Enhancing Safety in Production: Active and autonomous hot surface alerts using Thermal Energy Harvesting

Author: Jörg Rehder, PhD, Director Product Management and Sales, TEGnology Aps, Denmark

This paper examines the potential of autonomous, maintenance-free safety solutions for the production industry, powered by thermal energy harvesting technology. By converting local temperature differentials into electrical energy, thermal energy harvesting enables self-powered sensor and alert systems, eliminating the need for costly cabling and maintenance associated with traditional battery-driven systems, which often hinder the implementation of such safety measures. The paper includes a case study from the pharmaceutical and food industries, where periodic Cleaning-In-Place (CIP) processes elevate pipe temperatures to hazardous levels, demonstrating that standard safety procedures are often inadequate.

List of used abbreviations:

CIP – Cleaning in Process (Industrial cleaning process used in among other pharma and chemical industry)
IIoT – Industrial Internet of Things (also known as Industrie 4.0)
SensEver HSI – SensEver Hot Surface Indicator (Product TEGnology Aps)
ATEX - ATEX Directive (Short for “Atmospheres Explosibles”)
BLE – Bluetooth Low Energy (Communication protocol)
LoRaWan - Long Range Wide Area Network (Communication protocol)

Contact burns in industry

In industrial environments, hot surfaces are typically insulated or protected to maintain a safe workspace. However, space constraints may prevent the installation of such safety measures, or specific processes like CIP may only intermittently raise piping temperatures to dangerous levels while normally remaining cool. During CIP, piping systems can reach temperatures exceeding 100°C, posing a significant risk to personnel nearby.

Data on the "financial impact" of contact burns from pipes or hot surfaces is scarce, particularly compared to more severe incidents like fires, explosions, or steam eruptions involving open flames or hot gases. Consequently, this study relies on interviews with industry stakeholders, which confirm that accidental contact with unexpectedly hot surfaces often causes workflow interruptions and requires constant vigilance to prevent burns, thereby negatively affecting the overall working atmosphere.

The risks associated with contact burns or generally unsafe work environments have several consequences beyond the immediate injury. Feedback from our industrial partners for this study revealed the following impacts of contact burns that companies face if not adequately mitigated:

- Medical attention required for injured workers
- Downtime and decreased productivity
- Increased tension, reducing employee morale and focus

- The necessity for stringent safety protocols and additional safety training, further disrupting workflows
- Difficulty attracting and retaining skilled workers due to the safety record of the workplace

Investments in additional safety measures are often assessed against the costs and likelihood of severe injuries requiring medical attention. However, the impacts of smaller, more frequent injuries and their broader consequences are often overlooked.

Current status on warning systems

Conventional warning systems include visual alerts on control screens, static signs indicating potential hot surfaces, or visual signals on entire machinery sections during active processes.

Figure 1: Current typical warning measures in industry: Static sign, control screen and machine lights

While control screen alerts are effective for personnel in control rooms, they are often not visible to workers on the production floor. Static signs tend to be overlooked due to their constant presence, and single optical alerts, although effective, can contribute to increased stress levels across the production area due to their intensity. Additionally, these alerts deactivate when the process stops, even though pipes may remain at elevated temperatures for extended periods.

Active warning systems exist but often require expensive cable installations—averaging around €100 per meter in industrial settings—or demand regular battery maintenance, which introduces logistical challenges and additional costs. Battery replacements are not only inconvenient but also involve significant expenses, such as labor costs, scheduling with service providers, finding suitable times for maintenance, or even halting production to ensure a safe environment during replacement. An example of the cost of ownership for a customer providing service for installed sensor systems is summarized below:

Assumption: Average hourly rate for a service person in the EU: €100

- Logistics for refilling and tracking battery stock: equivalent to 0.15 hours
- Coordination of service appointments with the customer: 0.5 hours
- Travel time to customer premises, registration, pick-up, accessing the sensor location, and leaving: 1 hour
- Average time for changing batteries: 0.5 hours
- Cost of industrial batteries: €15 for two units
- End-of-life cost per exchanged battery, including logistics: equivalent to 0.1 hours
- Risk of reduced product lifespan due to damage during battery replacement (e.g., cracked doors, lost parts, damaged cables): equivalent to 0.5 hours

These elements add up to an average cost of €290 per battery change for a battery-powered sensor system. In our customer's case, this battery change is required every 2.5 years, accumulating to €1160 over 10 years of operation. Although smaller sensor systems, such as those used for hot surface alerts or similar safety devices, may result in a lower overall cost of ownership, the inconvenience of changing batteries and incorporating this activity into workflows remains a consistent challenge.

As a result, these sensor systems are often not implemented, especially when they are not mandated by regulatory requirements.

Introducing an autonomous power source for such sensor systems could significantly alter this cost analysis with a return of investment that typically matches or exceeds the expected lifetime of batteries in comparable applications and significant winnings over the combined lifetime of the sensor system including several battery changes.

Thermal Energy Harvesting enabling industrial safety products

Thermal energy harvesting takes advantage of temperature differences—such as those between a machine and its surrounding environment—to generate electricity. Through advanced design optimization and material selection, TEGnology has effectively integrated this technology into a range of industrial applications, including power supplies for IIoT devices and hot surface indicators to enhance safety in production environments.

The key benefits of thermal energy harvesting include cost efficiency, convenience, and sustainability. By converting otherwise wasted thermal energy into usable power, this technology eliminates the need for batteries, addressing growing environmental concerns. Devices equipped with thermal energy harvesters become self-sustaining and maintenance-free, with a return on investment that typically matches or exceeds the expected lifetime of batteries in comparable applications.

The SensEver HSI exemplifies this technology in a form factor that is both highly visible and easy to handle and mount, such as on piping systems in production environments.

An LED alert is activated at a surface temperature of 60°C, blinking at a frequency of 1Hz. The device can be mounted using a suitable plastic strip or metal hose clamp on surfaces up to 145°C and is certified for operation in ATEX Zone 2 environments. Its hermetic design provides IP67 protection and is also available with coated metal parts suitable for use with corrosive cleaning solvents. Due to the small size and thermal mass of the SensEver HSI, its responds time is between 5s and 15s dependent on the available temperature difference.

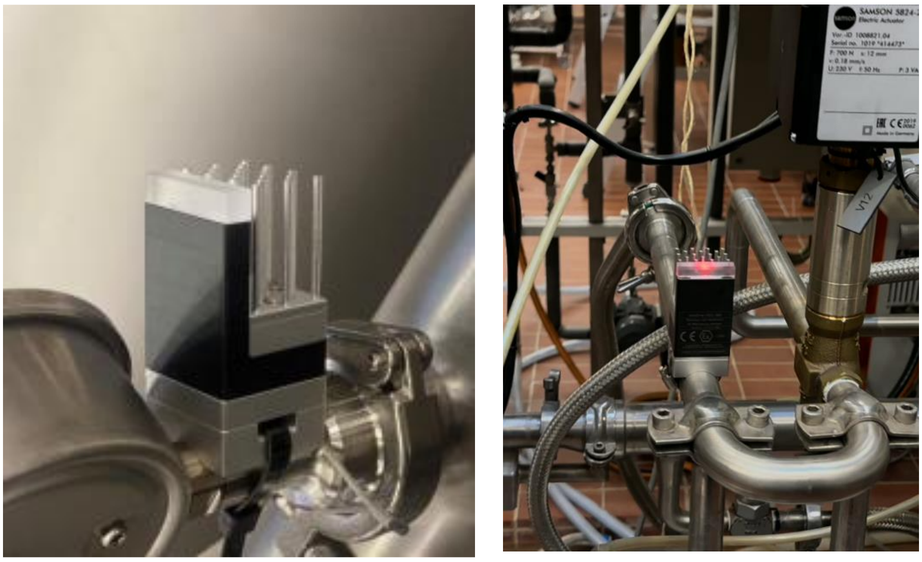

Figure 2: SensEver HSI hot surface indicator mounted to process piping

User feedback from Industry

The SensEver HSI has been installed in at pharmaceutical customers as well as in chemical and biochemical production facilities, including the pilot plant at the Department of Chemical and Biochemical Engineering at the Technical University of Denmark. Customers reported the following benefits of the SensEver HSI in various applications:

1. **Enhanced Safety:** Clear visualization of dangerously hot surfaces during operations, protecting staff and students working nearby.
2. **Localized Alerts:** Highly visible near hazardous machinery parts without disrupting the overall production hall environment, unlike integrated flashing lights.
3. **Cooling Phase Alerts:** Continuous visual warnings during the cooling phase while process-related indicator lamps are off.
4. **Process Visualization:** Effective monitoring of steam pipes, identifying issues such as a partially closed steam valve.
5. **Smart Alerts:** Efficiently replaces static warnings like "the surface may be hot," clearly indicating when surfaces are actually hot and when they are safe to touch..

System Design Using Thermal Energy Harvesting

Designing systems with thermal energy harvesting necessitates a different approach to power management than traditional battery-powered systems.

In conventional designs, the focus is on calculating total energy requirements over the product's lifetime, considering the energy needs for sensing and communication events. Designers typically prioritize managing peak current consumption to ensure that the battery can support maximum power demands.

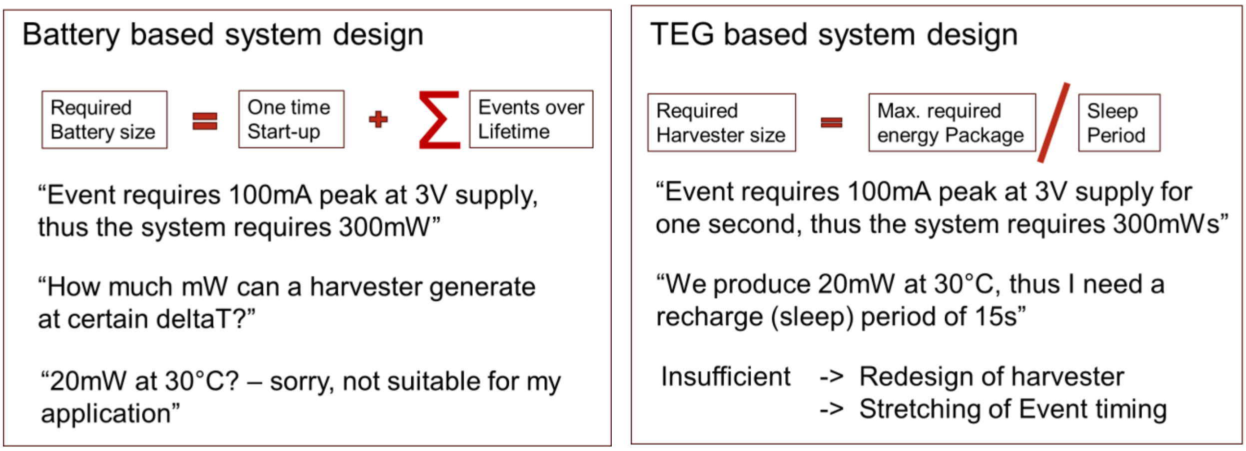

Figure 3: Comparison of system design approaches for battery driven systems versus energy harvesting driven systems

For example, an application with a peak current requirement of 100mA at a 3V supply results in a power demand of 300mW. If a thermal energy harvester can only supply 20mW under certain conditions, it might initially seem inadequate. However, in energy harvesting designs, the focus shifts from peak current to total energy consumption. While the system may require a 100mA current peak at 3V for 1 second (300mWs), the harvester can supply this by accumulating the necessary energy over time; for instance, a harvester producing 20mW could gather the required energy in 15 seconds, enabling periodic operation.

Often, optimizing the system configuration for energy harvesting is more effective than redesigning the harvester itself. By extending event durations or distributing power consumption across multiple intervals, the system can recharge between events, ensuring continuous operation. This approach is particularly valuable during startup phases, where energy demands are high due to activities like handshake protocols or server connections. Dividing the startup sequence into lower-energy steps can reduce the bill of materials (BOM) and the overall product cost, making the system more efficient and cost-effective.

Integration of thermal energy harvesting to existing systems

Integrating thermal energy harvesting into existing battery-driven solutions can make products autonomous and maintenance-free while retaining the advantages of battery systems, such as easy installation in industrial environments. Low-power sensors that measure simple parameters like temperature, pressure, or mechanical stress are well-suited for thermal energy harvesting. Low-power communication systems like BLE (Bluetooth Low Energy) or LoRaWAN can also be implemented without altering the product's form factor. For instance, the SensEver HSI has been upgraded to the SensEver HSI-BLE, which transmits temperature data via BLE. This enhancement transforms the safety device into a process monitoring tool, contributing to predictive maintenance and process optimization.

Due to the high efficiency of the SensEver HSI design, data readout begins at a temperature difference of just 10°C between the surface and the surrounding air. This implementation is planned for late 2024 at the Department of Chemical and Biochemical Engineering, Technical University of

Denmark, due to the device's ability to retrofit existing machinery easily and provide both a local optical alert and online data simultaneously.
For more energy-intensive applications, such as vibration sensing, thermal energy harvesting can be combined with a buffer capacity that charges between events and discharges to provide high power levels for short durations. For example, TEGnology's system can store energy during a 20-minute CIP process to power an Alfa Laval CN-type vibration sensor for 24 hours. Given that the process involves two CIP cycles per day, the system can be continuously powered.

Conclusion

Thermal energy harvesting represents a transformative approach to enhancing safety in industrial production environments by enabling the deployment of autonomous, maintenance-free sensor and alert systems. Compared to conventional battery-powered or cabled solutions, thermal energy harvesting offers significant advantages in terms of reliability, operational lifetime, maintenance costs, and sustainability, while providing a very fast responds time of only a few seconds.
The SensEver HSI hot surface alert, leveraging this technology, demonstrates a robust and effective solution for detecting and signaling hazardous temperatures in real-time, with a lifespan exceeding 10 years without the need for battery replacements or maintenance.
By capitalizing on otherwise wasted thermal energy, this technology aligns with industry trends toward greater sustainability and operational efficiency. It offers a cost-effective solution with low installation costs similar to those of battery-operated systems, but with the added benefit of eliminating ongoing maintenance and end-of-life waste management challenges. As demonstrated in this study, thermal energy harvesting not only supports compliance with safety regulations but also proactively enhances workplace safety, worker confidence, and overall productivity. As industries increasingly seek sustainable and reliable safety solutions, thermal energy harvesting is poised to play a pivotal role in the next generation of industrial safety devices.