talk-troughs, etc.) before being allowed to work independently. Training must be reinforced with periodic drills so workers can practice and perfect their skills. If certain tasks are performed frequently, proficiency re-training may be unnecessary.

Operating and Maintenance Procedures (The #1 Most Likely Reason for Human Error Currently)

Procedures are written instructions for performing a task. Procedure-related errors are errors that occur because some characteristic of the written instructions causes task performance to fail. ***This is currently the most critical human factor at most sites since 90% of accidents have at least one root cause related to mistakes within procedures.*** Reducing these procedure deficiencies can reduce human error rates by a factor of 2 to 20.

Accurate and well written procedures reduce the likelihood of human errors when a task is complex or performed infrequently; even the most experienced workers may forget the steps required or

the order in which certain steps must be performed. Data from more than 50 sites has shown that when the procedures are written in the wrong language (engineering language instead of operator language) or when the written steps are less than 75% accurate, the operators stop referring to the written procedures.

Scan the QR code to see the paper for the best practice rules for developing operating and maintenance procedures (and other work-instructions/procedures).

To develop accurate and useful procedures:

- **Have the worker write the procedure (with consultation with technical staff as necessary).** Development of technically accurate and usable procedures is enhanced by the authorship of the user. They will inherently write in the language used by the other users of the procedure. However, they will need help in the form of training on how to write procedures and they will need access to computers.
- **Have a writer's guide** with rules that will provide information to procedure writers regarding techniques for formatting procedures, presenting different types of content (e.g., action and decision steps), and for developing usable graphics. If a writer's guide is not followed or it is incomplete, the resulting procedures may not reduce errors as much as possible.
- **Have other users validate the procedures.** This must be accomplished by a walk down during mock use; simply reading at a desk will not find the errors left by the author.
- **Have the procedure reviewed by technical staff.** Procedure verification is a process that provides a final check on the technical accuracy of the procedure steps and on the procedure's compliance with writers' guide requirements.

Human-Machine Interface

Human-machine interface errors is the 4th most likely cause of human error in any complex system. The *human-system interface* (HSI) is defined as the technology through which personnel interact with plant systems to perform their functions and tasks. The major types of HSIs include alarms, information systems and control systems, device labeling, color coding, and error proofing.

Computer-based control systems can dramatically improve the quality, productivity and safety of chemical processes. However, they are not immune to human errors. Programming errors and erroneous operator inputs account for about 40% of the observed failures of computer-based control systems.

Sources of HSI standards: The U.S. Nuclear Regulatory Commission (NRC) has promulgated a number standards and guides related to human system interface and other human factor engineering aspects; these apply to plants and control rooms. There are hundreds of non-governmental standards on human factors and about a hundred U.S. (only) government standards on human factors; many of these focus on human system interface issues.

Fitness for Duty (The #2 Most Likely Reason for Human Error Currently)

Successful task performance requires that the capabilities workers bring to the task fall within an expected range. Impairment or a reduction in an individual's mental or physical capabilities due to substance abuse, **fatigue**, illness, stress or physical limitation (such as weakness following an injury or color blindness) increases the likelihood of errors.

Many companies have a program to guard against fitness-for-duty issues related to substance abuse, shift rotation, number of hours worked, and illness; but some do not. Regardless of existence of a program within a company, most companies do not train supervisors how to identify and correct fitness-for-duty issues.

The aspect most commonly lacking is control of fatigue (or normally, lack of enforcement of the company standards for control of fatigue). According to the aviation and marine industries that have studied fatigue intensively, the overall relationship for fatigue can be expressed as:

Fatigue = function of [(cumulative fatigue) + (shift work fatigue – breaks) - naps]

Most chemical process operations do not allow naps (and have likely never thought of the use of naps) to limit the effect of fatigue. Instead, the hours worked are consecutive and sometimes quite long.

What to do?

- **Implement a company fitness-for-duty program** with a primary responsibility for detecting and preventing impaired personnel from performing tasks that may affect productivity and safety.
- **Overtime Policies and Practices** which establish limits for work hours to reduce on-the-job fatigue and the potential consequences for poor task performance.

Work Processes and Supervision

Supervision is the process by which work is directed and overseen by first-line management. Successful supervision requires a combination of leadership skills and technical competence. Supervision differs from peer checking or quality control because a supervisor has line management responsibility for the worker(s) as well as responsibility for the work activity.

Work Environment

The work environment refers to the physical conditions in which work is performed. Environmental conditions that can affect performance include excessive vibration and noise, temperature extremes, and insufficient lighting. These adverse environmental conditions can stress personnel, interfere with performance, and increase the likelihood that they will commit errors while performing a task. Work conditions that require protective gear, such as high radiation or some confined space environments, or that requires unusual physical postures, also can interfere with task performance, as may poor housekeeping.

Communication (The #3 Most Likely Reason for Human Error Currently)

Communication is the exchange of information while preparing for or performing work. Verbal communication occurs face-to-face, by telephone, hand radios, as well as over public address systems. Written communication occurs, for example, through policies, standards, work packages, training materials and e-mail.

Verbal communication involves two sets of activities: (1) creating and sending messages and (2) receiving and interpreting them. Communication always involves at least two individuals, the sender and the receiver, and occurs between individuals, within and among work groups, in meetings, in pre-job or pre-evolution briefings, and during shift turnover.

Shift handover is another critical aspect of communication.
The status of equipment, repairs that occurred, problems faced, upcoming chores, etc., are all key information the oncoming worker will need to know. One good guide on shift turnover is U.S. DOE 1038-93.

Concept for Sustainable Control of Human Error

The first step is always to assess the risk and understand what layers of protection a system needs. This is done with methods such as HAZOP, What-If, job safety analysis (JSA), and reliability centered maintenance (RCM) analysis. From this information, the process design and task designs are influenced.

Next, the human factors described in this paper must be optimized to control human error rates so that the prevention of initiating events and success of layers of protection give the targeted risk control. This paper gave some advice, but you may want to get a much deeper background on human factors to reduce your trial and error. We suggest you start with the papers at the QR codes below:

ARTICLE 1
Human Factors and their Optimization

ARTICLE 2
Human Factors Elements Missing from Process Safety Management (PSM) Systems

Although not the focus of this paper, you will also need to get very high reporting rates for near misses to learn quickly (and for low expense) where your systems are weak in controlling human error.

Of course, all of this will take a great deal of work, but the alternative is to allow human error rates to continue at the present level. Implementing the solutions mentioned in this paper can reduce losses by >95% and greatly reduce the number and severity of accidents (perhaps by >90%).

For more information, please contact William Bridges or visit his bio page below:

William Bridges
Technical Director,
Process Improvement Institute

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New Acquisitions

Trinity Consultants Aquires Verux

We are excited to announce the acquisition of Verux, a Sacramento-based consultancy with specialized expertise in stormwater compliance, construction management and Water Pollution Control Manager (WPCM) training. The company will operate within Trinity's environmental consulting practice, combining the capabilities of Trinity and Verux into one unified entity.

Since its inception in 2010, Verux has cemented its reputation for assisting contractors, agencies, municipalities and developers as they navigate an increasingly complex stormwater compliance and construction management landscape. With solutions that include program development and permitting, site monitoring and inspections, stormwater sampling and analysis, and WPCM training, Verux helps clients comply with federal, state and Caltrans regulations, improve water quality, and mitigate environmental impacts.

Verux's leadership team, led by Bob Shults and Ben Rau, will play a key role in Trinity's environmental consulting practice. The team will continue to operate from its corporate headquarters in Sacramento and regional offices throughout California.

"We're excited to join a global organization that will amplify our strengths and preserve the guiding principles that have always made us great," Shults said. "This partnership creates meaningful opportunities to broaden our technical expertise, extend our geographic footprint, and deliver greater value to clients in California and beyond."

This acquisition builds on Trinity's 50-year history of strategic growth, bringing new capabilities and expertise to clients while enhancing the firm's ability to deliver safe, reliable and efficient industrial operations.

EXPOSURE BLINDSPOTS: WHY IH IS BECOMING A STRATEGIC PRIORITY IN CHEMICAL AND REFINING

Kelly Lanz, Certified Safety Professional (CSP), *Manager of Industrial Hygiene Services, Chemical & Refining*

Regulatory agencies are examining exposure data gaps more closely than they have historically. As the regulatory landscape shifts, occupational exposure limits are changing, and so is scrutiny of over-the-fence exposures, bringing the impact closer to the workers inside the facility. Chemical and refining facilities may still be making workforce protection decisions based on outdated monitoring data that was collected under operational conditions that no longer exist.

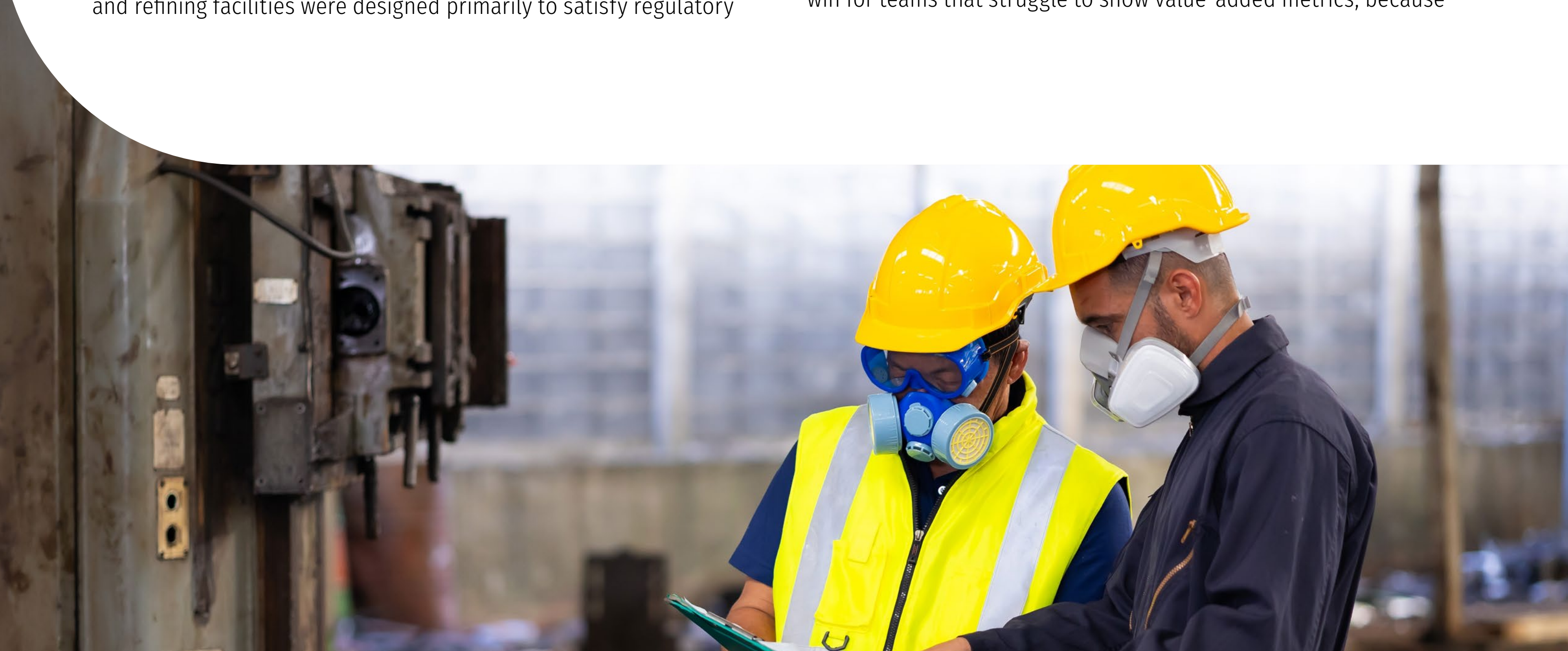
The gap between what facilities assume about worker exposure and what is happening on the floor tends to widen quietly, without the single dramatic failure that would make headlines. For EHS leaders and plant management, this gap is increasingly difficult to defend to regulators as well as a workforce asking more direct questions about what they might be exposed to.

This article looks at why industrial hygiene is moving from a compliance checkbox to a strategic priority in chemical and refining, and what it takes for a program to keep up.

The Compliance Checkbox Era Is Over

For the past 50 years, industrial hygiene programs at chemical and refining facilities were designed primarily to satisfy regulatory minimums. Facilities conducted baseline monitoring, documented exposure assessments, and updated programs when OSHA issued a new standard or when an incident triggered a closer look. Between those events, programs remained largely unchanged. The model worked as long as regulatory expectations were stable and enforcement was predictable. Today, with the regulatory landscape shifting faster than it used to, neither condition holds.

OSHA acknowledges that many of its permissible exposure limits (PELs) are outdated; most were adopted in 1971 and never updated. Therefore, it relies frequently on external organizations like the American Industrial Hygiene Association (AIHA), the American Conference of Governmental Industrial Hygienists (ACGIH), and the National Institute for Occupational Safety and Health (NIOSH) to define what constitutes a recognized hazard under the general duty clause. Enforcement actions driven by programmed inspections, rather than by incidents, aim to verify that monitoring is performed at an adequate frequency, that industrial hygiene assessment scope and coverage are sufficient, and that programs accurately reflect current operations. The upside to this shift is that reviewing documentation before an incident turns exposure management into a leading indicator rather than a lagging one. This is a meaningful win for teams that struggle to show value-added metrics, because



the avoided risk can be quantified. The obstacle is that many facilities are not staffed or organized for the front-end work required to understand if their current programs are sufficient to stand up to an inspection.

Beyond regulation, the business case has also changed. Workers' compensation costs tied to an occupational illness, litigation exposure from latent disease claims, and reputational risk in an era of workforce transparency are placing industrial hygiene programs under a higher degree of scrutiny. It is no longer enough to have a program on paper; EHS leaders are increasingly asked to show that it reflects how the facility operates today.

Regulators are already acting on these gaps. In 2020, OSHA cited Cleveland Brothers, a Pennsylvania machining and chrome-plating operation doing business as CB HYMAC, for overexposing workers to hexavalent chromium fumes, with $280,874 in proposed penalties across one willful and 18 serious violations. The case did not stem from a dramatic accident. It began with a complaint of overexposure and turned up basic program failures: no training on the hazard, and no respiratory protection program. Those are the kind of gaps that build quietly in an exposure program until an inspection or an illness brings them to light.

Four Blindspots Where Programs Commonly Fall Short

Industrial hygiene programs rarely fail in a single dramatic moment. More often they drift out of step with how the plant actively runs, through small gaps that pile up over the years. In the chemical and refining sectors, there are four categories where gaps appear most frequently.

Aging Monitoring Data

The most common vulnerability in legacy industrial hygiene programs is monitoring data that no longer reflects current operating conditions. For many facilities, the foundational exposure assessments were conducted during startup or initial permitting, sometimes fifteen or twenty years ago, and have never been formally revisited.

A great deal can change over decades of operations: production throughput climbs, feedstocks shift, unit operations are modified or expanded, control technology comes and goes, and work practices evolve informally. Each of these changes can alter the exposure profile for workers, but without a robust Management of Change (MOC) program that incorporates industrial hygiene, none of them automatically triggers a new exposure assessment.

The result is that a facility keeps drawing exposure conclusions from data that no longer describes how it operates. When asked whether monitoring data reflects current conditions, the answer should not be "we don't know." That uncertainty is difficult to defend in an inspection or in litigation.

The best case can be almost as telling: monitoring that simply isn't happening, and when someone finally asks why, it turns out the chemical is no longer used on site. At one facility, acrylonitrile had been replaced with a lower-hazard substitute, but the monitoring program was never updated to match. The actual exposure risk was gone, yet it went unnoticed until an audit surfaced it, and it could easily have been written up as a major finding.

A practical starting point is a systematic review of monitoring record dates against a timeline of significant operational changes. Facilities that can document a deliberate process for triggering reassessments when operations change are in a stronger position than those relying on periodic, calendar-driven schedules alone.

Similar Exposure Group (SEG) Gaps

Similar Exposure Groups are the organizing framework of most modern industrial hygiene programs. The concept is straightforward: group workers with comparable exposures, monitor a representative sample, and apply the results to the broader group. When implemented well, SEG-based programs are efficient and defensible. When implemented poorly, they become a mechanism for systematically under-assessing entire populations.

The most common failure modes fall into a few recognizable patterns. SEGs are defined based on job titles rather than actual task-level exposure profiles, leading to heterogeneous groupings where the monitored worker bears little resemblance to others in the category. Contractors and maintenance personnel are usually excluded from SEG structures entirely, and during a major turnaround the contractor headcount can run several times the size of the permanent operating staff, so the largest at-risk population on site at that moment carries no formal exposure assessment at all. Consider the turnaround at an Illinois facility. The ammonia scrubber had no risk of employee exposure while in operation, but during the turnaround, the blower was LOTO for maintenance, and the residual vapors flowed backward through the non-operating scrubber into the atmosphere and sent two contractors to medical. There was no evaluation or plan for this temporary risk. SEGs are created during initial program development and may not be revisited as roles evolve.

For chemical and refining facilities with complex job structures and significant contractor workforces, SEG gaps represent one of the highest probability areas of regulatory exposure. A periodic SEG audit, comparing documented groupings against actual task observations, is among the highest-value investments an industrial hygiene program can make.

Process and Maintenance Gaps

Industrial hygiene programs tend to be strongest for routine operations. Most exposure management breaks down in the non-routine work: turnarounds, maintenance activities, contractor operations, and process modifications.

Turnarounds present a particular challenge. A major unit turnaround can compress months of high-hazard work into a four-to-six-week window, drawing in hundreds of contractors unfamiliar with site-specific hazards, running simultaneous hot work and confined space entry, and creating exposure scenarios that never occur under typical running operations. Yet in many facilities, industrial hygiene oversight during turnarounds consists primarily of contractor safety orientation and periodic air monitoring, without a structured pre-turnaround exposure assessment or a systematic process for capturing and retaining the monitoring data generated.

Maintenance work presents a parallel challenge. Work orders that involve process equipment entry, vessel cleaning, or catalyst handling generate exposures that may exceed routine operational levels by an order of magnitude but are rarely captured in standard monitoring programs because they occur infrequently and unpredictably.

Building industrial hygiene considerations into Management of Change (MOC) processes and work permit systems is the most effective structural intervention. When an IH review is built into the workflow itself, non-routine exposures get captured in the process, before they become undocumented legacy risks. The difficulty is recognizing which non-routine tasks carry real exposures before the work is underway.

Emerging and Cumulative Exposure Risks

Legacy industrial hygiene programs were built around hazards that were well understood and regulated when they were designed, and as the underlying science has advanced, the range of what a program needs to evaluate has widened well beyond those original boundaries.

Occupational noise-induced hearing loss is among the most prevalent occupational illness in the chemical and refining sectors. Many facilities have noise monitoring data that is decades old or hearing conservation programs whose enrollment does not fully match the population exposed above OSHA's 85 dBA action level (29 CFR 1910.95).

Heat stress is receiving renewed attention as climate conditions shift baseline ambient temperatures across industrial regions. Facilities that established heat illness prevention programs based on historical temperature patterns are finding that those assumptions no longer hold, and that workers performing physically demanding tasks in process areas face physiological heat stress loads that their programs were not designed to address. Facilities where heat was historically not a relevant risk find themselves without programs or procedures to manage it.

Chemical mixture exposures are perhaps the most technically challenging frontier. Most occupational exposure limits were established from single-substance studies. Workers in chemical and refining environments are routinely exposed to complex mixtures (process streams, reaction byproducts, cleaning agents, and catalyst materials) where additive or synergistic effects may produce health risks that no single-substance occupational exposure limit (OEL) adequately captures. The science supporting mixture toxicology is advancing, and regulatory guidance is beginning to reflect it.

The regulatory attention to cumulative dust disease is real. In July 2025, OSHA cited Brazilian Stone Design, a Georgia stone countertop fabricator, for exposing workers to respirable crystalline silica, with seven serious violations and $33,000 in penalties. Beyond the overexposure itself, inspectors found the shop had never conducted air monitoring, had not required or fit-tested respirators, and ran no effective hearing conservation program, several of the gaps described above surfacing in a single inspection.

Programs that have not revisited their scope as these risks evolved carry hidden gaps. What made sense when they were designed may no longer match what the data now shows.

From Compliance to Strategic Asset

Facilities making the most progress have moved past simply collecting more monitoring data. They have built industrial hygiene into operational decision-making, so exposure management functions as a continuous process rather than a periodic documentation exercise.

Several characteristics distinguish high-performing programs from legacy ones:

- Exposure data lives in the same systems as process safety and operations data. When a process change is proposed, the MOC process triggers an IH review alongside the process safety and environmental reviews.
- Similar Exposure Groups (SEGs) are defined and maintained based on task-level observations, not administrative job categories. SEG structures are reviewed both when roles change and on the required periodic schedule.
- The facility's own IH program owns contractor exposure. On-site oversight is planned and staffed, not delegated to the contractors' safety programs.
- Monitoring data is reviewed against current operating conditions on a defined cycle, and operational changes trigger formal exposure reassessment.
- Emerging risks (noise, heat, chemical mixtures) are evaluated against current science on a periodic basis, with program scope updated accordingly.

None of this requires specialized capability. It is simply what a robust program looks like: one that can show auditors, regulators, or workforce representatives that exposure management still reflects how the facility currently operates, no matter when the original assessments were written.

This defensibility carries direct business value. Facilities with well-maintained, current IH programs tend to face lower regulatory and litigation risk, and their workers' compensation costs tied to occupational illness run correspondingly lower. They are also better positioned to demonstrate good-faith compliance as enforcement attention increases across the chemical and refining sectors.

A Practical Path Forward

For EHS professionals who suspect their programs have drifted, the temptation is to fix everything at once. Broad, all-at-once modernization efforts quickly become overwhelming and tend to stall before they finish.

A more effective approach begins with a structured program gap assessment, a systematic comparison of current program elements against the four blindspot categories described in this article. The first pass aims for a prioritized risk picture rather than a comprehensive remediation plan. It ranks gaps by regulatory exposure and by the size of the population each one puts at risk, flagging those most likely to surface in an enforcement inspection or discovery request.

That assessment typically reveals that a small number of high-priority gaps (aging monitoring data in specific high-hazard work areas, undocumented contractor populations, noise program deficiencies) account for a disproportionate share of overall program risk. Addressing those gaps first produces both regulatory risk reduction and operational credibility. From there, the path forward involves building the structural integrations (MOC, permit systems, contractor oversight frameworks) that prevent new gaps from developing as the facility continues to evolve and to close newly identified gaps.

Industrial hygiene is a living practice, one that should be kept front of mind. The facilities that treat it as part of how they run the plant day to day, and keep it current with changing regulatory expectations, will be the ones ready when the scrutiny comes.

Stay tuned for a free webinar offering on this topic. Trinity Consultants brings over 50 years of experience to EHS programs across industries. Our Chemical Sector Services team of SMEs have an average of nearly 25 years of expertise that translates to a deep understanding of the industry's exposure sources and business practices. For more information on how we can help, please reach out to our team of experts for assistance at 800.229.6655.

VIRTUAL WORLDS, REAL IMPACT: USING DIGITAL TWINS TO SIMULATE EMISSION SCENARIOS

Leah Hachmeister, *Managing Consultant* — Chicago, IL
Jasmine Clairsaint, *Consultant* — Orlando, FL

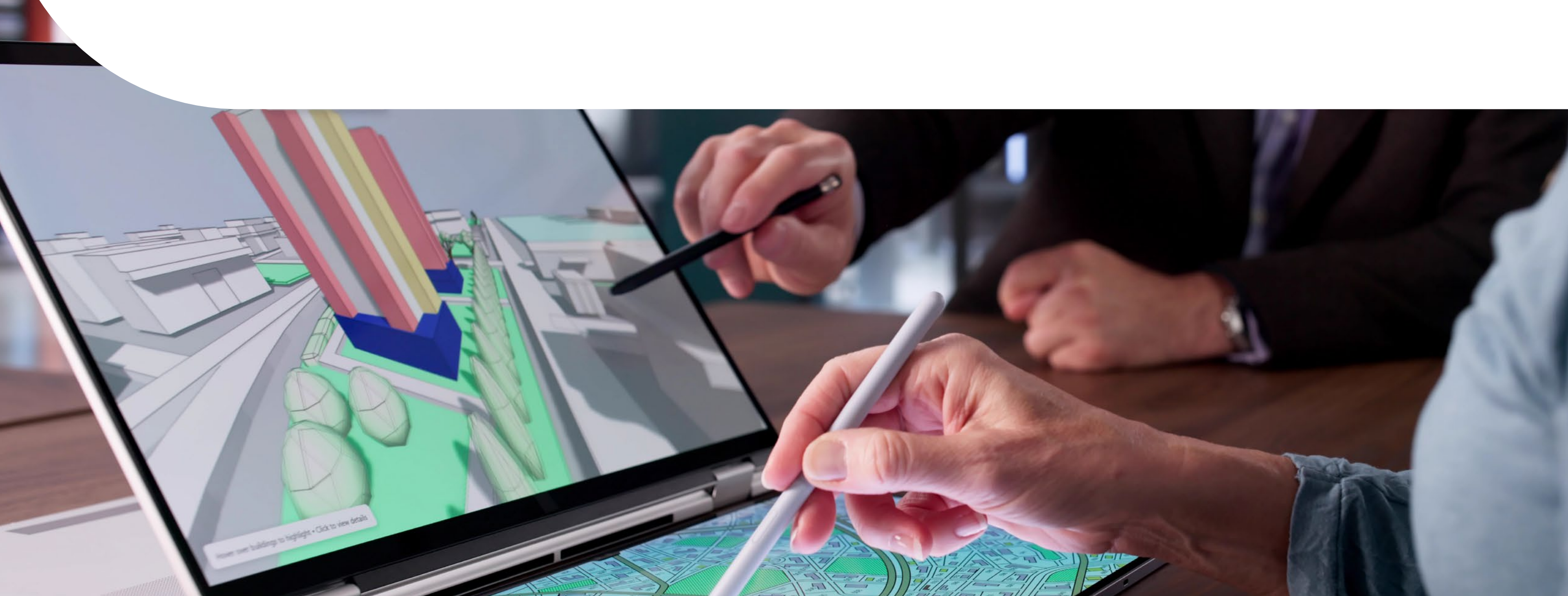
> Digital twins enable organizations to quantify the emissions impact of decisions before committing capital, changing operations, or affecting compliance.

Industrial operators across oil and gas, power generation, chemical, manufacturing and other sectors are under increasing pressure to manage emissions more precisely, more transparently, and at greater speed than legacy approaches allow. Changing regulatory requirements, voluntary emissions reduction commitments, and investor expectations have made emissions management increasingly complex and business-critical.

Yet many organizations continue to rely on static spreadsheets, manual data collection processes, and point-in-time calculations that provide only a retrospective view of emissions performance. These approaches often struggle to answer critical, forward-looking questions: *How will updated emission factors affect future emissions reporting? Which emissions reduction projects will deliver the greatest return on investment? What impact will a proposed regulatory change have on reported emissions and sustainability goals?*

This is where Trinity Consultants' Digital Solutions (DGS) team can help. By combining regulatory knowledge and digital solutions expertise with Environmental, Health and Safety (EHS) technology and structured emissions data, we help organizations move beyond historical reporting and begin using their environmental data to support proactive decision-making. As a trusted Cority implementation partner, Trinity helps organizations maximize the value of Cority's industry-leading EHS platform. Cority provides a unified environment for managing environmental, health, safety, quality, and sustainability data, creating the trusted foundation needed for advanced emissions analysis and decision support.

When implemented within EHS management platforms such as Cority, digital twins provide a secure, auditable environment for scenario analysis. Organizations can assess the impacts of regulatory changes, alternative calculation methodologies, operational modifications, and emissions reduction initiatives before making real-world decisions.



This article introduces the role of digital twins in emissions management and highlights three client case studies that demonstrate how these capabilities can help organizations reduce uncertainty, improve decision-making, and achieve measurable business and environmental outcomes.

What is a Digital Twin?

In the broadest sense, a digital twin is a virtual representation of a physical asset, system, or process. It relies on a combination of real operational data and synthetic assumptions, and it is used to monitor, simulate, and optimize in a low-risk environment separate from the physical system it mirrors.

In the context of emissions management, a digital twin is a configurable virtual model of a facility, process unit, or emission source that mirrors the structure, operating parameters, and regulatory relationships of its physical counterpart. It is not a one-time model or a static diagram. It is a living configuration within an EHS management system that ingests operational data, applies calculation logic, and generates outputs that can be compared, stress-tested, and updated on a continuous basis.

When Should Organizations Consider Digital Twins?

For many organizations, the need for a digital twin becomes apparent when environmental and operational teams begin asking questions that cannot be answered through traditional reporting and historical data analysis alone. Common examples include:

- *How will upcoming regulatory changes affect emissions, compliance obligations, or reporting outcomes?*
- *Can production increase without triggering permit modifications or compliance risks?*
- *Where should capital be invested to achieve the greatest emissions reduction?*
- *How will proposed operational or equipment changes impact emissions?*

These are types of questions for which digital twins can deliver significant value. By enabling organizations to simulate and evaluate potential outcomes before implementing changes, digital twins support more informed operational, regulatory, and investment decisions while reducing uncertainty and risk.

The following case studies illustrate how digital twins configured within Cority have been used to address real-world emissions management challenges, helping organizations proactively evaluate alternatives, quantify impacts, and make data-driven decisions with greater confidence.

CASE STUDY 1

Evaluating the Impact of Updated Emission Factors

Challenge

A client needed to understand how newly available engine stack test results would affect future emissions reporting and compliance. While the stack test data provided a more representative, site-specific emission factor for the engine, it was not immediately clear whether incorporating the new factor would materially influence reported emissions or compliance with permit and regulatory obligations.

Although the revised factor would only be applied prospectively and would not change previously submitted reports, the client wanted to understand what its effect would likely be on future emissions reporting, assuming operating patterns remained relatively consistent. Rather than waiting for future reporting cycles to reveal the outcome, the client sought a proactive, data-driven assessment.

Solution

Leveraging Cority, Trinity's DGS team created a virtual model of the engine using the new stack test results alongside historical operational data. The digital twin enabled the side-by-side comparison of emissions calculations using both the existing default emission factor and the newly derived stack test factor across a full year of historical operations.

Figure 1. Cority Portal Panel illustrating digital twin evaluation of future reporting and compliance impacts based on historical operating conditions

Note: To protect client confidentiality, all images are taken from a test environment and contain representative rather than client-specific data. The examples are intended solely to illustrate functionality and relative order-of-magnitude impacts.

While the analysis did not retroactively alter reported emissions, it used historical operating conditions as a baseline for expected future operations. By simulating how emissions would have been calculated under the new factor, the team quantified the likely impact on future reporting and evaluated how the revised factor could influence compliance outcomes if operating conditions remained generally consistent.

Result

The analysis demonstrated that the stack test-derived emission factor produced lower calculated emissions than the default factor. More importantly, it provided the client with a clear, defensible understanding of how future emissions reporting and compliance status could be affected by the updated factor.

Using historical operations as a predictive baseline, the client was able to:

- Quantify the expected impact of the new emission factor on future emissions reporting
- Evaluate potential compliance implications before incorporating the factor into ongoing calculations and reporting processes
- Support stakeholder discussions with a transparent, data-backed assessment of the change

By using a digital twin to evaluate the implications of updated emissions data before implementing the revised factor, the client transformed uncertainty into insight, gaining confidence in both future reporting outcomes and compliance decision-making.

CASE STUDY 2

Prioritizing Emissions Reduction Investments

Challenge

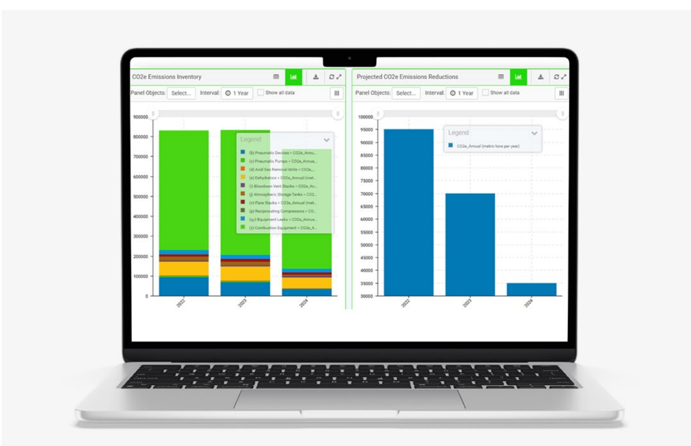
An oil and gas client was seeking the most effective path to reduce greenhouse gas emissions across a diverse portfolio of assets. With emissions originating from numerous source categories, determining where to invest limited capital for the greatest impact was not straightforward.

Rather than relying on intuition or broad industry benchmarks, the client wanted a data-driven understanding of which emissions reduction projects would deliver meaningful, measurable results and provide the strongest return on investment from both an environmental and compliance perspective.

Solution

Leveraging Cority, Trinity's DGS team analyzed the client's emissions inventory to identify the sources contributing the greatest share of portfolio-level greenhouse gas emissions. The analysis identified a significant emissions reduction opportunity and established a clear basis for targeting improvement efforts.

Figure 2. Cority Portal Panel illustrating digital twin evaluation of emissions reduction opportunities and quantification of resulting greenhouse gas emissions



Note: To protect client confidentiality, all images are taken from a test environment and contain representative rather than client-specific data. The examples are intended solely to illustrate functionality and relative order-of-magnitude impacts.

The team then leveraged a digital twin to model a proposed equipment upgrade across the portfolio. Using Cority, the expected emissions impact was quantified at the equipment, site, and portfolio levels before capital was committed. This analysis provided a clear, data-driven assessment of the anticipated emissions reductions and established a defensible business case for implementation.

By validating the expected outcomes in a virtual environment, the client gained confidence that the proposed investment would deliver measurable emissions reductions and could proceed with greater certainty regarding its expected environmental benefits.

Result

The digital twin analysis transformed emissions reduction planning from a theoretical exercise into a quantified investment strategy.

Key outcomes included:

- Identified the source categories with the highest-value emissions reduction opportunities within the portfolio
- Quantified the emissions impact of proposed equipment upgrades before capital was deployed
- Enabled capital to be directed toward projects with the greatest verified environmental benefit
- Achieved a material reduction in annual greenhouse gas emissions from the upgraded source and total portfolio through a focused, targeted investment program

In an environment of increasing regulatory scrutiny, investor expectations, and corporate decarbonization commitments, a material portfolio-level reduction is a significant achievement. More importantly, the client achieved it through a simulation-validated strategy backed by operational data rather than trial-and-error spending.

The project demonstrated how digital twins can serve as a powerful decision-support tool, allowing organizations to evaluate emissions reduction opportunities, prioritize investments, and build defensible business cases before committing resources. By turning emissions data into actionable insight, the client was able to accelerate progress toward its sustainability goals while maximizing the value of every capital dollar invested.

CASE STUDY 3

Preparing for Regulatory Change

Challenge

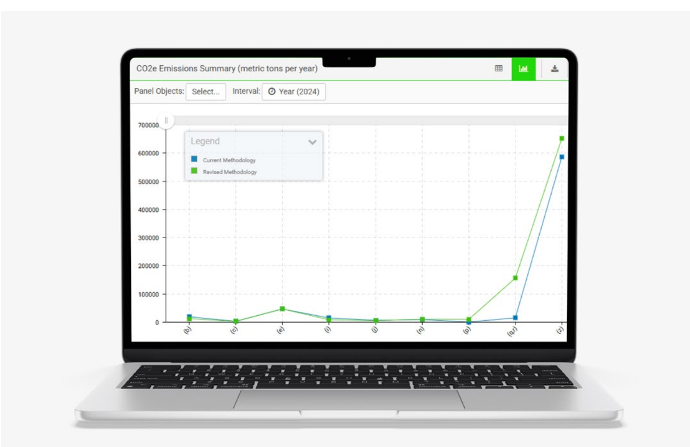
Recent revisions to the U.S. Environmental Protection Agency's (EPA's) 40 CFR Part 98 Subpart W, which governs mandatory greenhouse gas reporting for the petroleum and natural gas sector, introduced significant changes to emissions calculation methodologies. For operators with established inventories, emissions targets, and public sustainability commitments, these revisions created a critical question: How much of a reported emissions change would be driven by actual operational performance versus a change in reporting methodology?

A leading oil and gas client needed to understand the impact of the revised requirements before the compliance deadline. They required clear visibility into how the updated methodology would affect reported emissions, internal reduction targets, and external disclosures, while maintaining confidence that future reporting would withstand regulatory and stakeholder scrutiny.

Solution

Leveraging Cority, Trinity's DGS team developed a digital twin of the client's greenhouse gas reporting program configured to reflect the revised Subpart W requirements. The digital twin replicated the client's emissions inventory and reporting framework, allowing emissions to be calculated under both the legacy and revised methodologies using the same operational data set.

Figure 3. Cority Portal Panel illustrating digital twin assessment of reporting impacts across emission source categories prior to a compliance deadline



Note: To protect client confidentiality, all images are taken from a test environment and contain representative rather than client-specific data. The examples are intended solely to illustrate functionality and relative order-of-magnitude impacts.

This side-by-side comparison enabled the client to evaluate the impact across all applicable emission source categories and quantify precisely how reported emissions would differ under the new rule. Since the analysis was completed well in advance of the compliance deadline, leadership had time to assess potential impact, align internal stakeholders, and prepare communications regarding and resulting from material changes in reported emissions.

Result

The digital twin provided a transparent and auditable assessment of the regulatory changes before they became a reporting obligation. Rather than discovering the impact during annual reporting, the client gained early insight into how the revised methodology would influence reported emissions, sustainability metrics, and compliance planning.

Key outcomes included:

- Quantified the impact of the revised Subpart W methodology across the client's entire emissions inventory
- Identified the emission source categories most affected by the rule changes, including categories where reported emissions increased materially under the revised methodology
- Established a defensible and auditable reporting approach aligned with the revised EPA requirements

Most importantly, the project demonstrated the strategic value of maintaining a living digital twin of the emissions reporting program. By testing regulatory changes in a virtual environment before implementation, the client transformed a compliance challenge into an opportunity to proactively manage future reporting outcomes and investment decisions.

Lessons Learned from Digital Twin Case Studies

The greatest benefits are realized when digital twins are thoughtfully designed, built on reliable data, and maintained as living representations of operational and emissions processes. Across numerous emissions management and regulatory reporting projects, Trinity and its clients have identified several key practices that consistently drive successful outcomes:

- **Start with a focused business challenge.** Successful digital twin programs often begin with a specific regulatory, operational, or sustainability question. Demonstrating value through targeted use cases creates momentum for broader adoption.
- **Build on a foundation of trusted data.** The accuracy of a digital twin is only as strong as the data behind it. Reliable operational, emissions, and asset information is essential for producing results that can confidently support compliance, investment, and strategic decisions.
- **Treat the digital twin as a strategic asset.** Digital twins should not be viewed as a one-time project. As operations evolve, assets change, and regulations are updated, models should be continuously validated and refined. Organizations that maintain their digital twins as living systems can respond more quickly to new compliance requirements, business opportunities, and sustainability initiatives.

Collectively, these practices help organizations develop digital twins that are trusted, actionable, and sustainable over time. More importantly, they enable organizations to shift from reactive emissions management to proactive decision-making, using simulation to understand the implications of regulatory changes, operational improvements, and capital investments before those decisions are implemented.

As organizations continue to mature their emissions data and governance practices, digital twins will become an increasingly powerful platform for advanced forecasting, optimization, and strategic planning. Combined with emerging AI capabilities, they have the potential to further enhance decision support by identifying risks and uncovering reduction opportunities.

Looking Ahead: AI and The Future of Emissions Management

As digital twin capabilities continue to evolve, AI has the potential to further enhance how organizations analyze emissions data and evaluate future scenarios. While today's digital twins are primarily driven by rule-based calculation logic and user-defined scenarios, AI may help make these models more dynamic, predictive, and efficient, supporting capabilities such as:

- **Improved forecasting** by identifying patterns in historical operational and emissions data
- **Automated model refinement** to help keep digital twins aligned with changing operating conditions
- **Optimization recommendations** that identify emissions reduction opportunities within operational or regulatory constraints
- **Earlier risk identification** through predictive analysis of potential compliance issues
- **Accelerated scenario evaluation** by automating routine analysis and highlighting the most relevant scenarios for review

While these capabilities continue to mature, the value of digital twins is already being realized today. Rather than relying on assumptions or discovering consequences after the fact, organizations can use digital twins to quantify potential outcomes in advance. By providing a safe, auditable environment to test potential outcomes, digital twins bridge the gap between environmental data and confident business decision-making. As AI continues to expand what is possible, the organizations best positioned for the future will be those using digital twins today to turn uncertainty into actionable insight, stronger decisions, and measurable emissions management progress, tomorrow.

WHEN BATTERY RECYCLING MEETS TSCA: NAVIGATING CONSENT ORDERS AND SIGNIFICANT NEW USE RULES

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Trinity Consultants - Integrated Risk and Regulatory Science (IRRS)

Introduction

The rapid growth of the U.S. battery industry has created tremendous opportunities for manufacturers, recyclers, and downstream processors. At the same time, it has introduced new regulatory complexity that many organizations have never encountered before. While most companies are familiar with environmental permitting requirements, hazardous materials regulations, and workplace safety obligations, fewer organizations recognize that battery components themselves may be subject to restrictions under the Toxic Substances Control Act (TSCA).

For one battery recycling client, this realization occurred when the company began evaluating opportunities to process battery materials containing substances regulated under TSCA Section 5. What initially appeared to be a straightforward recycling and materials recovery operation evolved into a sophisticated compliance challenge involving Significant New Use Rules (SNURs), TSCA Section 5(e) Consent Orders (CO), industrial hygiene (IH) requirements, hazard communication obligations, customer notification provisions, recordkeeping responsibilities, and downstream product stewardship considerations.

The project illustrated how increasingly complex chemical regulations are affecting not only chemical manufacturers, but also downstream users, processors, recyclers, and other participants throughout the supply chain. It also demonstrates the value of a multidisciplinary approach, bringing together toxicology, regulatory affairs, IH, environmental compliance, and hazard communication expertise to develop practical strategies for clients facing novel regulatory challenges.

Understanding the Challenge

TSCA Section 5 authorizes the U.S. EPA to review new chemical substances before they enter commerce. In many cases, EPA allows commercialization of a substance under specified conditions documented in a CO. EPA may subsequently issue a SNUR that extends certain restrictions more broadly across industry.

While chemical manufacturers often understand these obligations, downstream entities frequently discover that restrictions associated with a new chemical can follow the material long after it leaves the original manufacturer. This is particularly true when regulated substances enter complex supply chains such as battery

manufacturing, battery recycling, materials reclamation, and metals recovery operations.

A client's battery materials recycling facility was evaluating the receipt and processing of battery materials containing substances regulated under TSCA Section 5. Although the client was not the original submitter of the new chemical notification, its activities potentially brought it within the scope of both a CO and associated SNUR requirements. The key question was straightforward: *Could the client continue its desired recycling operations while remaining compliant with TSCA requirements?* Answering that question turned out to require much more than simple regulatory interpretation.

The Regulatory Gray Area of Recycling

Battery recyclers frequently operate at the intersection of several regulatory programs. Depending on the specific material and process involved, operations may be governed by TSCA, Resource Conservation and Recovery Act (RCRA) requirements, OSHA requirements, state recycling regulations, transportation rules, export notification obligations, and various customer-specific contractual provisions.

One of the first challenges facing the client was determining how EPA might view specific recycling activities. Questions emerged regarding:

- Whether the processing activities could constitute manufacturing under TSCA?
- Whether recovered materials remained subject to Consent Order restrictions?
- How do downstream distribution limitations apply to recycled material streams?
- Do certain activities trigger a Significant New Use Notification (SNUN)?
- How should worker protection requirements be implemented in a recycling environment?
- What information must be communicated throughout the supply chain?

These questions are increasingly common throughout the battery industry. As domestic battery manufacturing expands and recycling infrastructure grows, more companies are encountering TSCA provisions that were originally developed for new chemical commercialization rather than end-of-life battery management.

Moving Beyond Regulatory Interpretation

Many consulting engagements begin and end with identification of applicable regulations. This project quickly demonstrated why that approach alone is often insufficient.

The client needed a practical framework for operationalizing compliance requirements. In other words, understanding the regulatory requirements was only the first step. The greater challenge involved translating those requirements into workplace practices, procedures, monitoring programs, documentation systems, and business decisions.

To support the client, Trinity assembled a multidisciplinary team that combined expertise from several practice areas. The IRRS team led interpretation of the COs, SNUR requirements, and broader TSCA obligations. Environmental compliance specialists evaluated operational practices and facility controls. IH professionals reviewed monitoring approaches and workplace exposure assumptions. Hazard communication specialists assessed Safety Data Sheet (SDS) requirements and workplace communication obligations. Together, the team provided an integrated assessment of regulatory applicability and risk management requirements.

Evaluating Real-World Operations

A critical component of the project involved understanding what actually occurs at the facility. Consent Orders and SNURs often contain requirements related to worker exposure controls, environmental releases, personal protective equipment, engineering controls, waste management, and recordkeeping. Determining applicability therefore required careful evaluation of how battery materials moved through the client's operations.

Trinity reviewed material handling practices, recycling processes, operational controls, waste streams, and employee protection measures. The goal was to compare actual facility practices against the assumptions and requirements embedded within the TSCA regulatory framework.

This evaluation identified areas where existing practices already aligned well with regulatory expectations as well as opportunities to strengthen documentation, procedures, and compliance systems. Importantly, the review provided the client with a roadmap for demonstrating compliance during future regulatory inspections or customer audits.

This type of operational assessment is often where organizations derive the greatest value. Many companies discover that their facilities are already implementing appropriate controls but lack the documentation or compliance framework to connect those controls to regulatory requirements.

The Industrial Hygiene Connection

One of the most significant aspects of the project involved worker protection and exposure assessment. Certain TSCA Section 5 restrictions include detailed workplace protection requirements, including engineering controls, respiratory protection, and exposure controls. In some cases, EPA defaults to conservative assumptions when site-specific exposure data are unavailable.

For the client, evaluation of exposure conditions became an important component of the overall strategy. IH specialists reviewed monitoring approaches and exposure assumptions to help determine whether worker protection measures aligned with regulatory expectations. The team also provided input regarding air monitoring strategies and exposure characterization.

This highlights an emerging trend for TSCA compliance projects. Successful compliance requires collaboration between toxicologists, regulatory specialists, and IHs. Regulatory obligations can no longer be viewed solely as paperwork exercises; they increasingly depend on demonstrating how workplace controls manage actual exposure risks.

Product Stewardship and Hazard Communication

Another important component involved downstream communication. Many organizations focus on manufacturing operations and overlook the product stewardship obligations for regulated substances. However, COs and SNURs frequently contain employee communication, labeling, SDS content, customer notification, and recordkeeping requirements.

Trinity's hazard communication specialists worked to evaluate and develop SDSs for recycled material streams while considering both conventional hazard communication requirements and additional obligations associated with TSCA-regulated substances. The effort involved reviewing hazard classifications, labeling considerations, workplace communication requirements, and specialized language associated with regulated materials.

This work illustrates another important lesson for industry: compliance with TSCA obligations often extends beyond the environmental department. Legal teams, EHS personnel, operations personnel, logistics teams, and commercial functions may all play a role in ensuring compliance.

Bridging the Gap Between Business Objectives and Regulatory Requirements

Perhaps the most valuable aspect of the project involved helping the client understand the practical implications of regulatory requirements on its business.

In several instances, the client needed to evaluate how specific material recovery activities, downstream transfers, and commercial arrangements intersected with restrictions embedded within the CO framework. Trinity facilitated discussions among stakeholders, evaluated potential compliance pathways, and helped identify approaches that balanced operational flexibility with regulatory obligations.

This role is becoming increasingly important throughout the battery industry and other advanced manufacturing sectors. Regulatory requirements are no longer simply compliance exercises; they can directly influence supply chain design, investment decisions, commercial agreements, and long-term business strategy. Organizations that understand these implications early are better positioned to avoid costly redesigns and compliance surprises.

A Repeatable Model for Emerging Technologies

Although this project focused on battery materials, the underlying approach applies to a wide range of emerging technologies. Many sectors are now encountering TSCA Section 5 restrictions associated with advanced materials, specialty chemicals, biotechnology products, recycled materials, and novel manufacturing processes. Organizations often find themselves navigating complex regulatory requirements that were not originally developed with their operations in mind.

The client's situation demonstrates how multidisciplinary consulting support can help bridge that gap. Rather than approaching compliance as a narrow regulatory exercise, Trinity combined expertise across:

- TSCA compliance and regulatory strategy
- Toxicology and risk assessment
- Industrial Hygiene
- Environmental compliance
- Hazard communication
- Product stewardship
- Operational auditing
- Supply chain communication and documentation systems

This integrated approach enabled the client to better understand regulatory obligations, evaluate operational practices, strengthen compliance systems, and support business objectives simultaneously.

Key Takeaways for Industry

Several lessons emerged from this project that are relevant to manufacturers, recyclers, processors, and downstream users across many industries.

First, TSCA obligations do not stop at the manufacturer. Downstream processors, recyclers, and customers may inherit compliance responsibilities associated with regulated substances.

Second, operational details matter. Regulatory applicability often depends on actual workplace practices, recycling methods, material handling procedures, and exposure conditions.

Third, environmental compliance, IH, and toxicology increasingly intersect. Modern compliance challenges frequently require expertise from multiple disciplines.

Fourth, product stewardship extends beyond simply preparing SDSs. Effective compliance involves communication throughout the supply chain, employee training, customer notifications, and supporting documentation.

Finally, organizations benefit from evaluating these issues proactively. Early assessment can identify practical compliance pathways before operations become constrained by regulatory requirements.

Looking Ahead

The growth of the battery industry, advanced materials sector, and circular economy will almost certainly continue creating novel regulatory questions. As manufacturers seek sustainable pathways for material recovery and reuse, regulators and industry participants alike will face new challenges regarding the application of existing regulatory frameworks.

For many organizations, the most effective solution will be a multidisciplinary approach that combines scientific expertise, regulatory knowledge, operational understanding, and practical implementation support.

As regulatory expectations continue to evolve, organizations that proactively assess TSCA obligations, CO requirements, SNUR applicability, and product stewardship responsibilities, will be best positioned to maintain compliance while preserving business flexibility.

For companies navigating complex chemical regulations, whether in battery manufacturing, recycling, specialty chemicals, advanced materials, or other emerging technologies, early engagement and cross-functional expertise can make the difference between viewing compliance as a barrier and using it as a strategic advantage.

For assistance evaluating your facility's compliance obligations or developing a practical compliance strategy, contact Trinity Consultants at 800.229.6655 or visit trinityconsultants.com.

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