Integrated Intelligent

Operations & Production:

Delivering Increased Safety

Volume 3

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Dedication

With due credit to individuals, companies, contractors, and consultants mentioned throughout the text and pictures including technologies, products, and services from these and other entities doing really good work in the world of Digital Transformation.

Energy Industries are fortunate to be able to access so many of these solutions to help deliver increased safety for our people, our communities, our assets and developments – and to help demonstrate this safety performance to our internal and external stakeholders.

Volume 3

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1. How to Deliver Increased Safety Through Digital Transformation

In the previous two volumes, we reviewed Digital Transformation technologies, tools, workflows, and organizational culture changes available to help deliver Integrated Intelligent Operations and Production. We now want to focus on one of the most important outcomes Digital Transformation can help deliver better: **Safety**.

We want to ensure that we are delivering the most safe outcome for our personnel, our communities, and our assets. Safety can be better delivered with a range of Digital Transformation technologies, tools, and workflows which will be described over the course of this volume. We would like to start by a brief overview of the range of applicable Safety related topics.

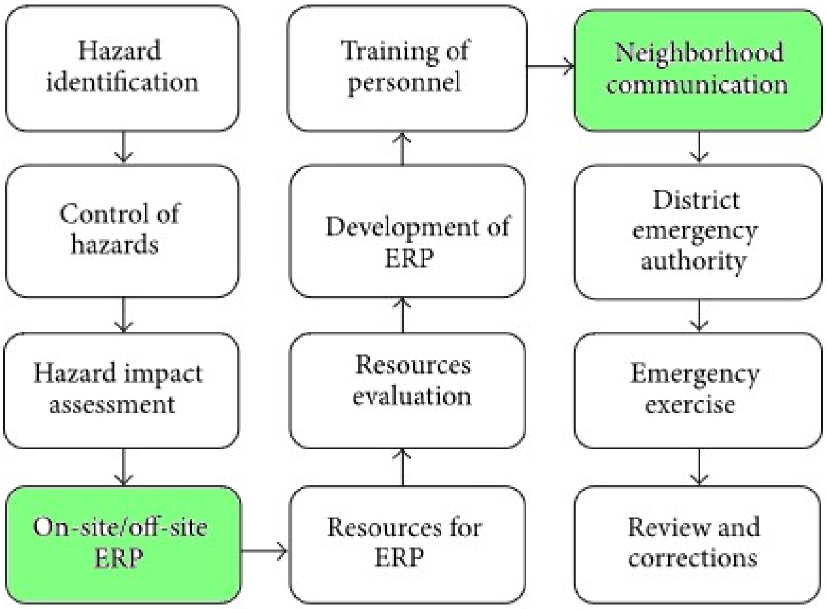
Personal Safety

Personal safety involves the physical safety of field workers and site visitors within our energy industry facilities. Every day these personnel may be subject to potential risks of being in proximity to energised equipment (i.e. pressure, temperature, or electrical power). Most people are familiar with a range of Personal Protective Equipment (PPE) as shown above, but there are additional valuable “digitally connected” tools to help improve personal safety.

Wearable devices, either independently powered and connected or else linked and connected through a user’s smart device (i.e. handsets, tablets, other specialist devices) can provide a range of safety solutions. It is possible to incorporate IoT devices into safety vests or overalls, or other wearables to allow centralised systems to track locations, monitor movements (or lack thereof), detect for gas or oxygen deficiency (e.g. *Dräger*), monitor noise (e.g. *Casella*), and to monitor biometrics of the individual worker themselves (e.g. *Zephyr*).

Safety communications to individuals can include advice or alerts to move from unsafe locations to safer locations, provide path guidance in case of impaired visibility (e.g. smoke), and to provide alerts to specific individuals (e.g. response teams).

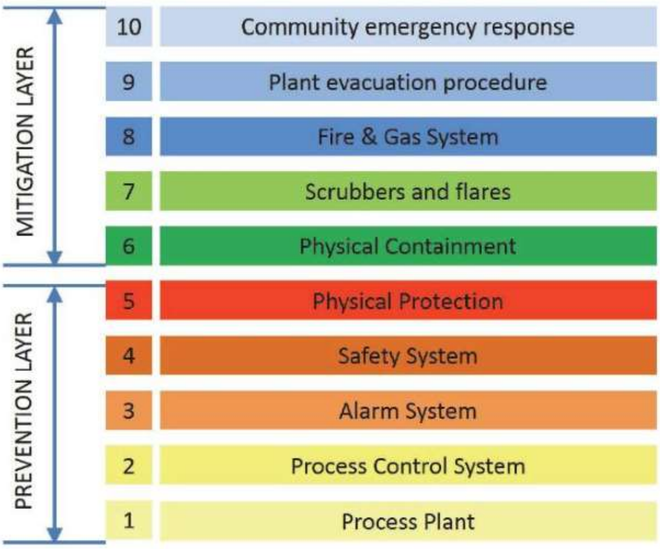
Community Safety

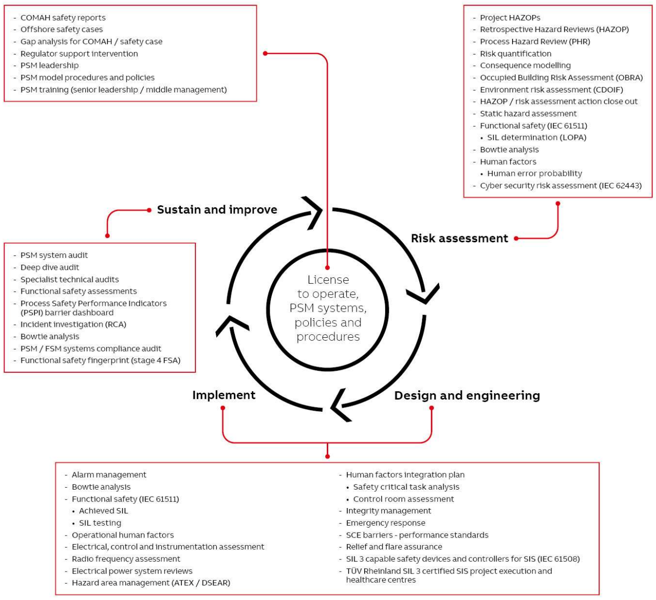


Community safety involves ensuring that the neighbouring communities to our energy industry facilities are appropriately protected from any of our risks and in some extreme instances notified with mass messages or alerts.

The boundary of our facilities could be exposed to emissions or leakages of products off-site. We may need to provide warnings of fire, blast, or chemical releases. As part of most regulatory processes, we need to provide education about any risks from our facilities and how we are managing them to ensure safety. There may be voluntary alerts and response training provided to these communities as part of off-site ERP with local agencies. Boundary integrity monitoring and, if required, mass notifications are well suited to Digital Transformation tools.

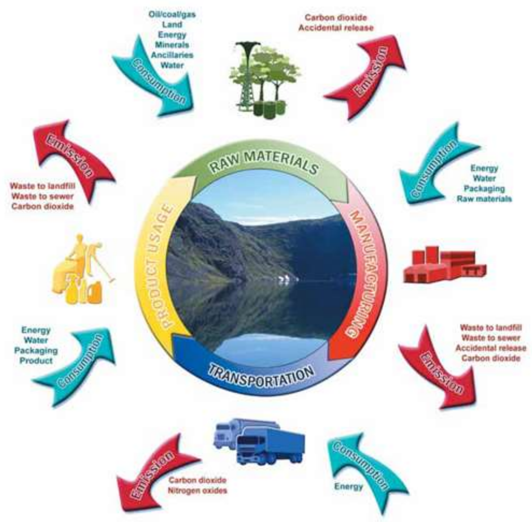
Technical Safety





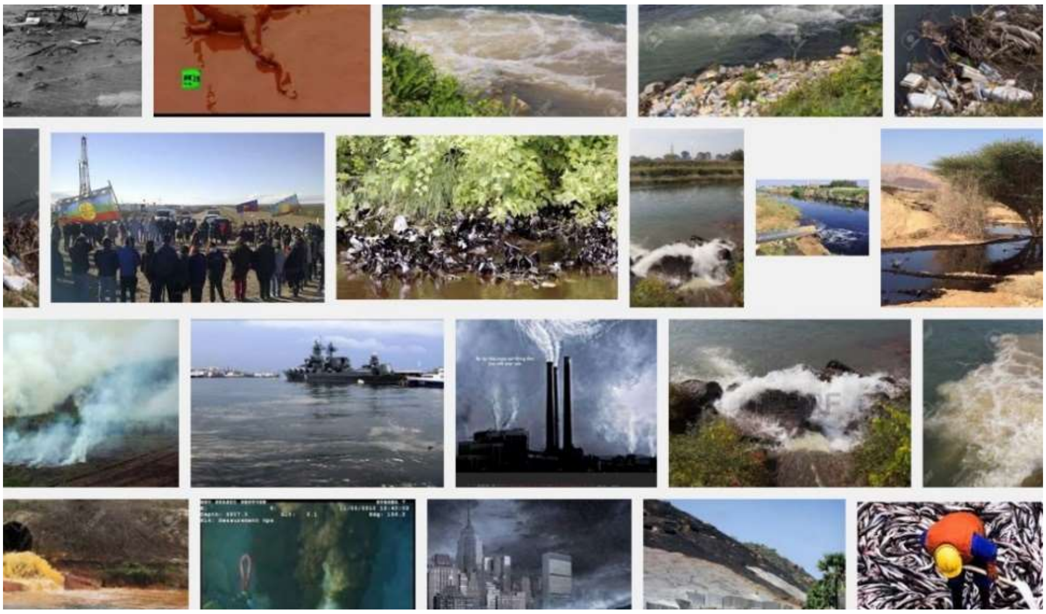
Technical /process safety systems need to be layered and need to be contextual, automatic, and integrated. Work begins with technical risk assessments, then engineering and design, then implementation, then management as part of a Process Safety Management system. Technical work includes: (1) Quantitative Risk Assessments (e.g. potential incidents – preventions and mitigations); (2) identification of Maximum Accident Events or scenarios; (3) physical effects modelling (e.g. fire, blast overpressure, electrical discharges etc.); and (4) Facility Risk Visualization (e.g. risk heat maps). Implementation then includes: (1) Isolation Management (including barrier management (i.e. structural integrity, process containment, ignition control, detection systems, protection systems, shutdown systems, emergency response, lifesaving systems, critical processes) and alarm management); (2) Job Safety / Hazard Analyses (including consideration of SIMOPS) which would be incorporated into (3) the Permit to Work (PTW) system (and linked to EAM/APM/CMMS systems). Technical and implementation work needs to be audited and assured on a continuous basis.

Environmental Safety



Environmental safety is delivered through setting proper policies, planning, implementing an environmental management program, inspecting the outcomes, and reviewing / auditing / assurance.

Energy industries can have various atmospheric emissions including CO_2, CO, methane, and chemical fumes. Liquid discharges can include liquid hydrocarbons, produced water, sanitary effluent, and chemical streams. Solid waste can be packaging waste, garbage, and chemical by-products. Noise is an important "emission" from many types of facilities that similarly needs to be considered.. All of these waste streams can have adverse environmental consequences and need to be managed throughout their life cycle from raw materials, to manufacturing, to transportation, to product usage, and ideally to reuse or recycling. Environmental management can be facilitated with Digital Transformation tools.



Regulatory Safety

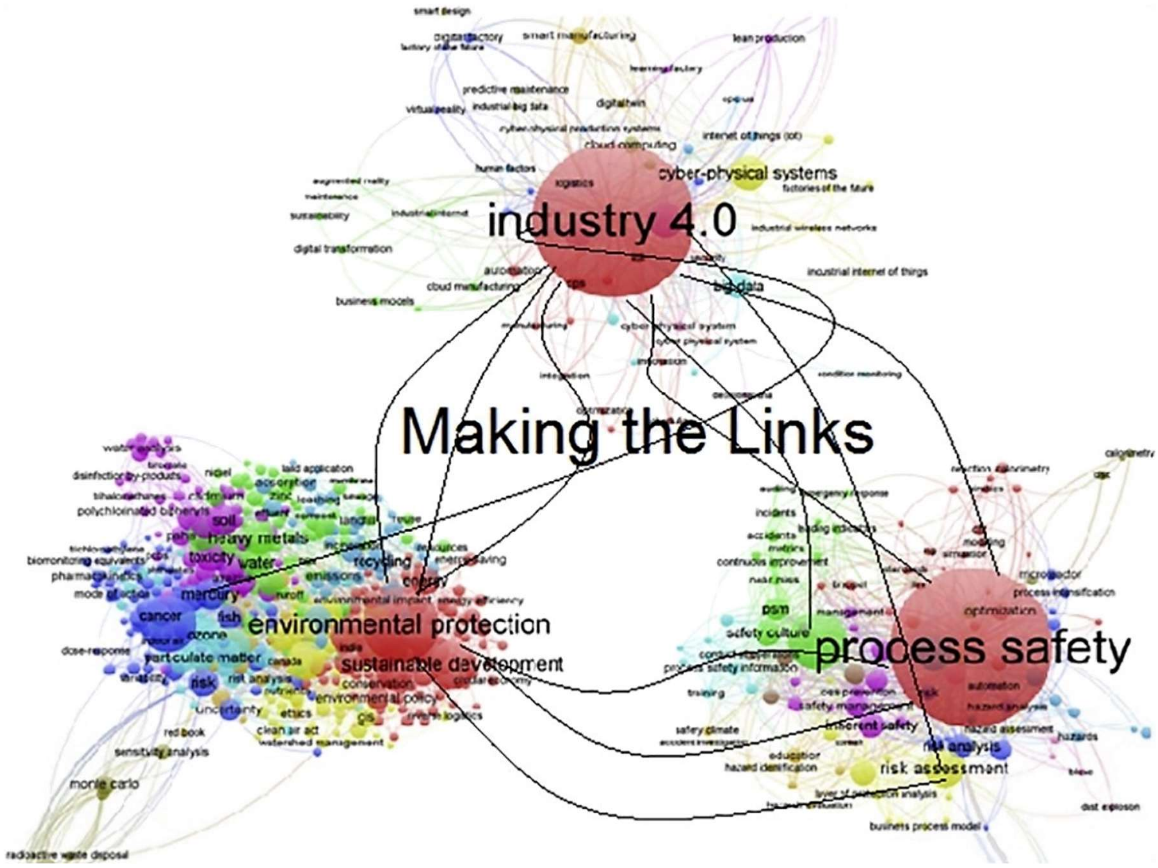
Regulatory "safety" can mean being able to demonstrate to regulators that your energy industry facility is compliant with a range of legislation and rules across various aspects of your business from people to process to land stewardship to emissions. Workplace safety and employee safety need to be demonstrated both to regulators as well as to the employees themselves. Commercial transactions including exports, revenues, and taxes need to be properly recorded and accounted for within business systems and available for audits (including any charges for operations and emissions). Emissions or discharges are important consequences to be monitored and controlled. Implementing environmental management processes and then automatically documenting them is an important deliverable for regulators.

Regulators could require physical inspections but with public health and remote location considerations, it would be good to be able to virtually demonstrate compliance with remote inspections and automatic documentation on secure data platforms accessible to these stakeholders. Investors with Environmental, Social, and Governance (ESG) requirements will also be able to benefit from these types of assurance systems to help ensure funding and finance is sustainably delivered and maintained.

The Energy Transition requires us to fully identify and be able to demonstrate the life cycle impact of our energy industry inputs (i.e. materials, equipment, systems, manufacturing, construction, installation, and operations) and outputs (i.e. products, energy streams, emissions, and waste). Access to all of this data is facilitated inside Digital Transformation tools.

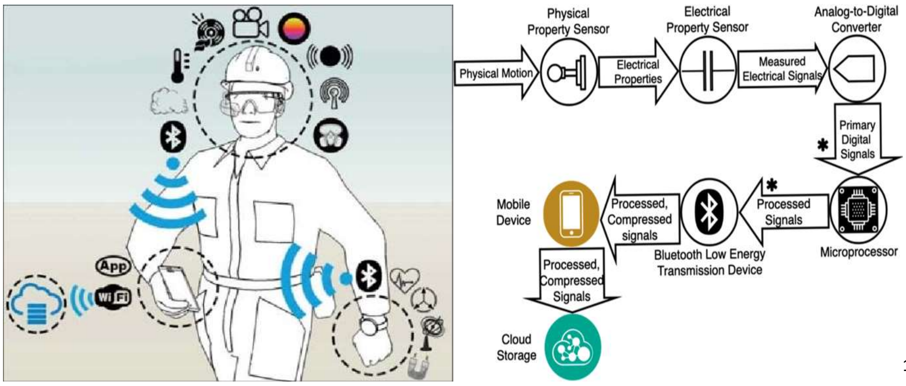
Summary

Delivering increased Safety in any form is essential and there are many technologies, tools, and work practices to help our Energy Industries. Digital Transformation (sometimes called “Industry 4.0”) is linked to Process Safety and Environmental Protection through Integrated Intelligent Operations & Production.



2. Increased Personal Safety

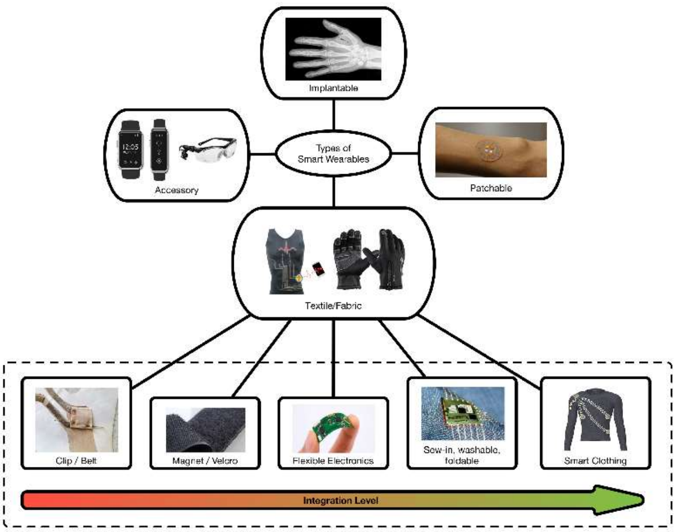
Personal safety is the safety of our personnel on site inside our energy industry facilities. It is not just about wearing the appropriate Personal Protective Equipment (PPE) or having received some HSE briefing or training. Effective safety needs to involve both passive and active measures to ensure we have safe outcomes for those working inside these facilities. Our facilities typically have energised equipment which could include wellheads (oil and gas wells), separators (process equipment), compressors (gas reinjection or transmission), and power generation including switchgear, transformers, and high voltage equipment. Personnel may have to work at height (e.g. wind turbines) or work solitarily over large sites (e.g. solar farms). Confined workspaces are often encountered inside equipment assemblies or vessels or buildings. Digital Transformation offers key technologies and tools to assist these personnel in the safe performance of their duties.



[1]

"Digitally connected" tools can help improve personal safety. The key is real time safety information to field users as well as remote asset teams. We have the ability to know where every field worker is located at all times and can check that he has the adequate competencies to be in hazardous locations, whether he has the necessary PPE, and whether there are any environmental factors of concern (i.e. air quality, weather, temperature, noise, or movement). Real-time safety notifications and information are possible both to the worker and from the worker's location.

There are several types of wearable IoT devices able to provide this functionality. Different devices have different functionalities usually based on their size and power requirements. Accessories and wearable garments have the most functionality since they can include as much power as is reasonably needed as well as wider ranges of communication abilities. Implantable and patchable devices are usually used for biometric data to monitor the physical health of the user (i.e. heart rate / ECG, temperature, and breathing)[2].

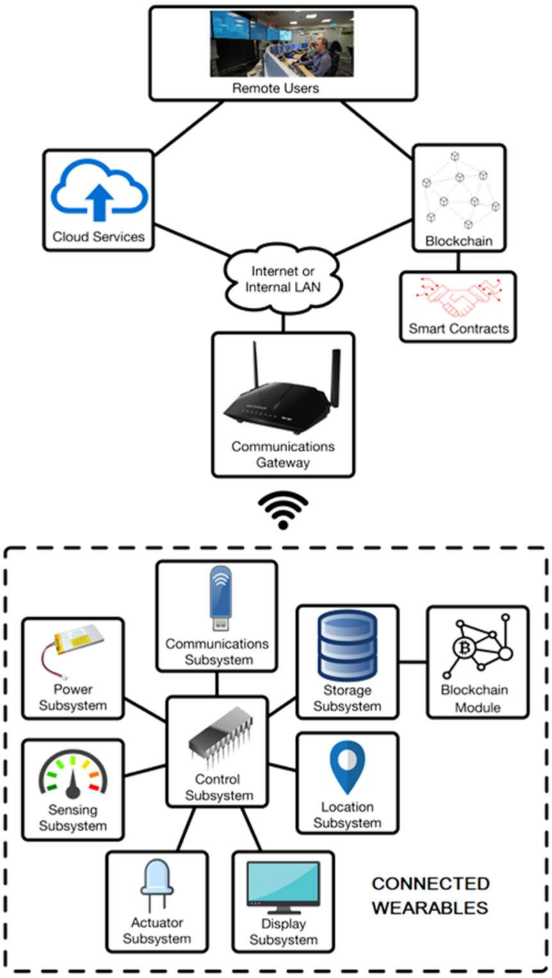


[1] https://www.nature.com/articles/s41746-020-0260-4
[2] https://www.mdpi.com/2079-9292/7/12/405

Wearable devices, either independently powered and connected or else linked and connected through a user's smart device (i.e. handsets, tablets, other specialist devices) can provide a range of other safety solutions. It is possible to incorporate IoT devices into safety vests or overalls, or other wearables to allow centralised systems to detect for gas or oxygen deficiency (e.g. *Dräger*), monitor noise (e.g. *Casella*), and to monitor biometrics of the individual worker themselves (e.g. *Zephyr*).

One of the first points of site safety management is usually access control – how we decide and control whether a worker is allowed onto a facility. It is typical to have identification badges, but they need to be more than manually checked (in a remote facility there might not be anybody there to check it). These badges can contain a lot of information that should be maintained and kept up to date constantly – and be read automatically by both visual and electronic means. Visual picture scanning is used to check the person entering is the person on the badge. Electronic scanning is used to check the worker's authorisations, fitness records, and details of work assignments. Work assignments are then able to be cross-referenced to work permits, competencies, training records, and required PPE and safety equipment. Any discrepancy can then be alerted to the individual (e.g. managerial issue) or alarmed to the remote asset team (e.g. security situations).

[3]



[4]

Once on site, personnel should be constantly monitored for location ("geospatial temporal monitoring"). Safety communications to individuals can then include advice or alerts to move from unsafe locations to safer locations, provide path guidance in case of impaired visibility (e.g. smoke), or to provide alerts to specific individuals (e.g. response teams). Tracking locations and directional guidance is possible with RFID chips being externally monitored or by active GPS reporting from a person's smart device. Wearable emergency buttons can be used linked via Bluetooth to these smart devices, so the worker would not need to unlock their device to summon assistance.[5]

If a person stops moving during a task or in a non-routine location, it is possible that some safety incident or health incident has happened and other personnel can be directed to the location to investigate. There are means of monitoring potential falls – Blackline Safety has something called True Fall Detection technology which "can automatically detect the signature movements of a fall in contrast to other

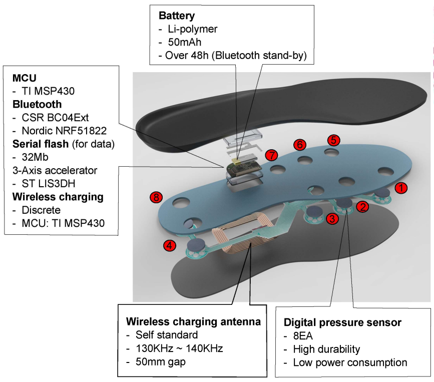
[3] https://eleksen.com/
[4] https://www.mdpi.com/2079-9292/7/12/405
[5] https://staysafeapp.com/lone-worker-solution/wearable-technology/

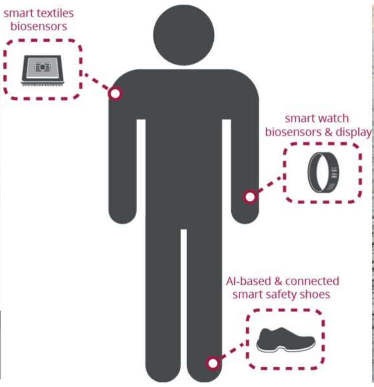
activities—such as walking down stairs or jumping off the tailgate of a truck….(using) advanced micro-electromechanical sensors to continuously monitor an employee's motion."[6] Sensitivity is adjusted to suit different roles and activity levels. If a worker falls and does not get back up right away, the device would trigger audible, visual and tactile alarms that would request the worker to confirm their wellbeing by pressing a check-in button. If not done, a safety alert would be transmitted to the remote asset team to investigate and arrange a response if required.

Dangerous equipment or systems can be "geofenced" so that if a worker comes in close proximity without a work permit, necessary isolations in place, and the required PPE, he would be alerted and the remote asset team would be alerted. Conversely, data analytics may instigate an inspection requirement of critical equipment and workers need to be carefully prepared and ready to perform this work safely.

Weather data or metocean data or alerts can be transmitted to the field worker. For example in some locations there can be severe thunderstorms or squall lines which can be quite dangerous and workers might miss routine communications, so embedded devices can ensure the messages are not missed and are delivered to the worker.

"Smart" shoes are already fairly widespread in personal sporting equipment, Bluetooth connected to user's smart devices like phones and trackers. Smart shoes are advancing in a couple of different ways: (1) inner soles and (2) external clippables[7]. Industrial applications are being used for several functionalities: (1) providing directions in low visibility conditions; (2) temperature measurements of surfaces; and (3) motions (i.e. interruptions or rapid movements like falls).

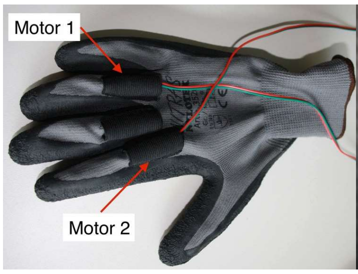


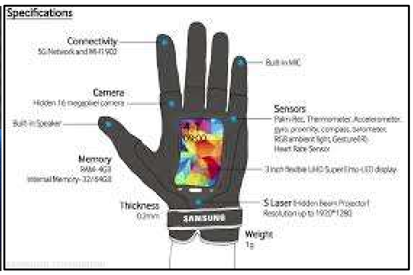


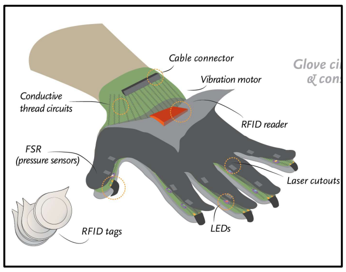
"Smart" gloves are available with various functionality. Smart gloves can provide both physical safety as well as notifications – for example if a worker is nearing extremely hot or cryogenically cold surfaces, the gloves can alert the person not to touch (in addition to audio alerts through other smart devices). Haptic glove devices have been developed by EAI partnered with ENGR Dynamics for firefighters[8] to give directional cues in visually impaired environments which could be applied to energy industry facilities. In situations where some intervention is required, there are haptic enabled gloves to provide directional assistance. They can be normal work gloves with vibration motors to give haptic feedback to the field personnel[9]. They can also incorporate additional sensors like barcode[10] or RFID scanners to provide safety information to the field user through other linked smart devices. R&D technology is developing smart

[6] https://www.blacklinesafety.com/blog/how-true-fall-detection-technology-benefits-lone-workers
[7] https://intellinium.io/
[8] https://gcn.com/articles/2020/01/30/haptic-devices-responders.aspx / https://www.nist.gov/ctl/pscr/engineering-acoustics-inc
[9] https://www.researchgate.net/publication/310822551_Haptic_Auditory_or_Visual_Towards_Optimal_Error_Feedback_at_Manual_Assembly_Workplaces
[10] https://www.proglove.com/

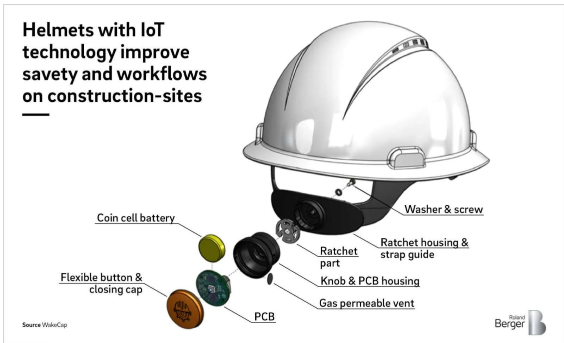
gloves with other functionalities and it is expected that other capabilities (especially developed for other industries) will become available. Hand gestures can also be coded to signify data input.



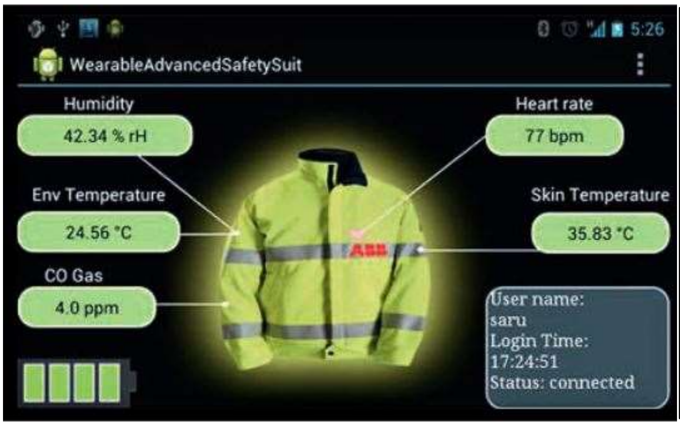



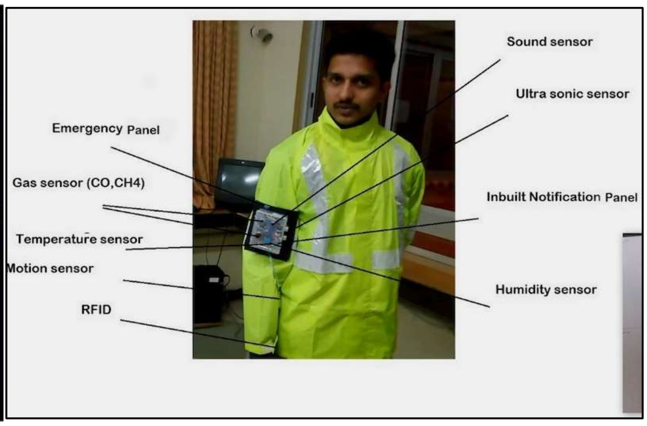


Safety helmets are another common wearable that have been used to support safety equipment. Functionality can range from simple two way notifications[11] to more sophisticated functionalities[12] with multiple sensors (e.g. noise).




Wearable clothing with IoT devices embedded are another way to provide safety information to field personnel[13]. More natural to wear than heavy devices on a person's head, as well as handsfree, clothes offer more places to locate devices, power sources, and communications equipment. More sensors can be deployed in contact to the wearer's body to gather accurate biometrics including respiratory and musculoskeletal data. Advances in sporting and leisurewear as well as other industries have meant that good technologies and fabrics are available for energy industries. Smart clothing can also potentially provide supplementary heating or cooling to improve the safe working conditions for the field personnel. Clothing can potentially provide protection to the person from abrasion or impacts or contact with temperature extremes of equipment and piping.





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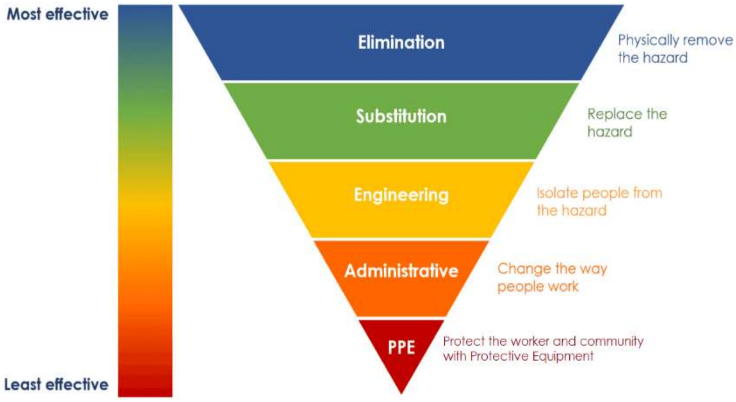
11 https://www.rolandberger.com/en/Point-of-View/Introducing-helmets-with-IoT-technologies-for-construction-sites.html
12 http://www.protechtio.com/
13 https://www.mdpi.com/2079-9292/7/12/405/pdf-vor

TC (Technical Commission) 124 of the IEC (International Electrotechnical Commission) categorises smart wearable into four types: (1) accessory wearables (i.e. smart watches, glasses, or fitness trackers); (2) clothing wearables (integrating electronics into the material); (3) patchable wearables (e.g. skin-patchable); and (4) implantable wearables (lightweight self powered implanted into the body, e.g. RFID chips. IEC Standardization Group (SG) 10 classifies these wearable smart devices according to their location with respect to the user's body: (1) near-body wearables (not necessarily in contact); (2) on-body wearables (in direct contact with the skin); (3) in-body wearables (implants); and (4) electronic clothing. All these types and classifications are available to users depending on the exact functionality desired and the nature of the working environment. Industrial wearables will be rugged and power requirements and durations will be significant. Distributed devices on a person could make use of a Body Area Network (BAN) that connects externally (wirelessly) with a Local Area Network (LAN). Mesh network communications will likely be used due to the congested nature of most energy industry facilities. Finally the data and communications would connect through major transmission links (i.e. microwave, satellite, or 5G) up to a Cloud Data Platform where multiple remote users could access using API's to utilize the data and communicate back to the field personnel. Data recorded during a person's movements around a facility would be captured, recorded, and be available for comparisons over time as another source of integrity data for the facility itself.

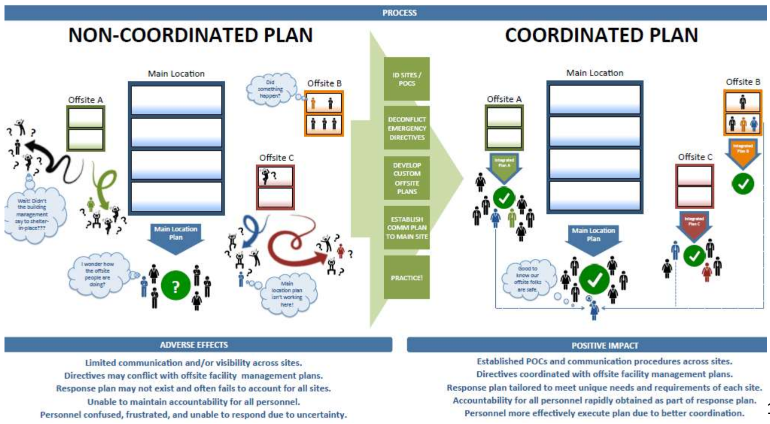
Field personnel work in hazardous locations, sometimes on their own, and they need better connectivity and data to ensure safe working conditions and facilitate remote monitoring by asset teams in case any assistance is needed. Smart wearables are in addition to normal communications equipment and Augmented Reality devices (e.g. headsets) and their advantage is handsfree support whilst the person is engaged in performing field work. Digital Transformation technologies and tools are available now to help deliver increased personal safety.

3. Increased Community Safety

Community safety is safety of the surrounding communities to our energy industry facilities. It involves proactive steps to prepare both preventative and mitigative measure associated with any potential risks to these communities. Community safety involves ensuring that these communities are appropriately protected from any of our risks and in some extreme instances notified with mass messages or alerts if some action may be required on their part (e.g. shelter in place). The boundaries of our facilities could be exposed to emissions or leakages of products off-site. We may need to provide warnings of fire, blast, or chemical releases. Fortunately Digital Transformation can provide technologies, tools, and work flows to help deliver increased community safety.



It is normal as part of a Safety Case or Planning document to consider potential hazards. As part of the hierarchy of controls we want to first try to eliminate hazards ("inherent safety"). Then if not possible, try to replace the hazard. If not possible to eliminate or replace, try to isolate people from the hazard. Then, administrative controls are rules and training to try to get people to work safer – primarily inside our facilities. It would be more difficult to ensure the community responds in some specific manner to be safer in case of our hazard, but it is on our hierarchy or controls to try to implement. Finally we would try to protect people with protective equipment (e.g. personal PPE).



[14]

This chapter is about how we can help those people outside our facilities ("off-site") in the communities, so we will assume that the hierarchy of controls has been worked and as much as possible has been done <u>inside</u> the facility to address the higher order preventative measures. Now we want to focus on what needs to be done at the <u>boundary</u> of our facilities and <u>outside</u> in the communities in a Coordinated Plan.

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[14] https://www.researchgate.net/publication/307926697_Coordinated_Disaster_Response_for_Offsite_Facilities_Using_a_Customized_Emergency_Action_Plan

Communications will be key and Digital Transformation technologies, tools, and workflows can help deliver this information in a timely, effective manner.

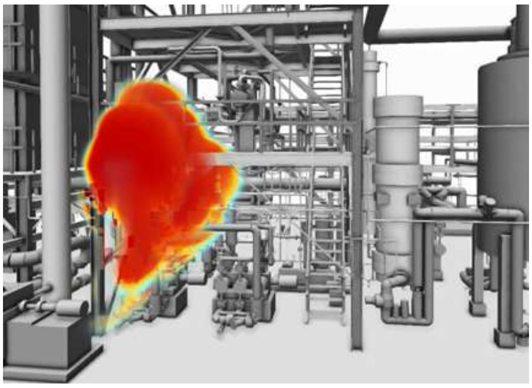
Several types of potential emissions or leakages are possible. Gaseous emissions are a common risk and could be hydrocarbon (light or heavy) or chemical gases. Emissions of carbon dioxide or carbon monoxide are also possible depending on the processes and equipment involved. There could be regulatory requirements on some emissions, but our own environmental commitments would apply to help minimise and eliminate these emissions. Being a good neighbour is important and the Energy Transition commits us to improving efficiencies and eliminating releases.

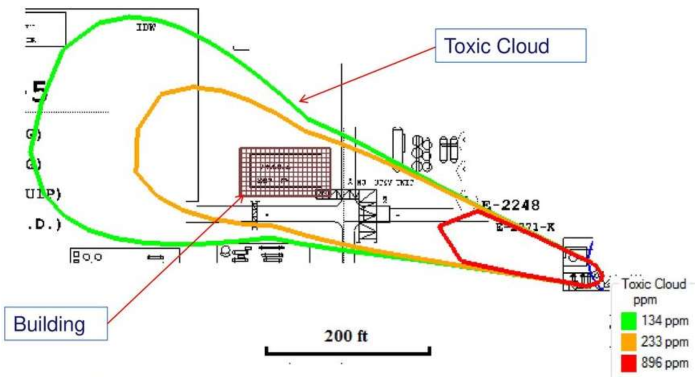
Liquid leakages could involve spills of hydrocarbons, untreated produced water, chemically contaminated process water, or liquid chemicals. All these liquids would have normal processes to control and treat, but accidents could lead to spills.

Another source of leakage of potentially harmful pollutants is chemical products from our facility leaching onto the ground and then rainfall further distributing the pollutants – this can be heavy metals (i.e. lead, nickel, cadmium, or antimony) used in batteries (e.g. power systems and/or energy storage) or even damaged solar panels. Pollutants can runoff along the ground and seep into groundwater or into drainage ditches that could connect to waterways. None of these scenarios are acceptable, so we need to work the hierarchy of controls as much as possible to eliminate them.

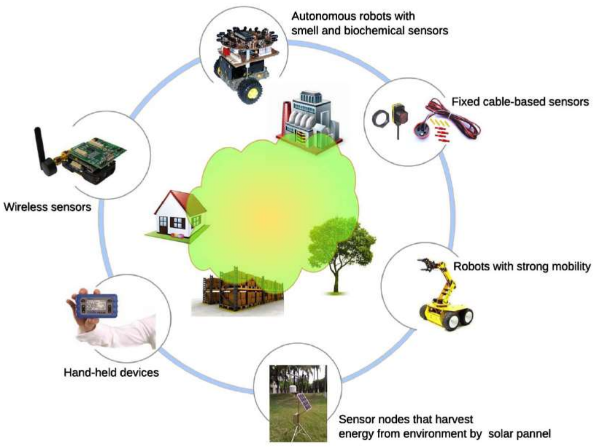
Any type of gaseous emission or liquid leakage crossing the boundary of our facilities could impact the community so we need to be prepared. After all the preventative measures are applied, we need to be ready with mitigating measures including detection and response. Gaseous emissions can be detected with a range of technologies to be discussed further below. Liquid leakages can be detected with subsurface grid-net systems measuring electrical conductivity changes in the soil. Groundwater monitoring systems could also involve upgradient and downgradient monitoring wells to sample groundwater on an ongoing basis. IoT sensor devices are being installed in some wastewater networks of communities to monitor and trace source events in real-time.

All these types of sensors should be networked and connected to Edge analytics to provide rapid notification of any material changes so that field or remote operators can intervene quickly to isolate sources and mitigate any impact on the communities outside our boundaries. Gas releases can be dangerous due to poor visibility. Invisible clouds of gas may not readily be apparent unless specialist means including FLIR (infrared) cameras are used. Sometimes these gas releases can be flammable or toxic which is obviously hazardous, and they are environmentally polluting like methane and carbon dioxide.



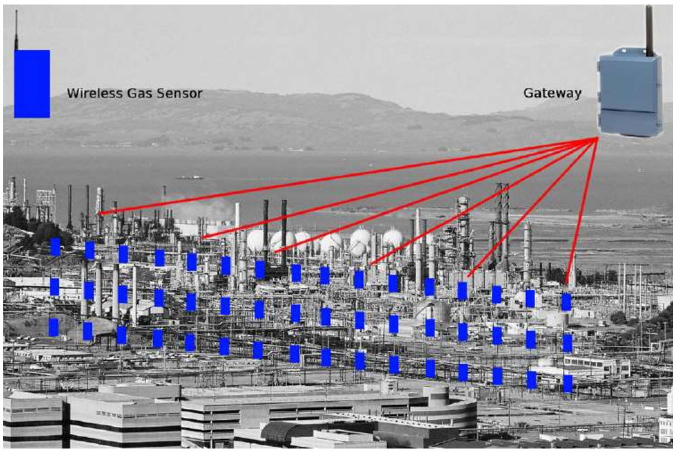


Various types of IoT sensors could be deployed around an energy industry facility to help detect potential gas releases. A very common type of sensor is fixed cable-based high-resolution sensors, but these are expensive when the cabling is considered and the number required. Another type is some kinds of autonomous robots – but again the coverage areas may be an issue. Smaller autonomous robots including drones offer some interesting capability during periodic routine inspections as well as being deployed after an initial release to help track dispersion and concentrations. Wireless sensors are perhaps one of the most attractive types of sensors due to cost and ease to distribute them. Another source of widespread data coverage is workers in the facility with wearable gas monitoring devices and/or site vehicles with similar gas monitoring devices.



[15]

In all cases the individual sensors should be networked and real-time data should be used to help locate the source of releases through "adaptive swarm intelligence" combined with data on environmental factors like wind speed and directionality input into advanced analytical simulation models to predict the path of any emissions and associated concentrations and/or toxicity.



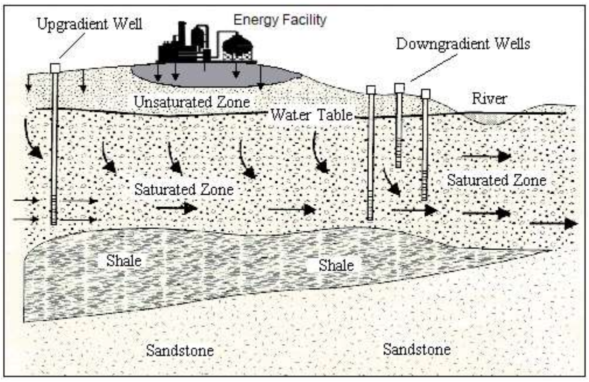
It would be possible to place wireless gas sensors along a facility boundary to help identify any potential gas releases at risk of impacting adjacent communities[16]. Data could travel through a mesh network towards the gateway device where Edge analytics would be performed to help identify the materiality of any potential release and facilitate responses.

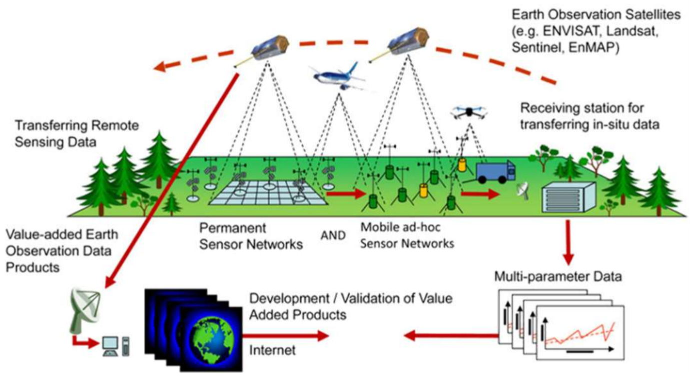
Invisible releases of methane and carbon dioxide are also under increased scrutiny today as companies work to meet emission targets of these environmentally damaging greenhouse gases. Methane releases called fugitive emissions can come from inefficient or poorly operated and maintained equipment which should be targeted by IoT sensors to isolate sources to allow improved operations and maintenance to eliminate these kinds of releases. Distributed networked gas sensors should maintain monitoring of facilities but it is also possible to have measuring and detection through autonomous drones flying over a

[15] https://core.ac.uk/download/pdf/77000493.pdf
[16] https://people.eecs.berkeley.edu/~pister/publications/2016/Chraim2016wirelessGasLeak.pdf

facility to spot such emissions. Field teams can also use manual measuring tools to scan areas for potential releases. Boundary sensors could include laser gas sensors and retro-reflectors as shown combined with three-axis ultrasonic anemometers to measure wind velocity and turbulence intensities[17]. Networked IoT sensors of gas and meteorological properties will help computer simulations better detect releases as well as determine if there are potential impacts on adjacent communities.

Liquid discharges into groundwater or waterways could be serious depending on the types and amounts of potential liquids at discharge risk and, in certain risk situations, we could need good monitoring with IoT devices to help control and respond to any such discharges. Groundwater discharges could be more serious due to the risk that they could occur with delays until noticed. There are several types of monitoring systems as shown to locate and track any suspected discharges or leakages including permanent or mobile ground sensors.





Outside of the boundary of a facility, there could be communities with wastewater systems that could be monitored for abnormal conditions down their manholes and in their waterways, i.e. the presence of hydrocarbons or hazardous chemicals not normally present. The concentrations measured with distributed wireless monitoring stations could provide information on the risk level and a spread of monitoring stations could help locate the source[18].

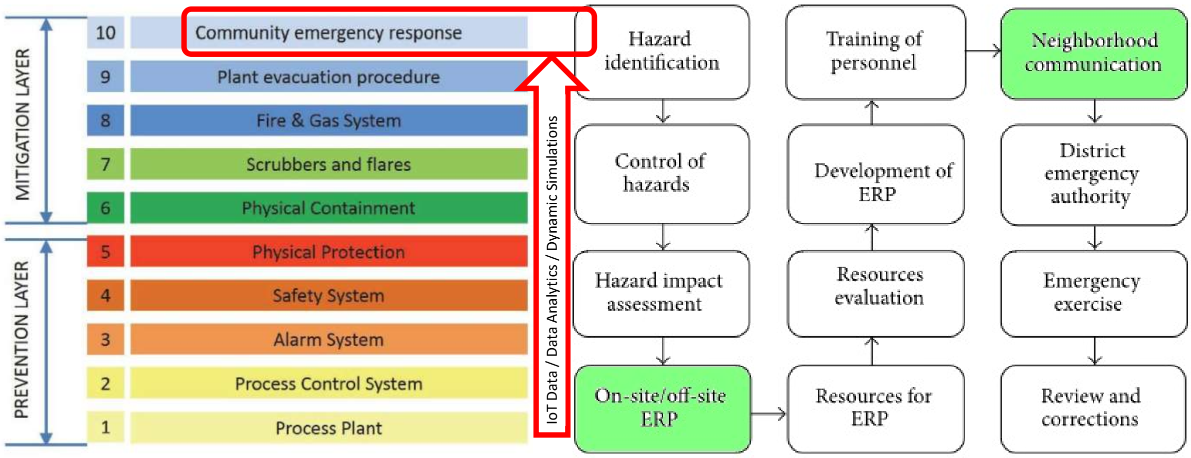
17 https://www.lancaster.ac.uk/staff/jonathan/HrsEA17.pdf
18 https://www.kando.eco/

Hazards associated with fire or blast events can escalate (i.e. subsequent gaseous emissions and/or liquid discharges) and also constitute a risk to neighbouring communities so the hierarchy of controls should try to initially prevent these hazards before the subsequent mitigating controls eventually get to the point of requiring some form of community emergency response. As part of most regulatory processes, we need to provide education about any risks from our facilities and how we are managing them to ensure safety. There may be voluntary alerts and response training provided to these communities as part of an "off-site ERP" with local agencies.

The most common historical response to prior industry emergencies was to advise potentially affected communities to "shelter in place" which essentially meant stay inside your house or business facility. This kind of advice was meant to provide some initial protection from gaseous emissions at higher initial concentrations, but people need more information to properly respond and to help answer their concerns with frequent updates.

People need to get these notifications and updates and there are a range of technologies currently used: (1) sirens; (2) digital signs (e.g. highway signs); (3) cellphones (i.e. SMS text messages or recorded voice messages); (4) emails (e.g. to previously registered participants); (5) land line or VoIP telephones (recorded messages); and/or (6) social media. Multiple communication paths would help improve the probability of receipt of these messages.

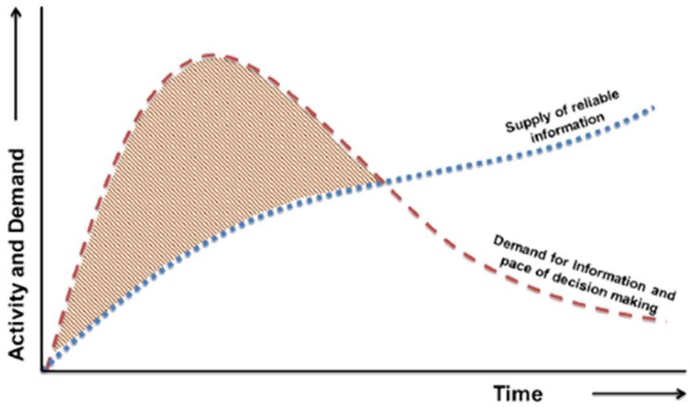
Emergencies (e.g. hazardous situations) have to be detected, then decisions made, and actions taken. But humans can make errors or have delays in responses sometimes, so automatic systems need to be in place to ensure the necessary communications are rapidly made to those at risk. Most safety systems incorporate these kinds of automatic responses (all previously analysed and decided with supporting engineering and managerial input) on the underlying process and control systems, and community notifications can be included in the hierarchy of responses. All these methods can easily be linked into Digital Transformation technologies and tools to be automated.



During a community safety scenario linked to a hazardous event on an energy industry site, it is likely that there would be a gap in crisis management information as shown in the figure below[19]. There would be a large demand for information from communities and regulators / officials, and the supply of reliable information would be inadequate initially. Digital Transformation gives us the technologies and tools to help fill this gap. Automated systems can compensate for potential delays caused by people in obtaining this kind of information. Sufficient IoT sensors inside these facilities, along the boundaries, and in some

[19] https://www.in-prep.eu/wp-content/uploads/2018/05/IN-PREP-D-2.1-Success-and-Failure-Factors_v1.00.pdf

instances inside the communities can help gather data able to be analysed and used to give the right messages.

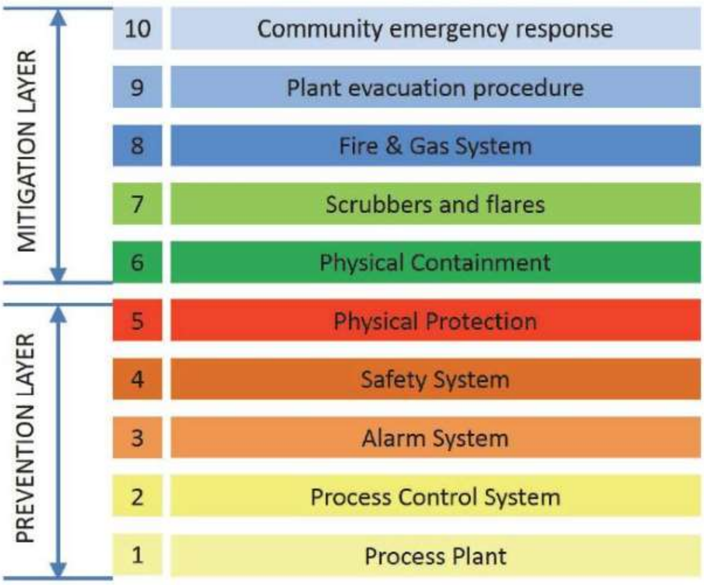


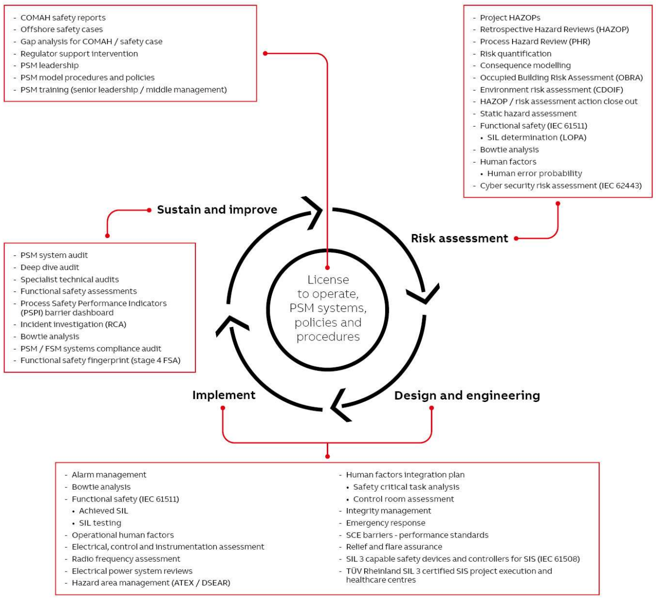
A last area to discuss is the safe export of products and waste from energy industry facilities. Energy could be exported, either as hydrocarbon products (i.e. oil, condensate, gas, LPG's) or as power (e.g. electricity). Either way, this energy will pass through our neighbouring communities and could have an impact on them in certain risk scenarios. We need our site safety systems interfaced with export systems' safety measures to ensure that the energy is controlled and stopped if needed to allow external stakeholders to deal with any external emergencies along the path of this energy to market. Safety and control systems need to be able to recognise and respond to external issues and safely shutdown our facilities. Waste may be produced from our facilities and it could be by-products of processing (e.g. reservoir fluid impurities) or else it could be discarded equipment or materials (i.e. batteries, damaged solar panels, or wind turbine blades) – in either case the waste needs to be safely monitored and sustainably and legally disposed in accordance with statutory requirements. RFID tracking devices as well as Blockchain can help with this challenge.

Digital Transformation offers many technologies and tools to provide data and work processes to help deliver increased community safety. There are multiple suppliers of these technologies and companies ready to help implement these solutions. As part of the Energy Transition, we need to be taking these steps to deliver safer outcomes with increased efficiency and less emissions or discharges.

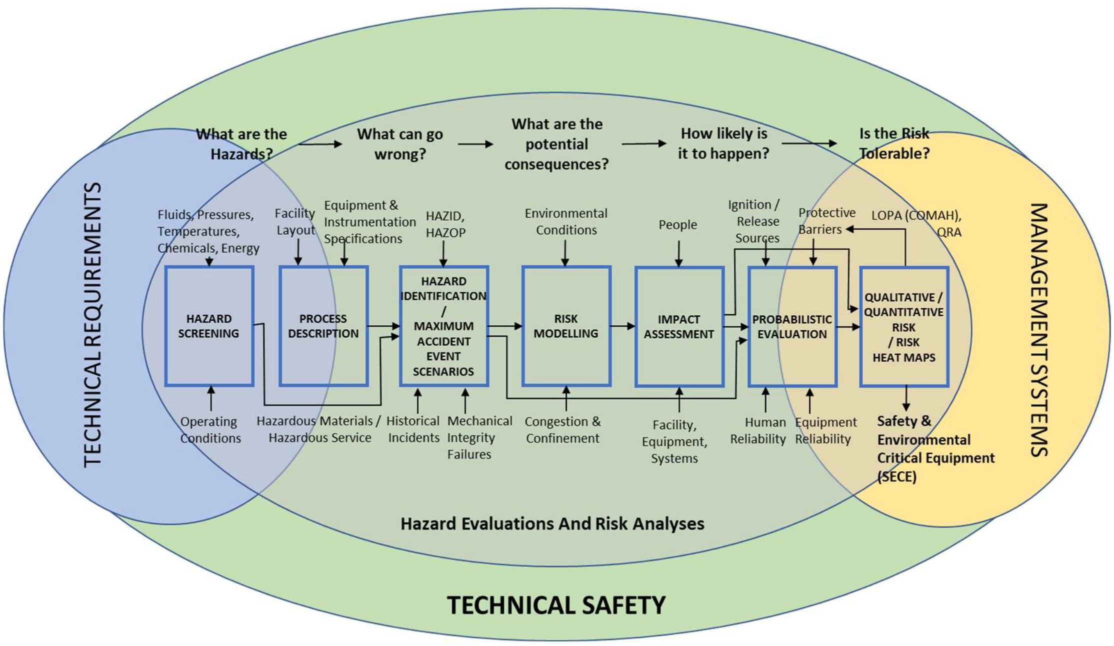
4. Increased Technical Safety

Technical Safety is delivered throughout a facility's life cycle from "Risk Assessment" to "Design and Engineering" to "Implement" to "Sustain and Improve". Elements of Technical Safety appear throughout the Risk Prevention and Mitigation Layers of Safety Management. Digital Transformation can help deliver increased Technical Safety through better analytical tools (during Design as well as during Operations); contextualised data throughout the life cycle; proper selection of IoT devices, safety and control systems, and data visualisation (including dashboards and risk maps); and improved training of Operations and Maintenance teams with respect to Technical Safety management.

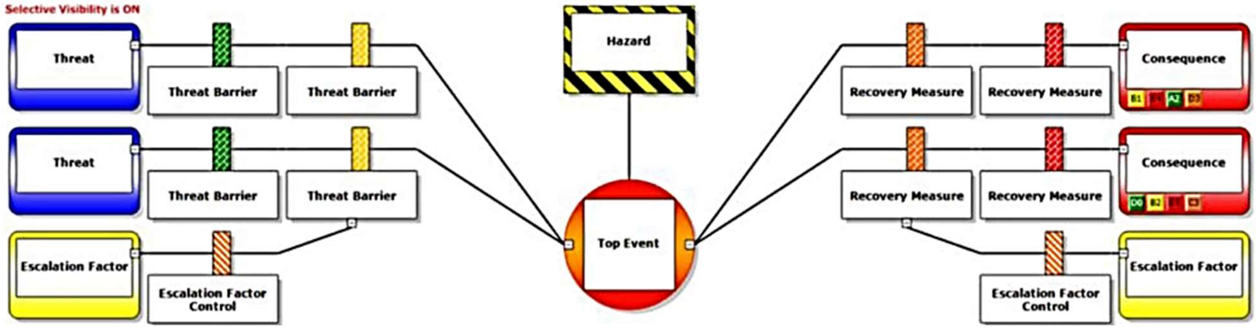




Technical /Process Safety systems need to be layered and need to be contextual, automatic, and integrated. Work begins with technical Risk Assessments, then Engineering and Design, then Implementation, then Management as part of a Process Safety Management system. This is a familiar cycle, and we have good Digital Transformation technologies, tools, and work flows to help improve this cycle.



Technical Safety work includes: (1) Screening for the nature of potential Hazards; (2) Identification of potential Maximum Accident Events (MAE) Scenarios; (3) MAE Technical Modelling (i.e. fire, blast overpressure, electrical discharges etc.); (4) Risk Impact Assessment (i.e. structural or mechanical integrity, energy release, escalation potential); (5) Probabilistic Evaluation of Risk Event; (6) Qualitative and Quantitative Risk Assessments (e.g. potential incidents – preventions and mitigations); and (7) Facility Risk Visualization (e.g. risk heat maps). From this technical work in the engineering analysis and design phase of a development, it becomes evident where attention is needed to address these risks – it is ensuring the integrity of Safety and Environmental Critical Equipment (SECE). Applicable Digital Transformation technologies and tools would include IoT devices to monitor potential Threats and Threat Barriers. Data from these IoT devices would be analysed, either on the Edge (Stream/Online) or remote in the Cloud (Offline), and the performance of these Barriers could be integrity assurance monitored for potential degradation or even misuse (e.g. alarms turned off / overridden / inhibited). Barriers are essential components of Isolation Management.



Implementation of Isolation Management includes both <u>Barrier Management</u> (i.e. structural integrity, process containment, ignition control, detection systems, protection systems, shutdown systems, and monitoring of critical processes) and <u>Alarm Management</u>.

Implementation work for these <u>Barriers</u> needs to be audited and assured on a continuous basis. Examples of critical production systems typically assured in the UK include the following tests[20] – and the role of potential IoT device testing, monitoring of functionality, and data analytics has been added to each item to demonstrate what is possible:

- <u>HVAC dampers</u> – "introduce test gas or test smoke into fan ducting" - internal gas/smoke and temperature IoT detectors should be utilised (as well as ensuring responses to external IoT detectors) and the dampers should be physically function tested (e.g. British Standard 9999:2017 Annex W.1 and UK HSE notice[21] and advice[22]) and visually observed – wireless cameras could be used (where external inspection is difficult) to monitor closure performance during these tests and wireless position indicators could be used – proper selection and positioning of IoT devices could allow personnel inside Temporary Refuges (TR) to monitor these dampers without having to leave the safety of the TR;
- <u>Fire detection system</u> – "check operation of multiple detectors, with voted input to ESD" – guidance is given by the FIA[23] and BS 5839 Part 1, Clause 45.4 but a lot of this testing historically was manual, so the use of real-time remote monitoring of these devices should be used with digital addressable detectors able to be checked (BS EN54 Parts 2 and 4:1997/A1:2006) for signal

[20] https://www.hse.gov.uk/offshore/kp3handbook.pdf
[21] https://www.hse.gov.uk/offshore/notices/sn_06_05.htm
[22] https://www.hse.gov.uk/offshore/trhvac.pdf
[23] https://www.fia.uk.com/uploads/assets/uploaded/c5f0c9cc-c4bb-45dd-9674a6e0c508957a.pdf

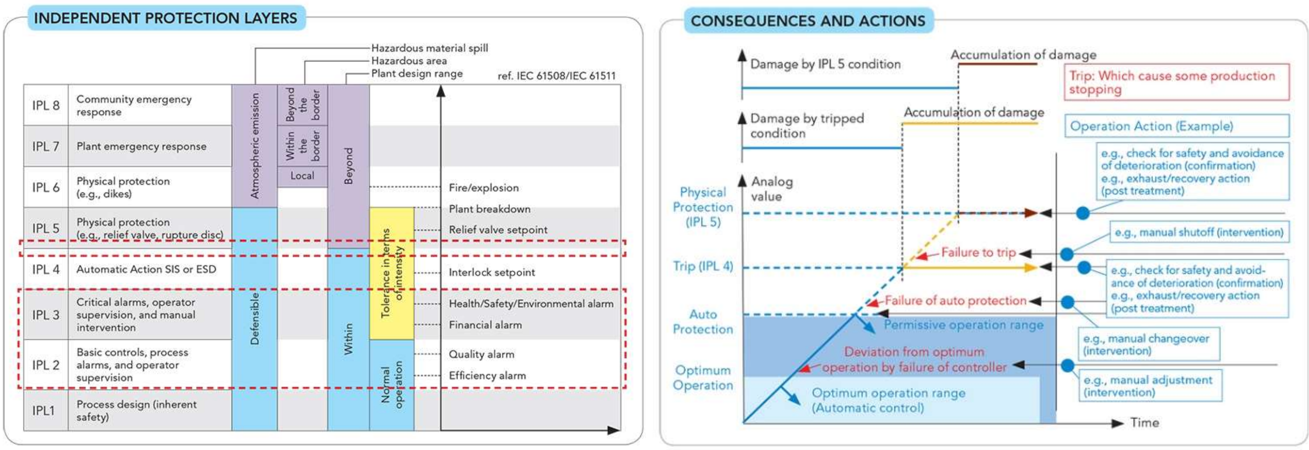
transmission integrity (e.g. fault checking), sensitivity settings, battery readings (e.g. wireless devices), and ambient (normal) environment readings, all structured, contextual IoT data recorded and monitored for degradation with data analytics;

- Gas detection system – "check operation of multiple detectors, with voted input to ESD" – testing guidance is provided by UK HSE[24] , BS EN60079-29-2:2015, and EN 45544-4 (2016); real-time diagnostic testing is recommended similar to that described above for fire detectors;
- Blowdown valves – "check individual operation by "blocking in" manual valves" – safety relief valves need testing to check lifting pressure and seating checks (e.g. passing) prior to installation, but in situ testing is more difficult due to safety concerns and possible damage to the valve and adjacent equipment, but specialist testing equipment and devices have been developed[25] to measure valve parameters and the readings, all structured, contextual IoT data recorded and monitored for degradation with data analytics;
- ESD interstage valves (on non-operating trains) – "check closure against performance standard by direct methods or operation of ESD loop" – emergency shutdown valves (ESD) are critical valves which need to be tested for closure performance[26] (including pneumatic or hydraulic actuator pressures, timing, and position indication) and leakage[27] – there are testing systems to measure these parameters in real-time with periodic partial stroking tests using smart positioning indicators and BUS communication systems (i.e. HART or Profibus) with structured data recorded and monitored for degradation with data analytics – an added benefit is that the partial stroking exercises the valve to reduce the chance of seizing/sticking and improves the Safety Integrity Level (SIL) rating of the valve;
- Deluge (wet test) – "select one area for test. Check all parameters in accordance with the performance standards. Consider simulated failure of sequential fire pumps" – this is called active fire protection and guidance is provided by UK HSE[28] since historically ~50% of deluge system tests had failed in the North Sea - testing is difficult and if wet testing (e.g. saltwater) was used, it could be difficult to clean up afterwards, so other forms of testing of the pumps, piping, and nozzles should be used – pumps are able to be tested with manual diversion into closed test loops and pump performance readings monitored and records maintained for subsequent evaluation of any degradation - piping could be tested with low pressure pneumatic tests to check integrity – nozzles could be checked with dry deluge tests which use pressurised vapour (nontoxic smoke[29] or air[30]) and wireless pressure and acoustic IoT devices could monitor potential nozzle blockages by the resultant differential pressures or sounds;
- Fire pump operation – "check in response to a number of different initiators" – manual testing has historically been used, but automated pump testing is possible with IoT devices connected into the PLC system using Modbus protocol and collecting pump system data on a periodic basis including pump power systems (i.e. diesel (fuel quantity and quality) or electric (power availability)), pump water sourcing systems (i.e. tanks or seawater), piping integrity (e.g. low pressure pneumatic

[24] https://www.hse.gov.uk/pubns/gasdetector.pdf
[25] http://ses.seetru.com/services/site-services/insitu-safety-valve-testing/
[26] https://www.hse.gov.uk/pipelines/resources/emergencyshutdown.htm
[27] https://www.hse.gov.uk/foi/internalops/hid_circs/technical_osd/spc_tech_osd_49.htm
[28] https://www.hse.gov.uk/offshore/infosheets/is5-2009.htm and https://www.hse.gov.uk/offshore/infosheets/is1-2010.htm
[29] https://siron.eu/dry-deluge-test/
[30] https://www.paradigm.eu/flow/services/fire-services/dry-flo

testing), valve systems, and the pumps themselves (i.e. speed, torque, vibration, etc.) – certain pump systems could be remotely activated periodically and run for short durations (e.g. 2 minutes) – with the resultant readings, all structured, contextual IoT data recorded and monitored for degradation with data analytics.

Alarm Management is the other critical Implementation activity which could be facilitated through Digital Transformation technologies and tools. Without better alarm management, the underlying alarm systems become less effective, and facility automation and therefore process safety could be impaired. “Over-alarming” is a typical failure in some facilities – too much information for the operators to easily identify root cause issues which often led to operators over-riding some alarms which could lead to unintended consequences of reduced layers of protection. The large number of tags and associated IoT devices and alarms need to be properly managed. Alarm rationalization is required and it should start with understanding the Independent Protection Layers present in a facility to handle potential incidents[31]. The kind of alarms useful for operators to avoid disruption to production are associated with IPL 2 and 3. Alarms associated with IPL 4 are related to the Safety Instrumented System (SIS) and emergency shutdown (ESD) functions. Alarms need to be prioritized to give operators the ability to react where manual actions may be required (e.g. failure of some part of the SIS) and these alarms should not be overwhelmed by a quantity of lower level alarms. This means the consequences of a event generating an alarm and the corresponding remedial action required needs to be understood. As the consequences escalate and the needed manual actions become more drastic, this must become rapidly clear to the operators without nuisance alarms clouding the situation.



Nuisance alarm characteristics include:

- “calling attention to a situation that the DCS or SIS can correct automatically with no production disruption or other ongoing consequences, and so not requiring operator action;
- duplicating another alarm or multiple alarms responding to the same root cause;
- giving a false alarm caused by an arbitrary trip, often due to an incorrect setpoint;
- indicating a situation, such as one created by planned maintenance, not needing an operator response;
- requiring an operator response — but the operators don’t know what it should be (which is actually a training issue);
- demanding an operator response that is too complex or involved to be carried out in the available amount of time;
- necessitating an operator response that the DCS could and should do (which really indicates the function should be automated more effectively in the DCS); and
- resulting in no consequences if the operators cancel or ignore the alarm.”[32]

[31] https://www.chemicalprocessing.com/articles/2018/optimize-alarm-management/

[32] https://www.chemicalprocessing.com/articles/2018/optimize-alarm-management/

These are pretty intuitive nuisance alarms, but they may not be immediately evident during the engineering phase of a development, so data is needed to be collected and analysed. An example of a facility with ~1,500 process measurements with an additional ~2,900 in subsystems (e.g. packages) could create ~10,500 function blocks for single points, which could then lead to ~64,000 potential alarms. Clearly rationalisation (prioritization) would be needed. Digital Twins prepared with dynamic process simulations combined with control system emulation should be tested against multiple process scenarios by the engineers to find as many possible unnecessary alarms. Then when the Digital Twin is utilised as an Operating Training Simulator (OTS), the operators being trained would help find and identify other nuisance alarms from their experience. Finally during field operations, the frequency of alarms should be monitored and recorded in an alarm database (e.g. in the Data Historian) with actions taken to identify root causes so that either addition training could be provided, or the DCS logic updated, or unnecessary alarms removed. Alarm activity statistics analytically compared against operational responses will help identify where alarm management could help. Evaluating process conditions and contextual event data before and after operator actions with data analytics would help optimise alarms to be "good" alarms under EEMUA guidelines ("good, unique, timely, prioritized, understandable, diagnostic, advisory, and/or focused"). Another useful strategy is to characterize alarms relevant to different areas and hierarchies – all alarms could be in the system, but operators might see alarms differently than engineers who might see alarms differently than management. This is sometimes called Alarm Shelving[33] and it is a useful part of temporary alarm management.

Another type of alarm requiring better management is Standing Alarms – tags that remain in alarm for extended periods, sometimes not cleared on a shift, sometimes not really requiring operator actions, and always congesting the alarm system. Alarm Floods are multiple alarms in a short period of time and they can make it difficult for operators to quickly determine the root cause and any necessary actions. Some of these alarms can be ones that are better characterised as Alerts and therefore may not necessarily require responses. Alarms with the wrong priority can cause confusion also. Out of Service Alarms are alarms from equipment not running still producing alarms or alarms that have been shelved and not revisited for unshelving. Finally Redundant Alarms are multiple alarms about the same event and same potential action. Analytical tools should be applied to these alarms to rationalise them or else ineffective alarm management could lead to serious process safety issues. GE gave a good "top 10" summary[34]:

	Top 10 Reasons to Rationalise Alarms:
1	To make sure operators get the information they need; formatted so they can recognize what's happening, its importance, and the appropriate action;
2	To reduce the total number of alarms to the minimum necessary to operate the plant safely and efficiently;
3	To prioritize alarms by importance or significance in terms of risk (safety, environmental, operational, and cost) and in relationship to other alarms;
4	To improve presentation, organization and availability of alarms for safe and efficient operation of the facility and for effective troubleshooting;
5	To reduce the number of alarms occurring during abnormal situations to the minimum required to diagnose, identify and understand the indicated condition;
6	To approach the "black screen" concept: Bring the number of alarms during normal operation to near zero by reducing standing, chattering, nuisance, and transient alarms; optimizing alerts; managing pre-alarms; improving field instruments; identifying process issues; etc.;
7	To validate all alarm parameters including action, setpoint, deadband (change required in the process signal to either activate the alarm or return the alarm to normal), test frequency, etc.
8	To verify alarm performance parameters including detection time, required action, appropriateness of action, required time to perform action, training, procedures, help screens or manuals, etc.;
9	To identify process design issues and faulty field instrumentation;
10	To document the alarm system for internal use and regulatory compliance.

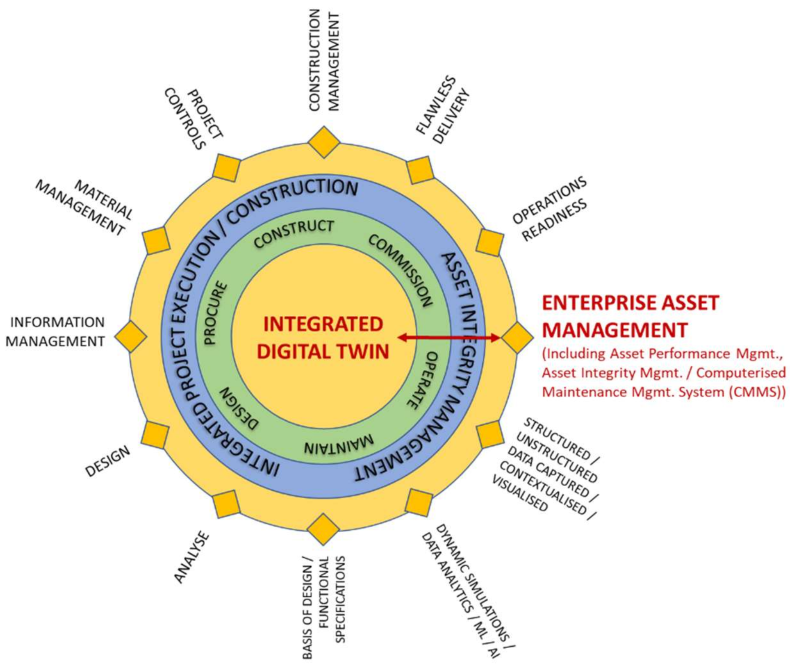
[33] https://info.yokogawa.eu/acton/fs/blocks/showLandingPage/a/18463/p/p-00c4/t/page/fm/0
[34] https://453271.app.netsuite.com/core/media/media.nl?id=22207&c=453271&h=e72aec47773062a9bead&_xt=.pdf

Process Safety Management continues during Maintenance. Maintenance issues and backlogs are a serious challenges to maintain Technical Safety. As well as SECE maintenance, inadequate Fabric maintenance could lead to safety issues and influence the effectiveness of barriers and layers of protection. UK HSE (as part of COMAH guidance) highlighted some key Technical Safety considerations with respect to Maintenance Procedures[35]:

Aspects to Consider	**Examples of Safety Risk Issues**
Human factors	Poor communication between operations and maintenance teams
Inadequately skilled work force	Human errors during maintenance
Unconscious and conscious incompetence	Incompetence of maintenance staff
Consideration of maintainability principles	Inadequate maintenance increases subsequent risk profile
Knowledge of failure rate and maintainability	Static or spark discharge during maintenance in an intrinsically safe zone
Clear criteria for recognition of faults and marginal performance	Failure of SECE due to lack of maintenance

Maintenance Management systems are therefore critical to consider these aspects and facilitate risk mitigation to help deliver increased Technical Safety during Maintenance. Maintenance could be some combination of planned, risk-based, reliability centred, condition based, and/or breakdown based. Digital Transformation gives us several tools to use and they are based on contextual data being created and maintained for equipment, Digital Twins used for training, IoT devices monitoring the performance of the equipment, data analytics on the data received, and the use of Machine Learning / AI to help identify insights and make maintenance decisions on these analytical results.

Communication between Operations and Maintenance teams should rely on a "single source of truth" which should be the Integrated Digital Twin connected into the Enterprise Asset Management System (including Asset Performance Management / Asset Integrity Management / Computerised Maintenance Management System):



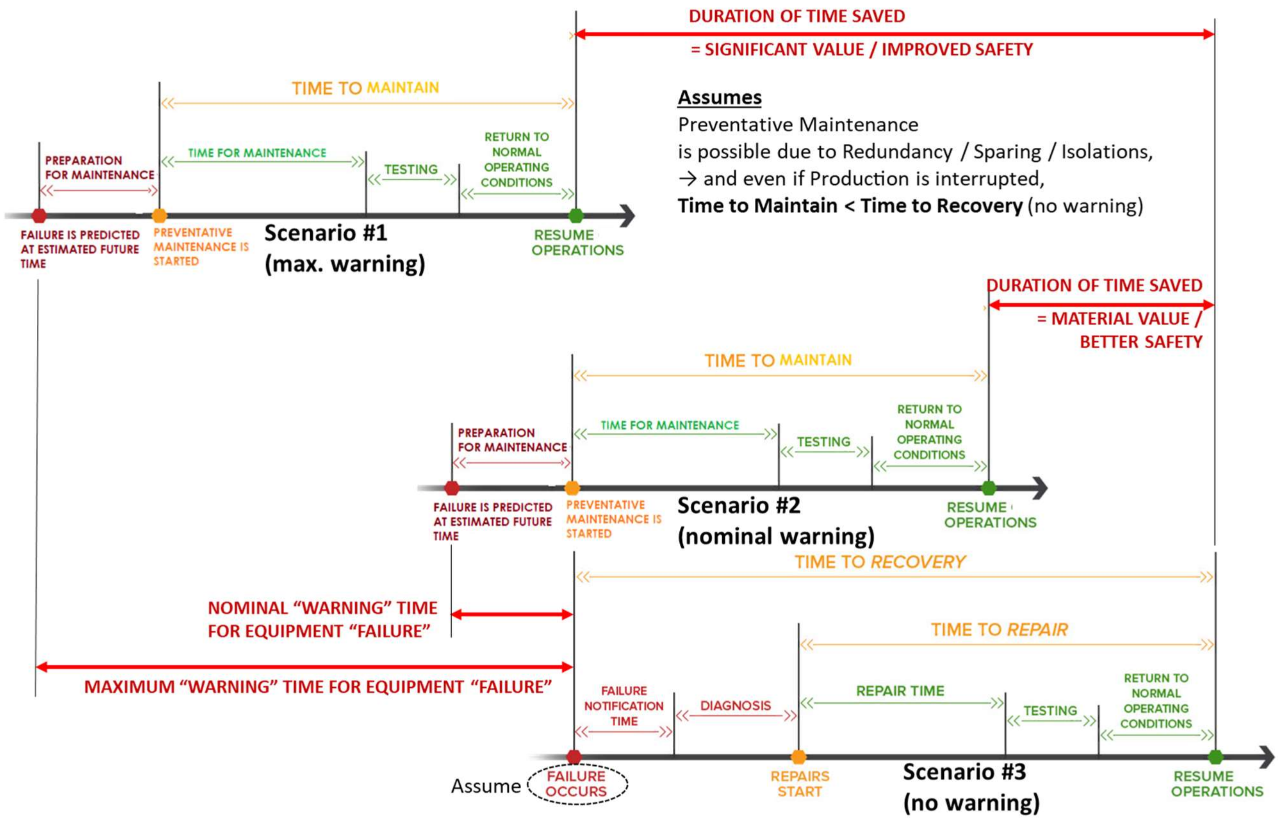
[35] https://www.hse.gov.uk/comah/sragtech/techmeasmaintena.htm

All up to date equipment and systems data from engineering to manufacturing and testing to installation to operations and maintenance would be safe and reliable, available immediately to any user. Training on how to safely operate and maintain equipment would be available to be accessed any time any where. Live field data on process conditions (i.e. fluids, pressures, temperatures, flowrates, and equipment settings) would be available – including whether a piece of equipment had been safely isolated and de-energised ready for maintenance. Data analytics (including ML/AI) performed either on the Edge or in the Cloud on equipment performance (and any signs of degradation e.g. “failure signatures”) would help the teams adjust operating settings or else begin preparations for maintenance. Having predictive maintenance analytics linked to the EAM means that work / job orders would be systematically staged to prepare for maintenance including ensuring the necessary spares, tools, and maintenance team competencies were prepared (i.e. ordered, logistically sent to the right place, and any training scheduled) and shown on a dashboard indicating state of readiness for upcoming maintenance. Details of Job Safety Analyses and any necessary isolations would be automated for action in a timely manner before being required.

In spite of aspirational efforts to stay up to date with Maintenance tickets, backlogs do develop and Operations and Maintenance teams have to know how to handle this to help minimise any Technical Safety issues. Historically backlogs developed for many reasons, with most now hopefully being addressed: (1) inadequate preparation (i.e. wrong procedures, spares, tools, or competencies); (2) lack of proper energy isolation; (3) no consideration of simultaneous operations in the area of the maintenance; or (4) inadequate planning of how long the maintenance might need to take and its consequential impact on production. We have addressed many of these issues in the preceding paragraphs, but still there will be backlogs. There are finite resources available in the field to do work and therefore prioritisation of these resources would be needed. Logistical challenges are typical in a busy world (including weather, third party performance, regulatory or security issues) with delays to materials and equipment or even people arriving at the facility location as requested. Public health issues are a more recent challenge but they impact all resources. Not all materials and tools may necessary be at a remote location without special preparations. And emergencies happen – things break, people have personal or family issues, or production fluids may have an uncontrolled release due to environmental conditions.

Asset criticality is a key element of prioritisation – is the work backlog item a SECE that needs to be maintained or else production needs to be shutdown? Is the maintenance required for a safety barrier critical to the layers of protection? Corrective maintenance of out of service equipment (breakdowns) may be higher priority than preventative maintenance (depending on the delay required). Time “available” or “required” to complete some maintenance tasks can also impact priorities depending on what impact there might be on production. Some tasks need to be done in daylight with improved visibility for safety reasons. Production Critical Equipment (PCE) would have higher prioritisation than routine fabric maintenance. These backlogs have to be managed and for most assets, a normal backlog per maintenance team technician has been estimated to be up to two weeks of work, but it should be a lesser percentage of deferred (critical) and a higher percentage of routine (non-critical) maintenance work.

With improved data analytics, it may be possible to estimate the time remaining until predicted “failure” (MTBF). The illustration below shows two durations of “warning” of predicted equipment failure compared to “no warning” – in either case it is better to predict “failure” and get started on preventative maintenance. Technical Safety is improved through Digital Transformation data analytics helping to minimise unexpected failures, particularly of SECE.



Delivering increased Technical Safety has obvious improvements in Personal Safety, Community Safety, Environmental Safety, and Regulatory Safety. The next two chapters will address these last two safety topics.

5. Increased Environmental Safety

Environmental safety is delivered through setting proper policies, planning, implementing an environmental management program, inspecting the outcomes, and reviewing / auditing / assurance. Somewhat related to community safety, environmental safety includes persistent impacts on air, water, and soil quality which could cause long-term harm to the ecology of our locations. Risks to flora and fauna have to be monitored and mitigated.

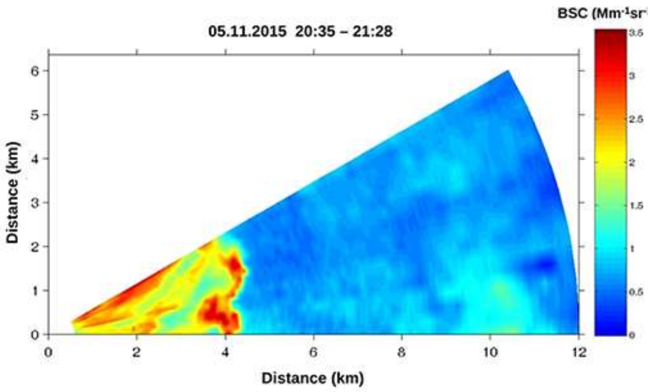
Energy industries can have various atmospheric emissions including methane, CO_2, CO, NO, NO_2, NO_X, and chemical fumes. Liquid discharges can include liquid hydrocarbons, produced water, sanitary effluent, and chemical streams. Solid waste can be packaging waste, garbage, and chemical by-products. Noise is an important "emission" from many types of facilities that similarly needs to be considered.. All of these waste streams can have adverse environmental consequences and need to be managed throughout their life cycle from raw materials, to manufacturing, to transportation, to product usage, and ideally to reuse or recycling. Environmental management can be facilitated with Digital Transformation technologies, tools, and work flows.

The familiar "Plan-Do-Check-Action" methodology can be used for Environmental Safety with the following additions (commentary) for how Digital Transformation can help:

- Plan: a key part of satisfying stakeholder and regulatory requirements is information – having a comprehensive database of environmental information, constantly updated with facility performance and emission, discharge, and waste levels, will be an important part of a good plan – a Digital Twin linked into the Enterprise Asset Management (EAM) system will help satisfy this objective;
- Do / Implement & Operate: again data is a key part of this aspect of the work – facilities need to have sufficient numbers and locations of IoT device sensors to track all the data needed for performance monitoring and these devices need to be in real-time communication with Edge and remote Cloud systems to store, clean, contextualise, and make the data accessible for visualization and data analytics. Proper environmental management systems need training of the operators and maintenance teams to ensure their work keeps the facilities operating efficiently, minimising emissions, discharges, and waste;

- Check / Inspect: once we have the IoT data in the systems described above, it is crucial to have good visualisation systems, not just large files of numbers or unstructured data which might not be adequately checked, and data analytics processing the data can then better highlight for operators and stakeholders where there are any risks (e.g. risk maps) or gaps in best possible environmental management of the facilities;
- Action / Review: a good management system facilitates communication for assurance and management reviews – the work processes above should be designed to filter the complex data and analytics into more manageable formats so that visualization tools like Dashboards, Reports, and Metrics can be extracted from the Digital Twin[36] and EAM[37]; and, from these outputs, lessons learned can be identified and improvements can be made to the environmental management program.

Emissions need to be monitored for several reasons: (1) to ensure facilities and equipment are running efficiently and safely (where increased emissions may be leading indicators of some issue); (2) to satisfy regulatory limits on specific types of emissions; and (3) to help identify and mitigate potential public health issues associated with particulates.



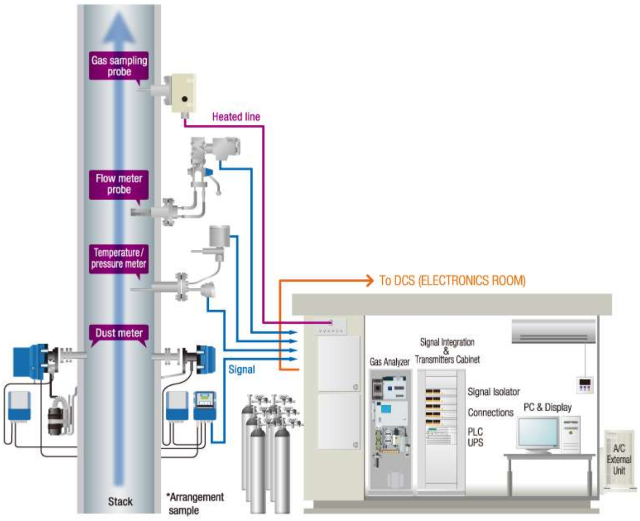
(b)

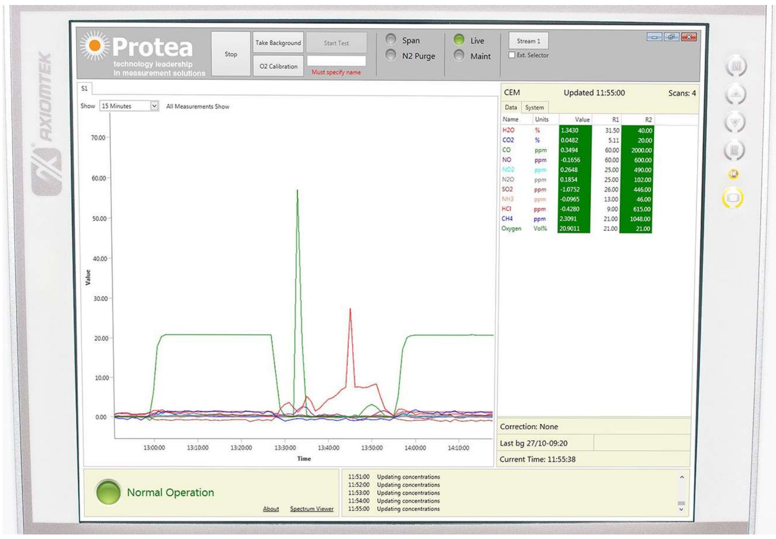
The emission of solid aerosols (i.e. asbestos, carbon dust, heavy metals) is a serious environmental safety risk. The size of particles is linked to their potential for causing health problems. The EU has set a limit of 40 µg/m3 of Particulate Matter (PM10) in the atmosphere which needs sensor systems at the source as well as potential use of mmWave radar[38] and Lidar mapping[39]. Different systems can be used to monitor these types of emissions for a range of meteorological conditions at a particular locations.

There are several sensing methods to obtain measurements of NO, NO_2, and NO_x including (1) chemiluminescence analysers (CLS); (2) infrared spectroscopic analysers (IR); (3) ultraviolet spectroscopic analysers (UV); and (4) electrochemical cells[40]. Legal requirements typically specify emission limit values (ELV) which need to be provided on a routine regular basis to stakeholders and regulators. These systems should be part of a Continuous Emissions Monitoring system linked into the Digital Twin.

[36] https://www.mdpi.com/2071-1050/12/3/1088/pdf
[37] 26# visualization types presented at https://eam-initiative.org/pages/rudhzkc6j35z/EA-Visualization
[38] https://www.researchgate.net/publication/326798744_Remote_Characterization_of_Particle_Streams_With_a_Multistatic_Dual_Frequency_Millimeter-Wave_Radar
[39] https://www.intechopen.com/books/aerosols-science-and-case-studies/lidar-mapping-of-near-surface-aerosol-fields
[40] https://www.sepa.org.uk/media/156002/gg5_monitoring_nox_sepa_version_1.pdf

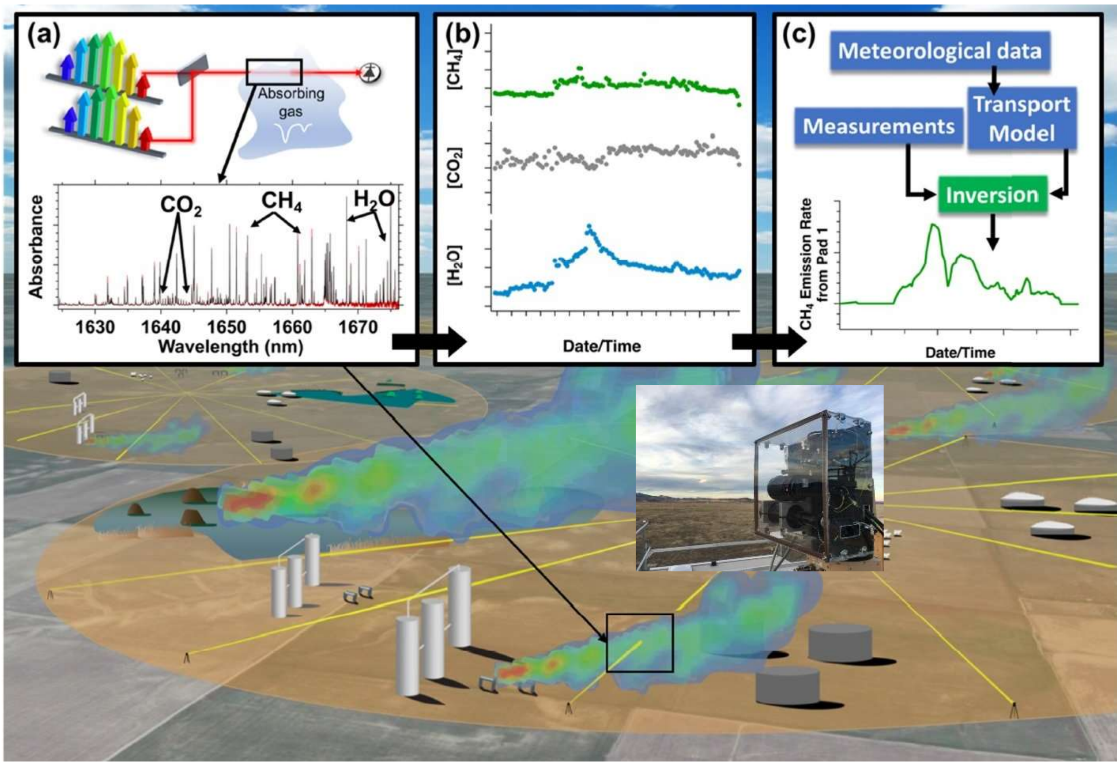
Stack emissions monitoring systems can check a range of emissions from combustion gas emissions to non-standard organic VOC emissions or CFC emissions. Along with the necessary sensors, Data Acquisition Software for emissions is a critical component of a Continuous Emissions Monitoring system. Emissions Reporting Software would combine gas readings with those of dust, flow, temperature and process conditions."[41] Continuous Emission Monitoring Systems (CEMS) are facilities to measure flow, dust, concentration of air pollutants (such as SO2, NOx, CO etc)[42] and capture structured data ready for data analytics and dashboards.



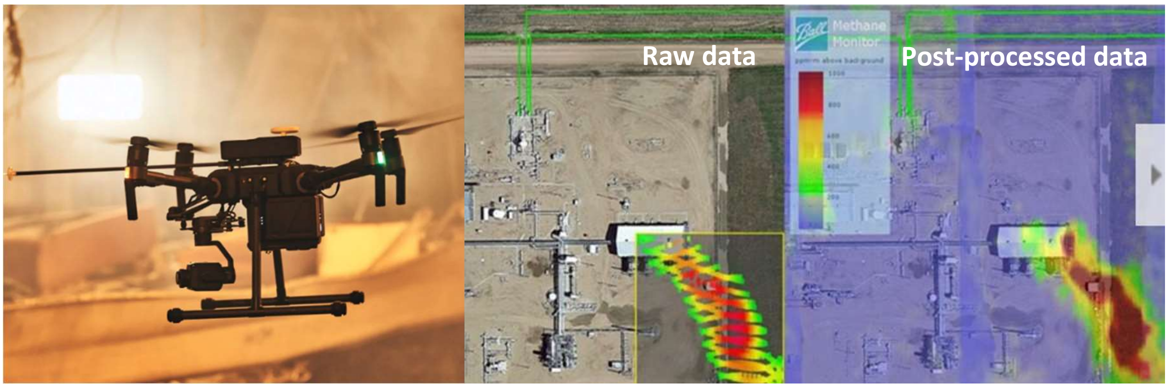


41 https://www.protea.ltd.uk/emissions-reporting-software
42 https://www.horiba.com/uk/process-environmental/products/system-engineering/continuous-emission-monitoring-system-cems/

Land based air quality measuring systems can be used with either fixed location air sampling sensors (as described previously) or with a unique remote method which utilises a dual-frequency comb laser spectrometer. The spectrometer sits in the center of a circle (illustration below) which is ringed with retroreflecting mirrors. Laser light from the spectrometer (yellow lines) passes through any gas clouds, strikes the retroreflector and is returned directly to its point of origin. The data collected is processed and then used to identify any leaking trace gases (including methane), as well as calculated leak locations and their emission rates[43]. All structured data would then be available for visualisation and data analytics.



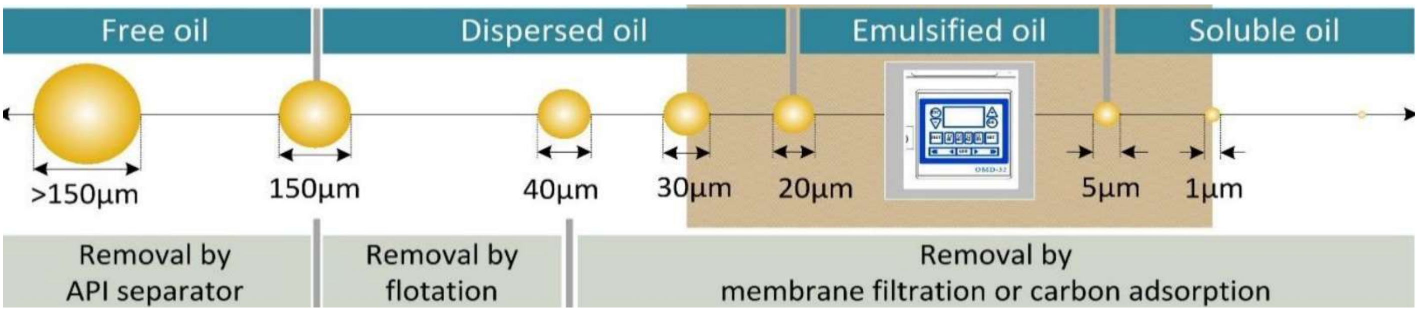
Drone based monitoring systems are able to incorporate photoionization detector (PID) and Lower Explosive Limit (LEL) detectors able to detect combustible gases (e.g. methane), carbon monoxide, chlorine gas, oxygen, nitrogen dioxide, hydrogen sulphide, and sulphur dioxide[44]. Methane monitors carried by drones or light aircraft can capture emission data during their flights which is able to be post-processed and prepared for visualisation as shown below. The data is structured data which can be used in data analytics to determine potential emissions and trends.



[43] https://phys.org/news/2018-03-laser-based-leaks-oil-gas.html and https://www.nist.gov/blogs/taking-measure/long-road-nobelists-invention-longpath-technologies
[44] https://www.coptrz.com/the-future-of-gas-detection-using-drones/

Liquid discharges from an energy industry facility are possible from several sources: (1) surface runoff of rainwater washing impurities (i.e. lubricants, chemicals, material corrosion products, or coating breakdown, etc.) off equipment and systems into natural drainage pathways in the surrounding countryside; (2) closed drains after some form of treatment (e.g. secondary or treated effluent) discharging to external drainage systems; (3) open drains discharging to external drainage systems; and (4) disposal of treated produced water (which may or may not have been effectively treated to remove any polluting components). In all cases, the surface water discharges can migrate downwards to groundwater through various mechanisms where they can potentially pollute drinking water. Pollution can affect ecologies by harming both flora and fauna. These risks mean that a range of IoT sensors should be deployed on: (1) source; (2) production and process equipment and systems; (3) water treatment equipment and systems; (4) drains; and (5) any external routes of disposal of liquids. Networked IoT sensors with Edge processing (for quickest reaction of safety and control systems) and remote Cloud processing (more detailed data analytics and better historical comparison) should be provided to deliver improved environmental safety.

Detection at source is an initial warning of issues. Online oil in water detectors[45] are valuable tools, and their ability to measure small concentrations and emulsions is important to ensure efficient water treatment systems under stricter regulatory limits. Detection technologies include fluorescence, spectroscopy, and microscopy. Remote management and diagnostics capability supports remote operations and multiple communication paths are available (i.e. 4-20mA, HART, Modbus, and Extended Ethernet). Structured data is processed and available for advanced data analytics and dashboards.





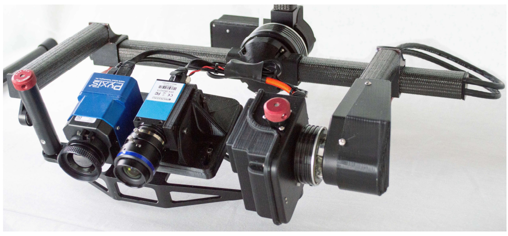
Sophisticated wireless IoT devices are available with digital and optical sensors to measure other water parameters including dissolved oxygen, pH, redox (ORP), conductivity, salinity, TDS – Kcl (total dissolved solids), temperature, nephelometric turbidity, suspended solids, sludge blankets, and ion selective probes to detect the presence of ammonium, nitrate, chloride, sodium and calcium[46].

[45] http://www.advancedsensors.co.uk/products/ex-400m/

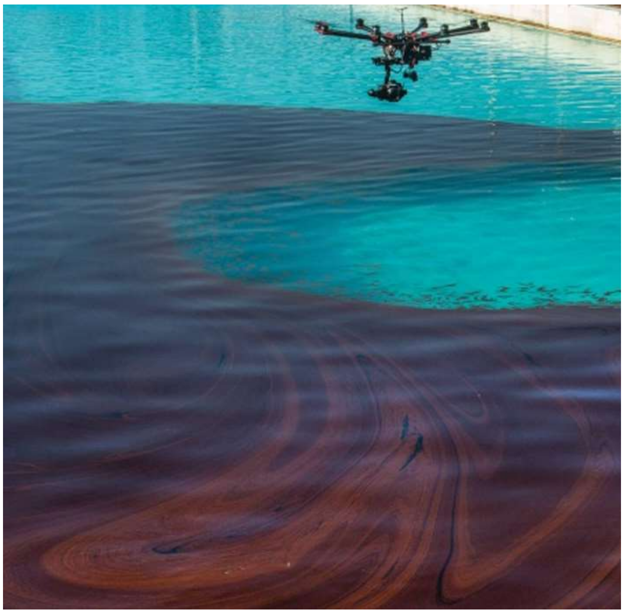
[46] http://www.libelium.com/libelium-pushes-the-water-quality-market-ahead-with-its-new-smart-water-xtreme-monitoring-platform/

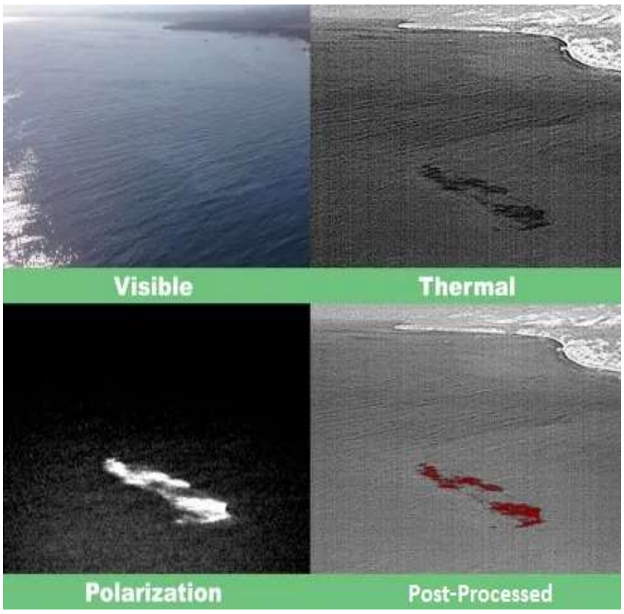
Water quality monitoring and measurements of both surface and groundwater are possible to be taken remotely, Edge processed, and data transmitted to centralised operations centers where visualisation tools and further data analytics can help identify remedial actions more quickly[47]. We do not need to necessarily rely on field teams to take sufficient, timely, and correct measurements and then enter readings manually into unstructured data that might never be properly used and acted upon. Increased reliability and safety can come from remote monitoring and diagnostics of water quality data.

Thermal imaging can detect certain elevated (high temperature) or cooled (low temperature) liquid leakages. Fixed or mobile (e.g. drones[48]) thermal imaging camera systems can be used to spot temperature anomalies:



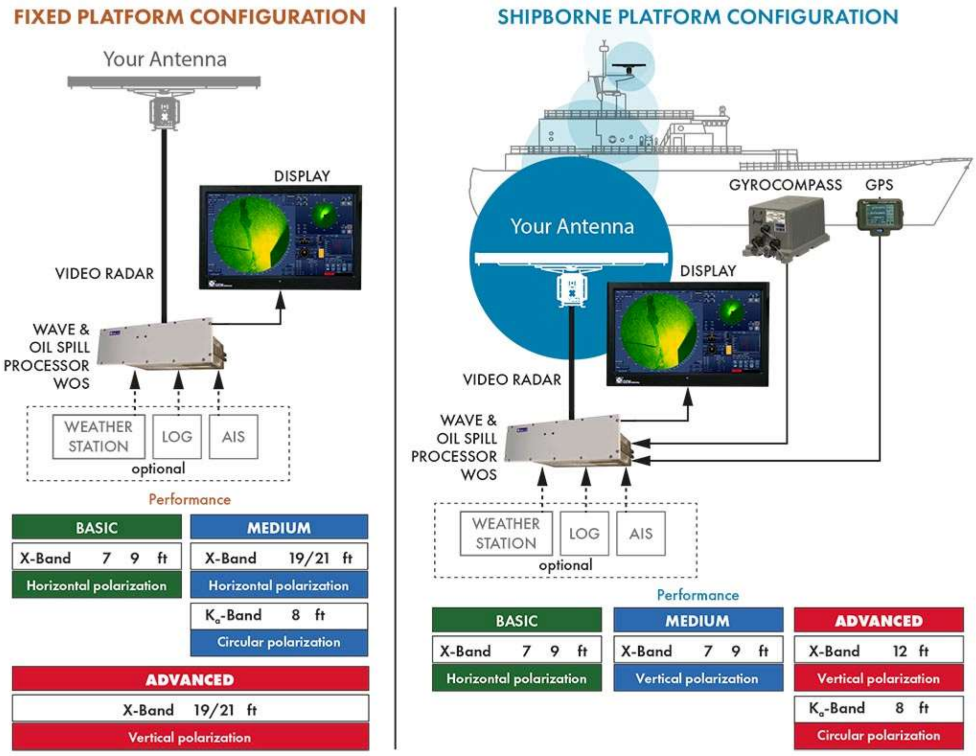
Post-processing of images can combine thermal and polarised imaging and then colourise the resultant image for better visualisation. Discharges of hot cooling water can be dangerous for ecologies and so water temperature is important to help operators make adjustments to operating settings to get the correct discharge temperatures. Routine regular imaging can help demonstrate environmental compliance to stakeholders and regulatory agencies.





[47] https://www.aquaread.com/portofolio/aquastation-self-calibrating-remote-water-quality-monitoring-station/
[48] https://www.polarissensor.com/applications/water-detection/oil-and-diesel/

High resolution X-band radar can also detect and monitor oil spills on the surface of waterways or the ocean[49]. Detectors can be fixed (i.e. on oil platforms or tanker loading jetties) or shipborne (e.g. on the back of FPSO's for monitoring offloading). Resultant imaging should be connected to analytics to give alerts to operators for anomalies to stop operations. Structured data records of imaging would help demonstrate environmental compliance.



49 http://www.gemrad.com/wp-content/uploads/2017/01/oilspill.pdf

Naturally occuring radiation from some wells can be released through gaseous emissions, liquid discharges, and/or disposal of solid waste (i.e. sludge, scales, and ashes). Environmental safety from this risk is well documented (but possibly not well understood) and is covered by detailed regulatory guidance[50]. Radiation telemetry equipment including personal wireless meters[51] are able to measure all types of radiation (i.e. alpha, beta, and gamma). Some wells can have produced water brines that carry radionuclides, specifically radium, which can be dangerous for people working in close proximity or located near treatment, discharge or disposal locations. Solid waste can include Naturally Occurring Radioactive Materials (NORM). "Radiological risk assessment and management of radionuclides entering or present in the environment are generally based on human health considerations alone."[52] So IoT device sensors, both fixed inside a facility as well as wirelessly connected wearables on personnel (illustration below at left) could be used to obtain radiation data that humans inside and outside the facility may be exposed to if associated wells have been previously identified to have this risk. Data would be collected, processed and used for data analytics and risk management. Historical data is able to be compared to look for trends that may represent issues associated with the performance of processing equipment used for treating waste streams to deal with any radioactive elements. It is critical to ensure that any material amounts of radioactive waste do not leave a facility to where it would be an environmental safety risk to unprepared communities or ecologies. Digital transformation gives us technologies and tools to help mitigate this risk.



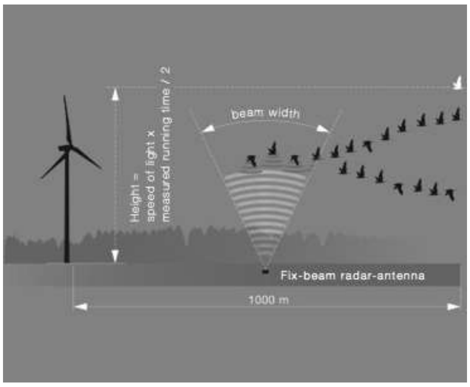
Environment noise can cause public health impacts and not just be a nuisance[53]. Adverse health outcomes (for people and wildlife) are associated with annoyance, sleep disturbance, and cardiovascular health. Disproportionate impacts have been noted on vulnerable populations (i.e. children, elderly, and breeding wildlife). Once again, IoT device sensors, both fixed inside the boundary of a facility[54] and wirelessly connected wearables on personnel[55] should be used to obtain sound levels data that humans inside and outside the facility may be exposed to – collected, processed and used for data analytics and risk management. Historical data is able to be compared to look for trends that may represent issues associated with the operational performance of equipment (e.g. loud noise caused by equipment degradation or incorrect operating settings). Communication devices carried by workers can be

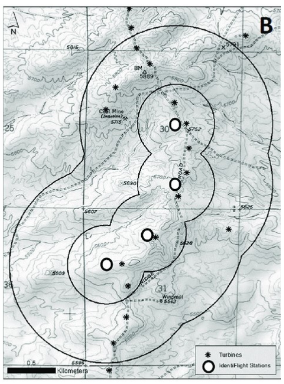
[50] https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/full-text.html (US)and https://www.hse.gov.uk/pubns/priced/l121.pdf (UK)
[51] https://www.mirion.com/products/rds-31-itx-telemetry-survey-meters
[52] https://www-pub.iaea.org/MTCD/publications/PDF/te_1638_web.pdf
[53] http://clkrep.lacity.org/onlinedocs/2017/17-0447_misc_44_07-29-2019.pdf
[54] https://www.iotsoundsensor.com/
[55] https://svantek.com/lang-en/product/127/sv_104a_noise_dosimeter.html#about

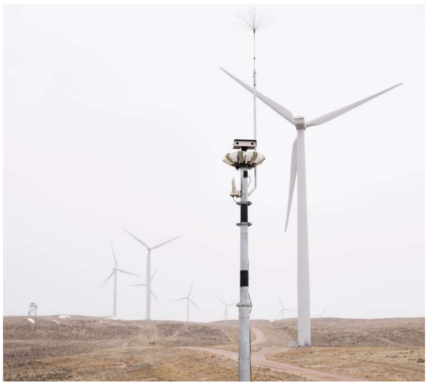
continuously connected for monitoring ambient noise levels to establish normal levels in spatiotemporal settings and then monitored for anomalies that may require intervention.

The lack of noise (e.g. audible warning) can also however sometimes cause risks for wildlife. Two examples: (1) propellors of vessels and marine mammals; and (2) wind turbines and birds. In the southern USA, Caribbean, north coast of South America, and northern Australia, marine mammals (manatees and dugongs) have been harmed by collision with vessel propellors. A partial solution for some vessels might be ducted propellors, but sound is another tool. These marine mammals have difficulty sensing low frequency humming from vessel engines and propellers. These marine mammals are good however at detecting high-frequency noises (16,000-18,000 Hz) so alarms could be used to project a high-frequency sound into the water from vessels or in harbours and ports when marine mammals are detected[56]. Remote monitoring and alarm systems could be used to provide protection to these vulnerable species.

Protection of migrating bird species is also an environmental safety concern[57]. Several potential solutions and mitigating measures are possible. Remote monitoring of bird proximity to wind farms is needed and can be provided with certain types of unmanned radar systems[58] and thermal imaging systems[59]. Two strategies are then possible once birds are detected: (1) active management of wind farms; or (2) alarm systems to "warn" birds of the risks.

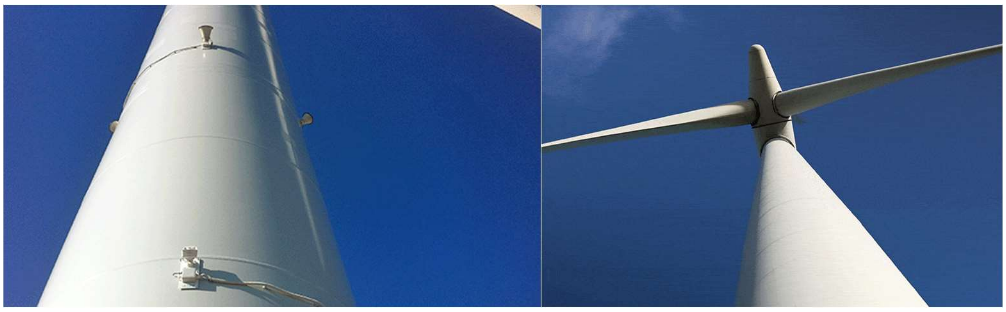




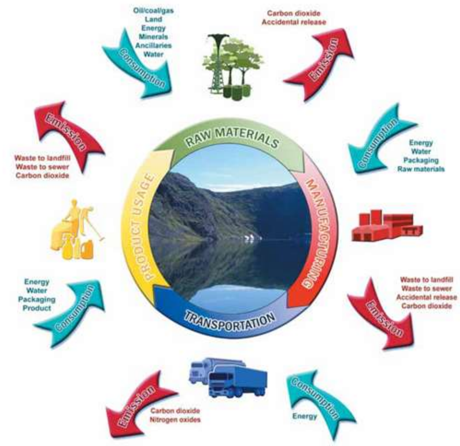


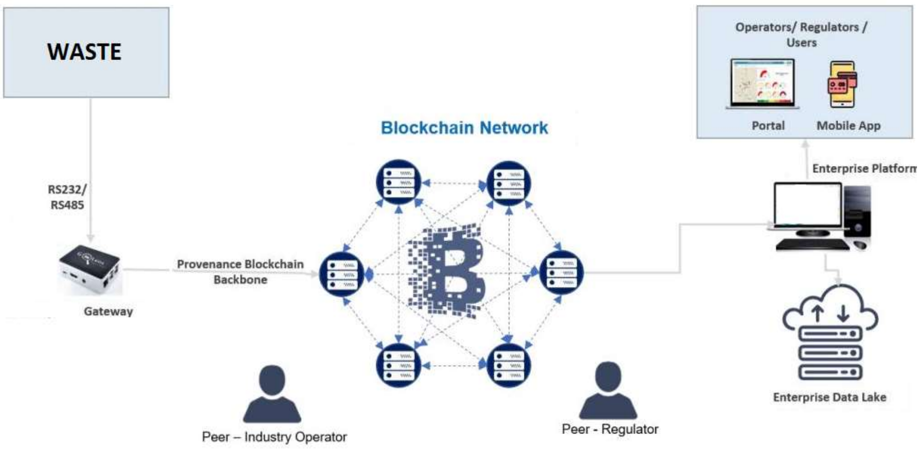
[56] https://www.nbcnews.com/mach/tech/sound-secret-saving-manatees-ncna782596 and https://asa.scitation.org/doi/abs/10.1121/1.4988032
[57] https://www.audubon.org/magazine/spring-2018/how-new-technology-making-wind-farms-safer-birds
[58] https://swiss-birdradar.com/birdscanmv.html
[59] https://www.identiflight.com/

In addition to individual wind turbine curtailment as a response option, audio warning systems have been developed. “The types of sounds, emission levels, and installation and operational settings are adjusted to: target species, WTG dimensions and local sound regulations. No energy production loss and applicable to all bird species. Species-specific sounds can be applied.”[60] Another solution has been proposed with transmitters on the wind turbine blades themselves to emit sounds to warn birds[61]. A passive system with acoustic “whistling” cues in the region of 2-4 kHz was also proposed[62].



Waste management is another part of environmental safety management. Raw materials are sourced, used for manufacturing materials and equipment, transported to the location of our energy industry facilities, and used for production and processing of energy. Waste streams are present at all stages of this cycle.





[60] https://dtbird.com/index.php
[61] http://www.freepatentsonline.com/20160366875.pdf
[62] https://www.nrel.gov/docs/fy02osti/30844.pdf

Processes need to be monitored with both technologies and tools. Technologies include IoT sensors including: (1) IoT data on waste quantities, characteristics, and production rates; and (2) RFID tags to track the locations, routes, and eventual dispositions of waste. A bad example was "recycleable waste" picked up in Australia (with an embedded satellite trackable RFID device) that was tracked when illegally dumped at sea in the middle of the Pacific. Tools like Blockchain could provide a "traceable and transparent way to regulate waste management activities."[63] Blockchain could help mitigate fraud and manipulation, ensure integral traceability, help avoid loss of information, and provide trusted documentation.

The risk that waste is not properly disposed when unethical participants divert waste to unapproved and illegal destinations can cause legal (and significant cost) issues for the originator when detected. Responsible corporate citizens want to track all streams of material, products, and waste to check efficiency of sourcing and production and then environment regulatory compliance.

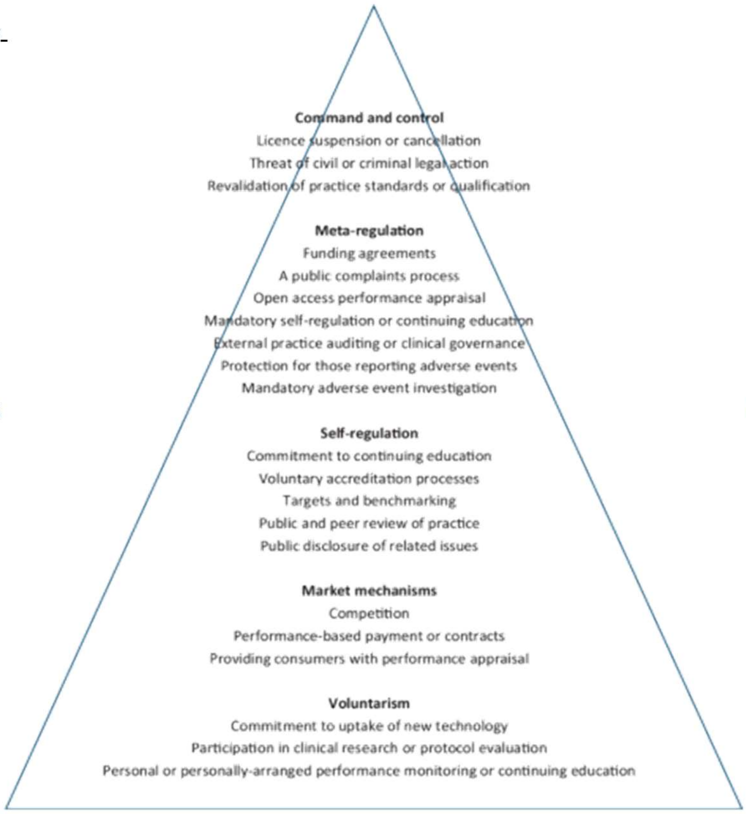
Digital transformation offers technologies, tools, and work flows to help deliver increased Environmental Safety for emissions, discharges, and waste. A more sustainable future is good business in a world of increasing environmental vigilence, regulatory oversight, and monitoring of corporate performance. In the words of Annie Leonard "There is no such thing as "away" when you throw something away – it must go somewhere." We need to make sure our Energy Industry facilities are engineered, constructed, operated and maintened efficiently and work to minimise unnecessary emissions, discharges, and waste. The next chapter is about Regulatory Safety which relies on the underlying personal, community, technical, and environmental safety being delivered.

[63] https://www.leewayhertz.com/blockchain-waste-management/

6. Increased Regulatory Safety

Details of how to best deliver personal safety, community safety, technical safety, and environmental safety have been reviewed in the prior chapters. All of these safety elements can also be seen to be part of what could be called Regulatory Safety. Regulatory Safety can mean being able to demonstrate safety performance to government regulators or other stakeholders who might have applied some form of requirements on your business that needs to be monitored (e.g. World Bank/IFC for funding/finance). Energy facilities need to be compliant with a range of legislation and rules across various aspects of business from people to process to land stewardship to emissions.

Regulatory strategies can range from (1) Voluntarism to (2) Market mechanisms to (3) Self-regulation to (4) Meta-regulation to finally (5) Command and control. The best level is Voluntarism where companies make their own commitments to complying with legislation and rules. Each level upwards is increasingly more complicated and ultimately the top level is highly regulated, directive, and associated with severe consequences of non-compliance. Compliance needs to be documented and auditable so data is the key – and better demonstration of performance helps support more voluntary compliance levels.



Data about personal safety, community safety, technical safety, and environmental safety needs to be collected from IoT devices and other structured inputs, contextualised, stored for processing with data analytics, and prepared for remote access and visualisation by multiple internal and external stakeholders.

Workplace and employee safety needs to be demonstrated both to regulators as well as to the employees themselves. These regulators include OSHA in the US, HSE in the UK, EU-OSHA in Europe, and in other countries they may be represented by local agencies linked to the standards of the UN International Labour Organisation (ILO). Most regulators want to see statistics and dashboards for leading and lagging indicators of workplace and employee safety. They want to understand root causes of any incidents and how lessons learned are applied for continuous safety improvement. Risk management will be important to be demonstrated with respect to this type of safety.

Commercial transactions including exports, revenues, and taxes need to be properly recorded and accounted for within business systems and available for audits including any charges for operations and emissions. Emissions or discharges are important outputs to be monitored and controlled. Implementing environmental management processes and then automatically documenting them is an important deliverable for many regulators. Examples of regulators in these areas could include the EPA in the US, the Environment Agency in England, the Scottish EPA in Scotland, the European Environment Agency in the EU, and various international organisations (mostly voluntary unless linked to funding/finance like World Bank/IFC).

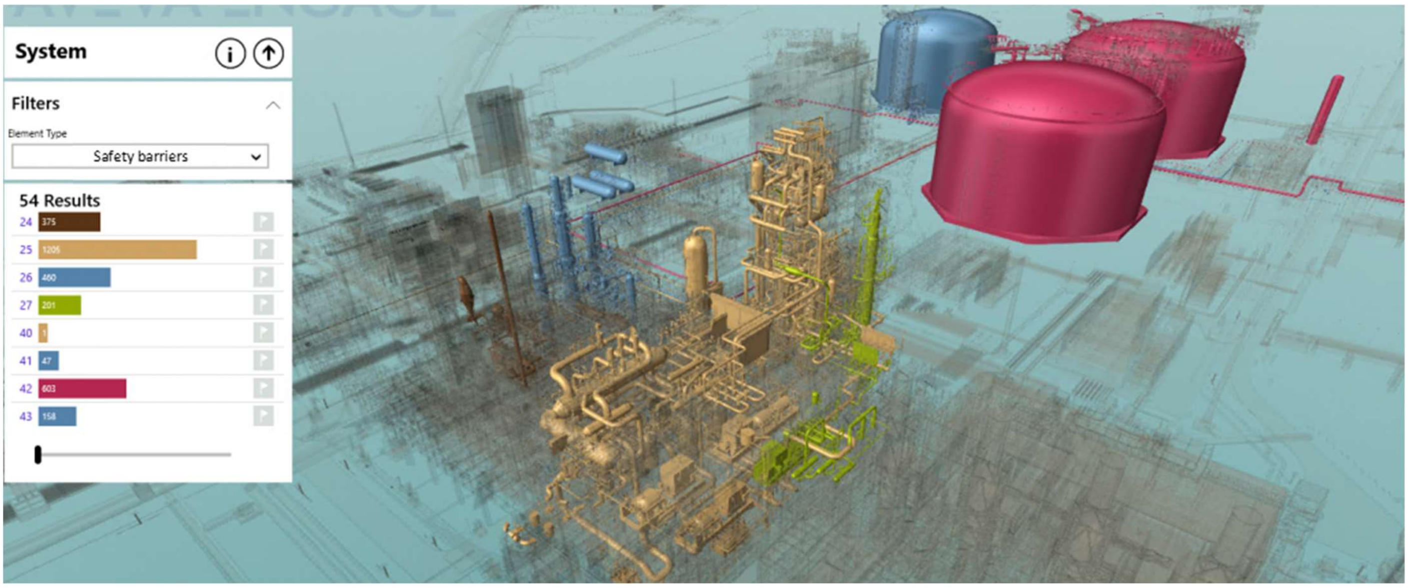
Regulators could require physical inspections but with public health and remote location considerations, it would be good to be able to virtually demonstrate compliance with remote inspections and updated documentation on secure data platforms accessible to these stakeholders.

A good example of typical inspection and operational performance criteria is available from the UK regulator HSE.[64] These criteria are able to be systematically monitored, documented, and made available on secure, online databases for the regulators to access and satisfy themselves as to the integrity of the assets.

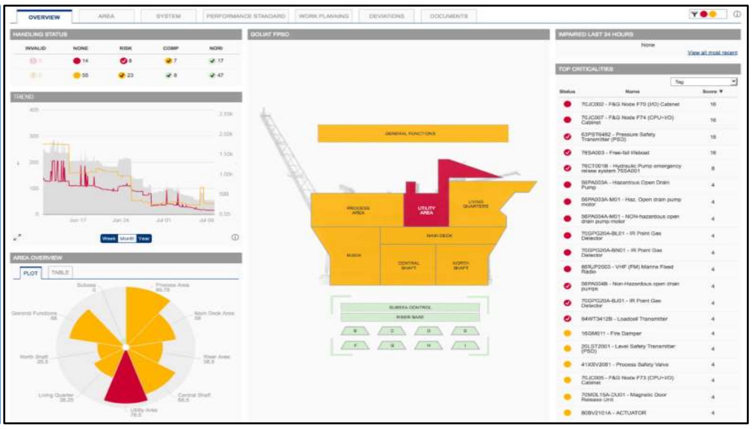
Investors with Environmental, Social, and Governance (ESG) requirements will also be able to benefit from these types of assurance visualisation systems to help ensure funding and finance is sustainably delivered and maintained.

Remote safety inspections are possible in several ways including fixed and mobile video and infrared cameras with audio, both live and recorded. Remote virtual inspections with Virtual Reality tools allowing participants to “walk” around a facility and view the status and condition of equipment and systems are possible with 3D computer models (CAD or point cloud) linked to contextual historical and real-time process and condition data.

[64] https://www.hse.gov.uk/offshore/inspection.htm



Safety regulators would want to check the status of Asset Integrity Management Systems (AIMS) associated with Safety and Environmental Critical Elements (SECE). Part of these programs should be Barrier Management and Alarm Management which need to clearly demonstrate that the integrity related systems are active and being sustained. Ineffective barriers reduce layers of protection. Facilities with alarms disabled will have increased risk. Safety drills and training scenarios need to be demonstrated to show the competency of operators. All these safety elements can be well demonstrated with Digital Transformation technologies and tools covered in earlier volumes. Different software packages (with some differences in capabilities and interfaces with other management systems) exist to monitor barriers and risk profiles (i.e. eVision "Barrier Vision"[65] and Eigen "Safety Barrier"[66]). The output of these systems could be available to internal and external stakeholders including regulators to provide online assurance of safety.



General integrity conditions and maintenance appearance of facilities can be visually reviewed by regulatory inspectors with remotely sourced photographic and video records. Unmanned drones and robotic vehicles can move over and through facilities capturing structured data of the condition of structures, piping, and protective features.

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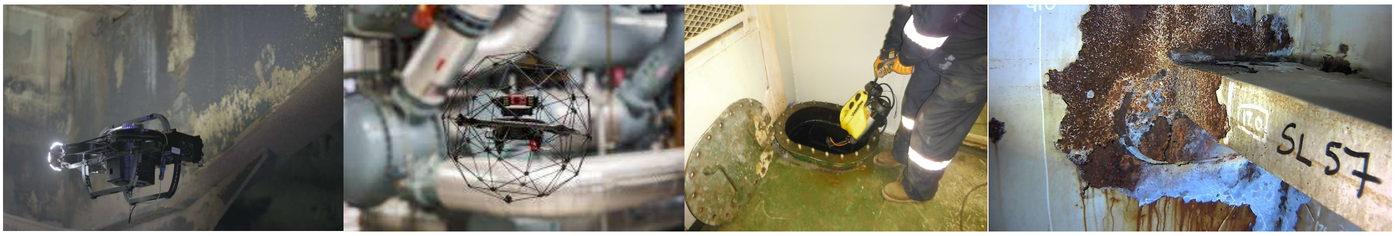
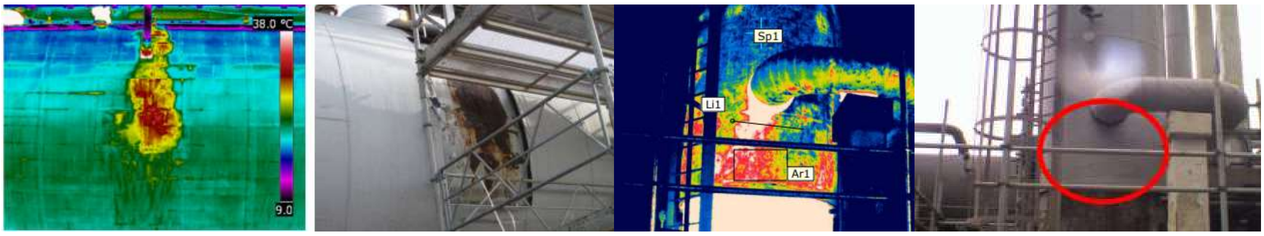
65 https://www.evision-software.com/barrier-management/
66 https://eigen.co/safety-barrier-health-monitoring/

The physical condition of internal product and chemical storage tanks and ballast tanks can be visually inspected with drones and micro/mini-ROV's and contextual data captured for the use of remote regulators, verifiers, or classification societies. The physical presence of external regulatory inspectors in these confined locations is not very feasible always and the quality of data available to be reviewed remotely is so significant that multiple marine classification societies have accepted this kind of evidence for the inspection of the structural fabric integrity.



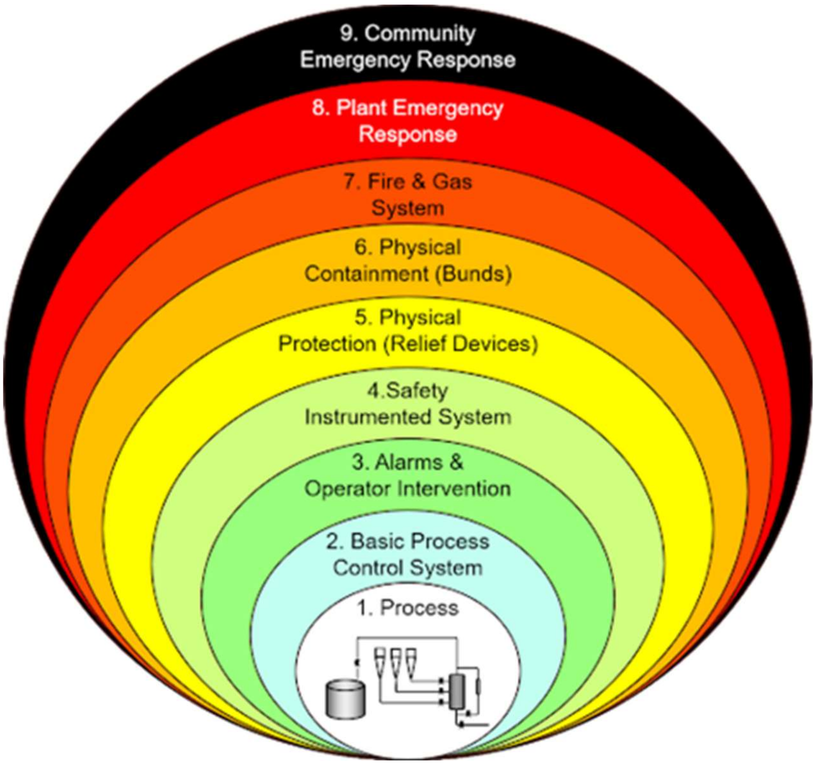
A large area inspection technique using specialised infrared cameras could be used to survey surface conditions like rust or coating breakdown to identify what is acceptable and what might need maintenance attention. Special infrared cameras can produce pulsed thermographic images able to be recorded on routine inspections as structured data which is able to be processed and analysed to look for changes in heat flows representing corrosion. This data loaded into an asset Digital Twin would then be available to the regulatory inspectors to see the presence (or lack thereof) of corrosion and the resultant integrity of coating and insulation systems.



Maintenance backlogs are typically reviewed by regulators to see how well the facility is being maintained. Excessive backlogs especially backlogs of safety critical elements are significant failings requiring urgent attention or, in serious cases, shutdown of facilities. Asset conditions and maintenance records should be available inside Computerised Maintenance Management Systems (CMMS), Asset Performance Management (APM) systems, and Enterprise Asset Management (EAM) systems. These systems should be connected to the Digital Twin of the asset in a Cloud Data Platform. Remote monitoring and retrieval of data should be provided with the use of API's so that users including regulators, verifiers, and applicable stakeholders could access this data and associated analytics to satisfy themselves (and their statutory obligations) as to the level of compliance with safety rules and regulations.

The Energy Transition requires us to fully identify and be able to demonstrate the life cycle impact of our energy industry inputs (i.e. materials, equipment, systems, manufacturing, construction, installation, and operations) and outputs (i.e. products, energy streams, emissions, and waste). Safety is not just about the individual workers, it also includes safety of the surrounding communities, and safety of the environment of our locations. Technical safety is a key requirement to be adequately addressed throughout engineering and operations, and it is typically addressed in great detail in Safety Cases (or similar documents). Demonstrating all types of safety preparations and performance to external regulators, verifiers, and stakeholders is normal and preparations should start early in a development's life cycle. Significant data is available and should be organised and properly managed through Digital Transformation tools. Significant effort would have been made throughout the engineering, procurement, construction, operator training and competency, testing, start-up, and operations phases to ensure risks had been evaluated and the facility prepared with layers of protection – and this is the kind of information that safety regulators expect to see.

We need to have started with ensuring inherent safety of the facility process equipment and systems and worked our way up through the various layers of safety. External regulators, verifiers, and stakeholders will want to conduct (or review) periodic audits and see assurance documentation on each of these layers throughout the life cycle of an asset. Physical inspections, which have historically been more common, may increasingly take advantage of remote monitoring and diagnostics technologies and tools in Digital Transformation. Data and data analytics in a Digital Twin located in a Cloud Data Platform are essential sources of verification and compliance demonstration readily available to these external regulators as well as our internal and external stakeholders.



7. Common Technologies, Tools, and Workflows for Increased Safety

Throughout the preceding chapters, we can see there are common Digital Transformation technologies, tools, and workflows to deliver increased Safety. A familiar thread of IoT devices, data, contextualisation, safety and control systems, communications, data platform, data analytics, and visualisation can help all types of safety performance.

Before any facility is operated, it must first have been adequately engineered and designed. Over the course of this engineering, technical simulation models will have been utilised to analyse and design these facilities. From these simulation models, predicted structural, mechanical, electrical, and process conditions will have been generated. During field operations, actual conditions are able to be measured and recorded. Comparison of theoretical conditions with actual conditions is a useful technique to check whether a facility was being correctly operated (e.g. inside Integrity Operating Windows) and maintained (e.g. degrading with the potential presence of failure signatures). Deviations of actual from theoretical conditions may also be indicative of potential safety issues (e.g. imminent failure or release of energy or hazardous emissions) and could be considered as "leading indicators" of safety issues:

IoT devices are key technologies to monitor, capture, and transmit conditional data. As described previously, IoT devices can monitor and transmit almost any kind of data:

- Personal safety related: wearable devices to show location; body position and proximity; working conditions; biometric data; environment sensors (i.e. gas, noise, temperature); and communications;
- Community safety related: fixed or mobile devices, located on-site / boundaries / off-site; environment sensors (i.e. gas, noise, effluent); transportation integrity of products or energy; and communications;
- Technical safety related: instrumentation for pressure; temperature; flow rates; speeds; voltages; compositions; valve / actuator characteristics (performance and isolation related); environment sensors (i.e. fire, gas, noise, temperature); alarms, and communications;
- Environmental safety related: fixed or mobile devices, located on-site / boundaries / off-site; environment sensors (i.e. gas, noise, runoff/groundwater); emissions; releases and effluent discharges; waste management / tracking;
- Regulatory safety related: fixed or mobile video/infrared/audio cameras, located on-site / boundaries / off-site; safety and control instrumentation devices (particularly barrier and alarm management related);

The amount of safety data from these IoT devices could be so significant that real-time monitoring and transmission of all data would exceed bandwidth availability, so some processing of the data could be necessary on the Edge. Contextualisation is the spatial temporal linking of each piece of data with the location and time where it was collected, and it needs to be done at the same time the data is collected so that during analytics any relevant data would be able to be linked together (e.g. biometric data linked to air quality data in the area of facility where the worker was located).

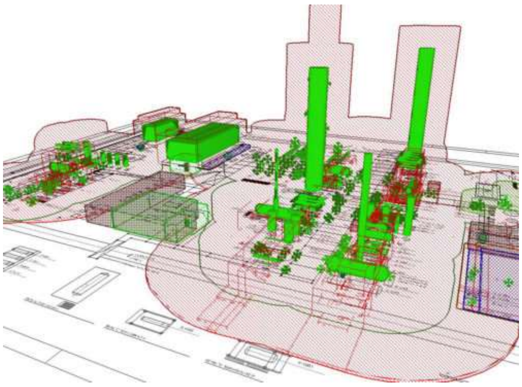
An example of Edge processing could be to check that a particular IoT device data point is within a specified range from expected or normal values and, if so, to just confirm that data was received but not the data itself. If the data point was significantly trending in a direction away from or exceeding normal ranges, the actual data values would be reported to allow analytics to use the values.

The frequency of data points can also be varied – in the case of normal data, the frequency could be spread out over larger time intervals, but, in the case of anomalous data or trends, the frequency could be increased to collect more granular data that might be needed for advanced analytics (e.g. electrical transient data associated with booster compressor start-ups).

With so many IoT devices, some reporting multiple data streams, we have to streamline the data with Edge processing so that the bandwidth requirements remain within the capabilities of the systems. For safety data, each individual in the facility could be monitored continuously, but on an "average, good day" there might not be anything to report or analyse. Conversely, a slowly increasing emission leakage (e.g. due to some equipment degradation) might need to be recorded over time so that it could be spotted by analytics. Impending failure signatures could be complex and only found by multiple simultaneous data streams being analysed (correlated) together, even when individual data streams might appear within normal ranges.

Once the data was captured, it needs to be communicated to appropriate locations for use. Local control rooms are routine locations connected through the normal safety and control systems by copper, fibre, or wireless means. The data needs to be made available to remote central control rooms or remote users since the energy facility may be minimally manned (or unmanned). Multiple means of communication have been reviewed in earlier volumes (i.e. fibre, cellular, microwave, or satellite). Data should go to a Cloud Data Platform where users can access it through API's to run or view analytics. The Cloud Data Platform should include Integrated Digital Twin and Enterprise Asset Management (EAM) systems.

Visualisation is a key capability that is enhanced with these Digital Transformation tools. Safety awareness includes maintaining a risk map view of a facility and identifying personnel proximity or simultaneous operation issues in risk areas. IoT data will be coming from these areas and analytics will provide processing to make visual images easier for operating personnel to make any necessary decisions.

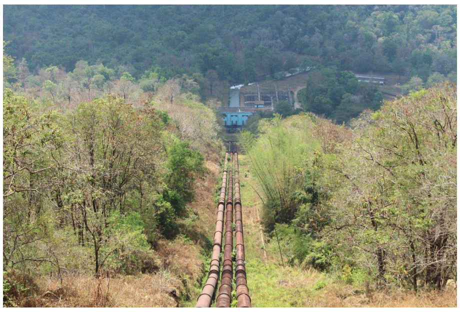


Critical process operation systems approaching their Integrity Operating Windows can be flagged (notifications including visual representations) to operators and, if relevant, to maintenance teams. Emission monitoring can identify fugitive emission sources requiring potential intervention prior to becoming more serious safety risks to people or infrastructure inside or outside a facility.

Personal GPS tracking and geofencing analytics can highlight when personnel may be in proximity to sensitive areas and real-time process data and analytics can identify whether any necessary isolations are in place prior to work being performed. RFID tagging and smart devices can help employees ensure they are working on the correctly isolated piece of equipment. Communications with remote technical experts can provide specialist guidance or advice during the performance of complicated maintenance work. The aim of these technologies and tools is to enable workers to be safe in the facility, doing safe work the right way the first time. Virtual rounds can replace physical rounds so that personnel only enter hazardous areas to perform required maintenance work (predictive and preventative).


Adjacent communities have to be confident that their community and environmental safety is not being compromised by the energy industry facilities – either by proximity or by the routing of power or pipelines through their communities. Regulators will need to be satisfied that adequate assurance is continuosly being provide to the integrity of these facilities. Remote monitoring of all types of IoT sensors (including external to the facility, along the routes) and the processing and management of this data will help provide useful assurance to internal and external stakeholders.





We have the Digital Transformation technologies, tools, and workflows necessary to deliver increased Safety to our people, our communities, our facilities (technical safety), our environment (surroundings), and our stakeholders (internal and external, including regulators and funders/financiers). It is up to us to reliably deliver this Safety on a sustainable basis.

Acknowledgements

Thank-you to all those doing such good work with these technologies and tools and sharing the information so widely online. The advice on how to better deliver Safety should help many Energy Industry users effectively deploy these Digital Transformation solutions to their facilities.

Energy Industries can and must deliver improved Safety in all its forms.