Japan Biomass Safety Workshop

SAFER BIOMASS HANDLING AND STORAGE: PREVENTING FIRE AND EXPLOSIONS

WOOD PELLET ASSOCIATION OF CANADA

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WHY THIS WORKSHOP MATTERS IN JAPAN

WOOD PELLET
ASSOCIATION OF CANADA

Masayoshi Takezaki
General Manager, Itochu

Japan Biomass Safety Workshop

SAFER BIOMASS STORAGE AND HANDLING THROUGH SHARED EXPERIENCES

Gordon Murray
Executive Director, Wood Pellet Association of Canada
May 2024

LOSSES IN BRITISH COLUMBIA

- 2012: two catastrophic sawmill explosions.
- Initiated a focus from the public and regulators on combustible wood dust hazards.

Massive BC sawmill explosion claims second life
Burns Lake sawmill explosion and fire called preventable

CANADIAN WOOD PELLET INDUSTRY LOSSES

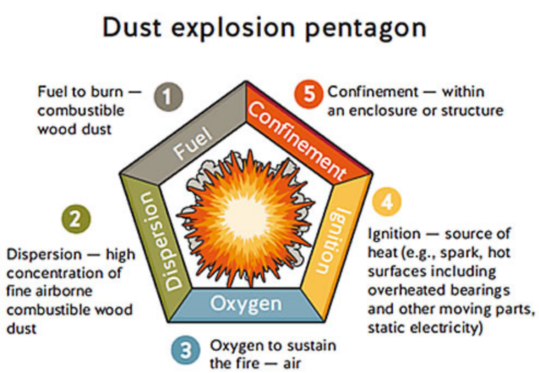
Incidents result in impacts to:

- Personnel
- Communities
- Reputation
- Production
- Assets

Explosion, fire at pellet plant in B.C.'s North Okanagan

WOOD PELLET OPERATIONAL HAZARDS

- Combustible wood dust.
- Potential for fires, explosions, and formation of combustible gas.
- Personal safety hazards include electricity and stored energy, confined spaces, working at heights, and ergonomics.



Dust explosion pentagon (WorkSafeBC, 2024)
Workers raised concerns about Entwistle wood-pellet plant before explosion

SAFETY INCIDENT BUSINESS RISKS

- Harm to workers and surrounding community.
- Damage to facilities and equipment.
- Poor industry image and reputation.
- Difficulty attracting and retaining employees.
- Not fulfilling production requirements.
- Scrutiny from regulators.
- Challenges obtaining affordable insurance.

OVERCOMING CHALLENGES TOGETHER

- WPAC members recognized shared challenges throughout the industry.
- In 2014, we agreed to a collective commitment to work together to raise levels of safety.

WPAC SAFETY COMMITTEE

- Established in 2014.
- Initial focus on combustible dust.
- Expanded to other occupational, health and safety matters, including lockout tagout, working at heights, and confined spaces.
- Expanded further into process safety.
- Continuously progressive safety projects that reflect and respond to the needs of the sector.

One-Stop Safety Resource

SAFETY IS GOOD BUSINESS

- Prevents catastrophic loss.
- Increases productivity.
- Proven to reduce costs.
- Enhances relationships and protects reputation.
- Helps retain and attract talented workers.
- Reduces downtime.
- Contributes to sustainable growth.
- Protects affordable access to insurance.

PROJECTS 2020-2023

- Critical control management.
- Inherently safer design.
- Belt dryer working group.
- Explosion isolation.
- Combustible gas.
- Operator training program and online learning platform.

HOW FAR WE'VE COME

- Completed numerous bow-tie analyses to evaluate operations.
- Established belt dryer working group.
- Performed cutting-edge research.
- Created numerous reports, factsheets and webinars on key topics.
- Developed state-of-the-art operator training platform.

CONTINUOUS IMPROVEMENT

Upcoming projects:

- Process safety management (PSM) implementation.
- Drum dryer working group.
- Mobile equipment risk reduction.
- New combustible dust regulations self-audit tool and action plan.

INDUSTRY ACHIEVEMENTS

- Enhanced safety culture.
- Supported sustainable industry growth across country.
- Fostered a positive relationship with regulators.

SAFETY THROUGHOUT SUPPLY CHAIN

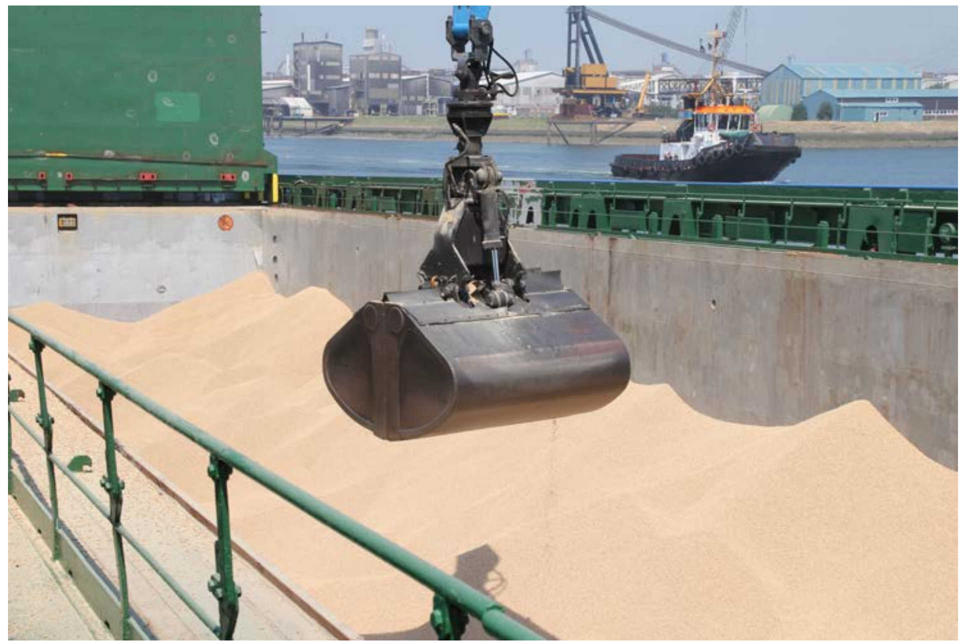
- Incidents in production facilities, as well as downstream in supply chain, threatens industry.
- There are trending issues related to combustible dust hazards leading to large-scale incidents, especially in Japan.

NEED FOR COLLECTIVE ACTION

- Now is a critical time to focus on preventing incidents.
- December 2023, Tokyo: successful biomass safety workshop.
- Call on industry to come together to identify a path forward to improve current state of safety.

BENEFITS FOR ALL

- The most productive industries are the safest industries.
- Addressing issues will help ensure the long-term success and sustainability of our industry.



CLOSING REMARKS

- Our industry is resilient and has overcome challenges in the past.
- Reflecting on our safety culture will help catalyze collective action.
- Consider what structure is needed to carry this forward.

Thank you!

Gordon Murray

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Japan Biomass Safety Workshop

STARTING WITH THE BASICS: PREVENTION THROUGH HANDLING & STORAGE UNDERSTANDING

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WOOD PELLET ASSOCIATION OF CANADA

BIOMASS HANDLING & STORAGE CONSIDERATIONS

- Emission of carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and in some cases hydrogen (H_2), and oxygen depletion — off-gassing
- Self-heating or external ignition sources e.g. sparks, friction, overheating etc. — smoldering and fires
- Generation of combustible dust and gas – gas and dust explosions

BIOMASS STORAGE AND SAFETY

- Biomass storage is essential part of bioenergy supply chain. Without it, there would not be a way to maintain a continuous supply of feedstock for bioenergy systems.
- Storage space for solid biofuel is not a place where people stay or move about, except where their presence is needed.
- Solid biofuel storage facilities should only be entered for reasons connected to the operation of the heating installation, such as installation or maintenance.

During storage, natural biological, chemical and physical processes occur, resulting in:

- Dry – Matter loss
- Off-gassing
- Self-heating
- Combustible gas and combustible dust

OFF-GASSING AND OXYGEN DEPLETION

- Condensable and non-condensable gases: stored wood pellets are known to emit non-condensable gases like CO, CO_2, CH_4 and small amounts of aldehydes and ketones including hexanal and pentanal in addition to acetone and methanol.
- The biological and chemical processes consume oxygen causing its depletion in the storage environment.
- Low oxygen concentrations can lead to suffocation of the handling personnel when entering closed biomass storage without proper ventilation.

OFF-GASSING AND OXYGEN DEPLETION

- The risks from off-gassing are significant in enclosed storage spaces and vessels including silos, storage bunkers, and the holds of ships.
- In enclosed spaces the primary concerns are the generation of CO and the depletion of oxygen.
- Lethal CO concentrations, close to 1% (10,000 ppm), have been recorded in enclosed storage spaces and a number of fatalities have occurred in ships during transport and unloading.

THRESHOLD LIMIT VALUE: CARBON MONOXIDE, CARBON DIOXIDE, METHANE AND OXYGEN

Chemical Substance	Threshold Level	
CO_2	5,000 ppm for 8 hours	Maximum exposure allowed by OSHA in the workplace over an 8-hour period
	30,000 ppm and above (short exposure)	headache, loss of judgment, dizziness, drowsiness, and rapid breathing
CO	25 ppm for 8 hours	Maximum exposure allowed by OSHA in the workplace over an 8-hour period
	200 ppm for 2-3 hours	Mild headache, fatigue, nausea and dizziness
	400 ppm for 1-2 hours	Serious headache- other symptoms intensify. Life threatening after 3 hours
	800 ppm for 45 minutes	Dizziness, nausea and convulsions. Unconscious within 2 hours. Death within 2-3 hours
	1600 ppm for 20 minutes	Headache, dizziness and nausea. Death within 1 hour
	3200 ppm for 5-10 minutes	Headache, dizziness and nausea. Death within 1 hour
	6400 ppm for 1-2 minutes	Headache, dizziness and nausea. Death within 25-30 minutes
	12800 ppm for 1 minutes	Death
CH_4	500,000 ppm- 8 hours	Could asphyxiate by displacing oxygen this concentration. The main danger with CH_4 is explosions. CH_4 is one of the main constitutes of natural gas. Being lighter than air, it tends to be removed through ventilation as the gas is being produced.
O_2	17%	Breathing is faster and deeper; impaired judgment may result
	16%	The first signs of anoxia appear
	< 6%	Convulsive movements and gasping respiration occurs; respiration stops and soon after the heart also stops

OFF-GASSING AND OXYGEN DEPLETION

Safety considerations of volatile organic compounds:

- Hexanal causes skin and upper airways irritation.
- Methanal and ethanal, are suspected to be carcinogenic in high doses.
- Monoterpenes also cause eyes and respiratory system irritation.

Safety considerations of CO:

- Does not constitute a risk of explosion on itself but may act synergistically with self heating and/or high level of fine dust to contribute to ignition or explosion incidents.
- Most of fatal accidents have been due to CO poisoning.

OFF-GASSING AND OXYGEN DEPLETION

Safety considerations of methane:

- Not very toxic but it is extremely flammable and may form explosive mixtures with air.
- Due to oxygen depletion, possible health effects of breathing in methane at high concentrations are increased breathing and pulse rates, lack of muscular coordination, emotional upset, nausea and vomiting, loss of consciousness, respiratory collapse and death.

Safety considerations of CO_2:

- An increased risk of oxygen depletion. The associated health risks are increased breathing and pulse rates, lack of muscular coordination, emotional upset, nausea and vomiting, loss of consciousness, respiratory collapse and death. Sufficient ventilation is therefore essential.

ISO STANDARDS ON SOLID BIOFUEL STORAGE

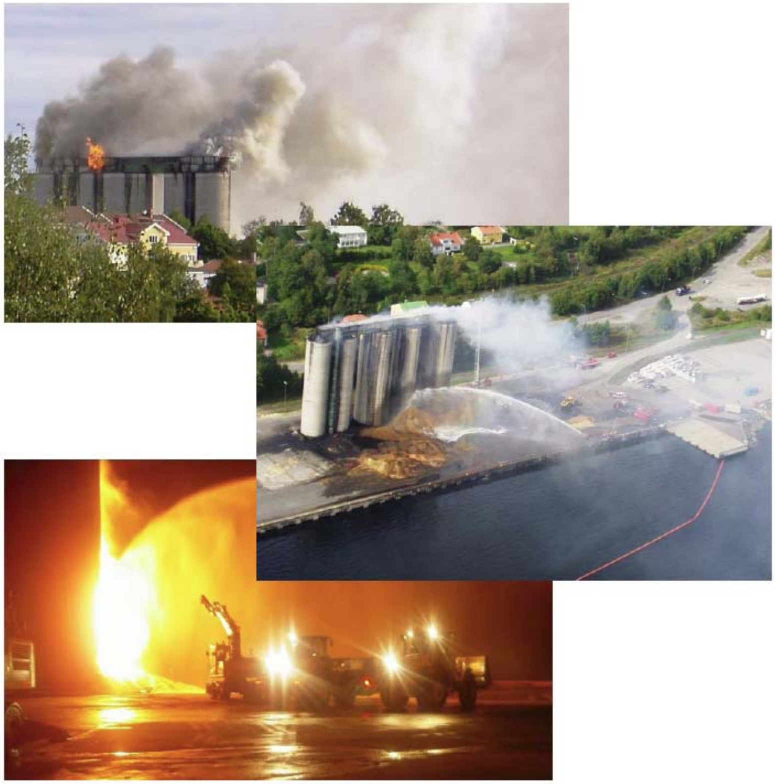
- Six standards and technical specification documents are published or under development.
- ISO 20023 - Solid biofuels — Safety of solid biofuel pellets — *Safe handling and storage of wood pellets in* ***residential and other small-scale applications.***
- ISO 20024 - Solid biofuels — *Safe handling and storage of solid biofuel pellets in* ***commercial and industrial applications.***
- ISO 20048 - Solid biofuels — *Determination of* ***off-gassing and oxygen depletion*** (2 parts: Part 1-Laboratory method, Part 2-Operational method).
- ISO 20049 - Solid biofuels — *Determination of* ***self-heating*** (2 parts: Part 1- Isothermal calorimetry, Part 2-Basket heating tests).

SAFETY RECOMMENDATIONS

- Monitoring the pellet bulk inside a silo by using gas detection system, or the gas concentration using CO/CO_2 detectors. The measurements should be made in the silo headspace and preferably also close to the discharge outlet.
- Risks for personal injuries should be considered, both during pre-planning of various possible emergency situations and during an ongoing emergency operation such as exposure to toxic gases, areas with low O_2 concentration
- Normal operation in a wood pellet warehouse might cause a dusty environment, which combined with possible off-gassing from the pellets, needs to be considered both from a health point of view and from a fire/explosions point of view.

SELF-HEATING

- Any material that can decompose or be oxidized by air can exothermically reach spontaneous combustion.
- Similar to coal (and wood chips), wood pellets self-heat when stored as a bulk.
- The self-heating can increase the bulk temperature to the point of self-ignition.
- Silo fires require a different approach than conventional fires.



SELF-HEATING

- Self-heating and spontaneous combustion can lead to fires and cause significant destruction.
- Unless handled correctly, the results can be catastrophic in both damage to the storage and plant assets and, in a worst-case scenario, the loss of human life.
- Knowing how to control a self-heating situation is essential, as silo or pile fires require a different approach than conventional fires. They occur rarely and are often catastrophic.
- Fire-rescue personnel often inexperienced with silo fires.

COMBUSTIBLE DUST: WHEN IS WOOD DUST EXPLOSIVE?

When dust is:

- Dry – less than 25% moisture.
- Fine enough to be airborne < 500 microns.
- Suspended in air at an explosive concentration – 40 grams/m^3 or greater.
- Contained in a confined area.

Adding an ignition source and oxygen will cause an explosion.

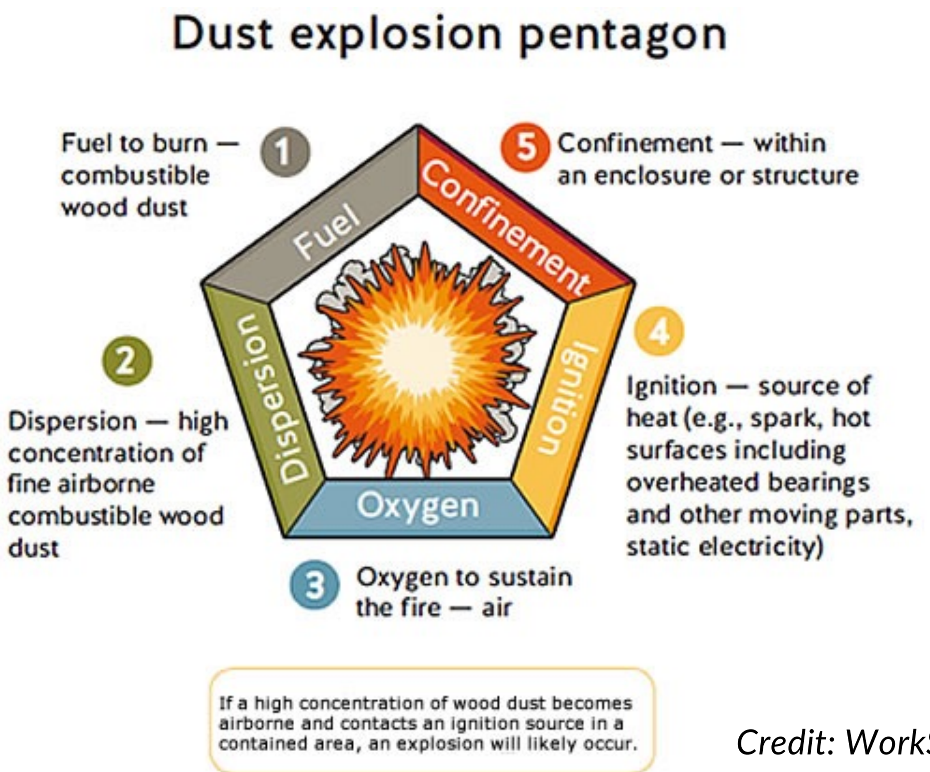
COMBUSTIBLE DUST

COMBUSTIBLE DUST:
WHAT IS A DUST EXPLOSION?

A dust explosion occurs when a fine combustible dust is suspended in air and ignited.

This causes rapid burning and release of combustible gases, and instant pressure increase causing an explosion.

COMBUSTIBLE DUST:
DUST EXPLOSION PENTAGON



Credit: WorkSafeBC

- For a dust explosion to occur, all 5 of these elements must be in place.
- Dust explosions happen when dust fuel is dispersed into oxygen reaching a sufficient level of concentration in an area of confinement and comes into contact with an ignition source, heat.

COMBUSTIBLE DUST: PRIMARY AND SECONDARY EXPLOSIONS

- Primary explosions occur in confined spaces.
- Fine dust is disturbed that may have accumulated in such areas as rafters or on elevated flat surfaces.
- When airborne, this dust can support a larger explosion known as a secondary explosion.

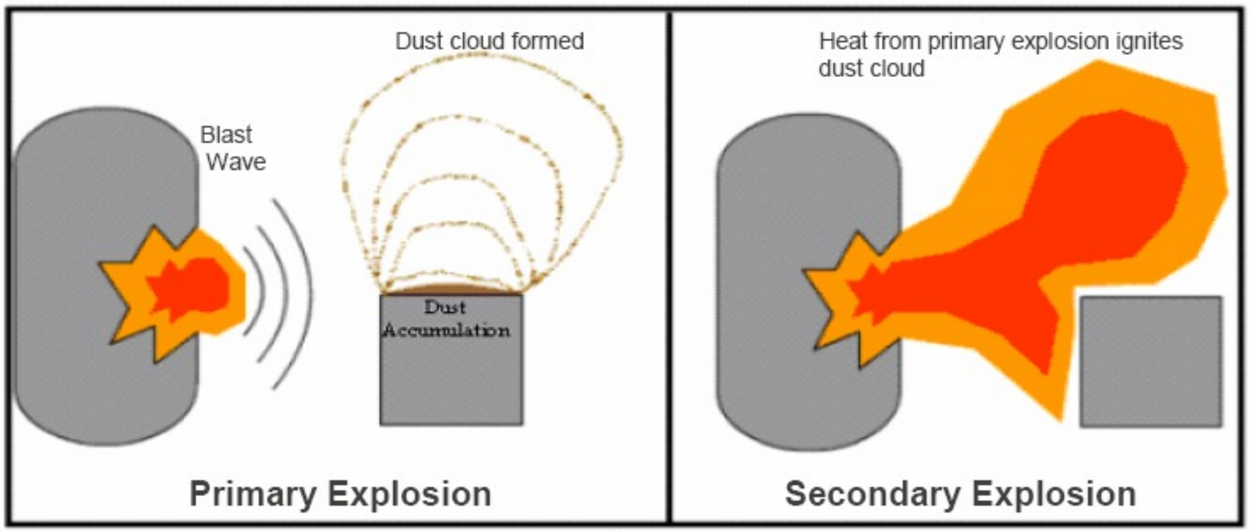
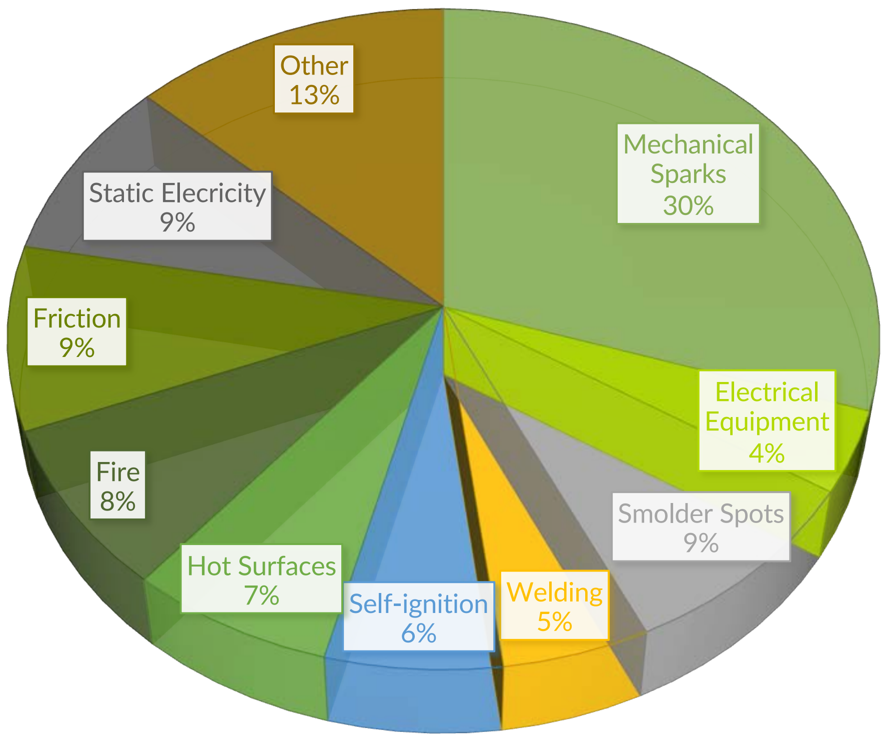


Figure 2

Credit: OSHA Factsheet Hazard Alert: Combustible Dust Explosions. US Department of Labour.

COMBUSTIBLE DUST: IGNITION SOURCES



- Fire only caused 8% of these explosions.
- The largest cause of dust explosions was from mechanical sparks, at 30%.
- Many of these sources are preventable with routine maintenance and fire safety procedures.

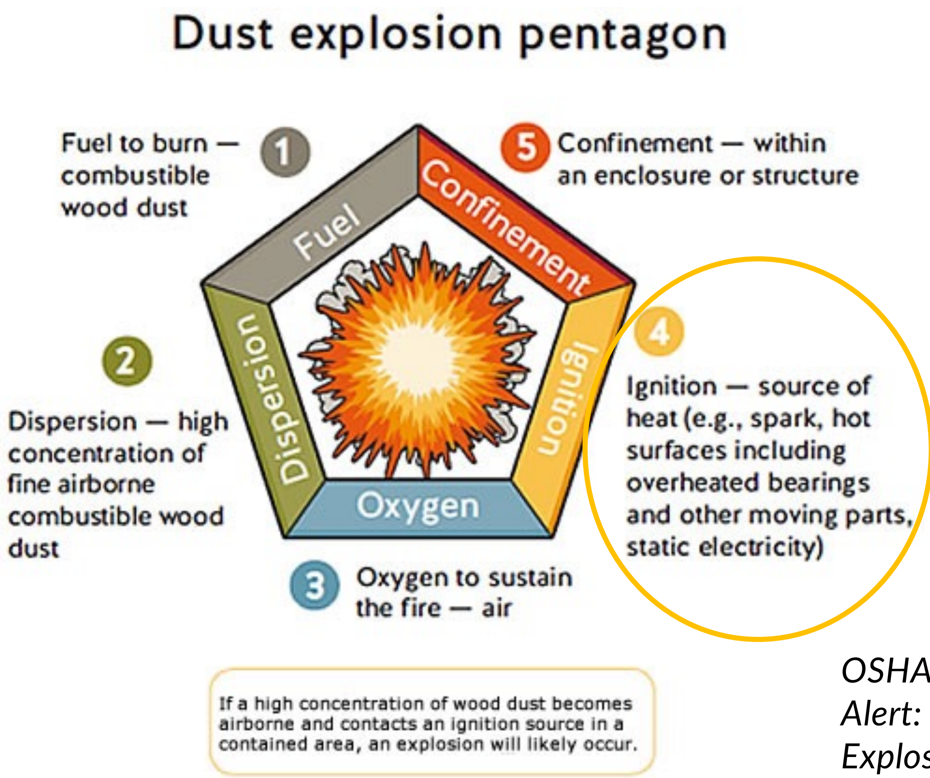
COMBUSTIBLE DUST: DUST HAZARD ASSESSMENT

- Conduct regular hazard and risk assessments.
- Common areas to consider: raw and finished product storage areas, grinding/hammer mills, conveyors, hoppers, screening.
- Consider less obvious areas:
  - Dust collection systems
  - Inside electrical cabinets
  - Conveyor transfer points
  - Horizontal surfaces
  - Conduit, pipe racks, cable trays, rafters, above suspended ceilings

COMBUSTIBLE DUST: DUST CONTROL APPROACHES

Passive Containment	Engineering Controls	Housekeeping
• Identify areas that produce fugitive dust and look for ways to enclose/contain it in that location. Example: covered conveyors.	• Collection systems that remove dust are the best solution. • Suppression systems such as misters can be effective but pose challenges in cold weather. • Ventilation systems such as wall and ceiling fans can provide are circulation and assist in controlling fugitive dust. • All dust control systems must be inspected and maintained in good working order.	• Rule of thumb: dust should not exceed 3 mm thickness over more than 5% of area. • Schedule regular housekeeping. • Pay attention to walls and beams. • Methods include vacuuming, water washing, brooms and compressed air. • Include regular inspections, note deficiencies, and track corrective actions.

COMBUSTIBLE DUST: IGNITION CONTROL

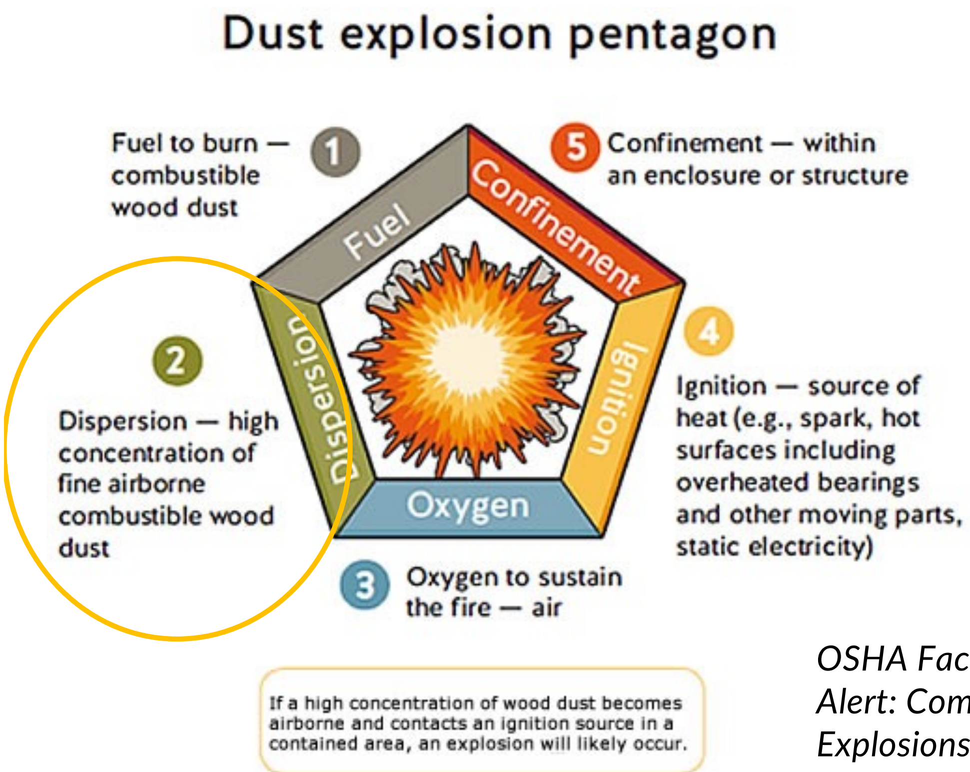


OSHA Fact Sheet, Hazard Alert: Combustible Dust Explosions

Need to control

- Hot work.
- Preventative maintenance.
- Mechanical sparks and friction.
- Electrical equipment.
- Static electricity.
- Hot equipment and surfaces.
- Smoking and open flames.

COMBUSTIBLE DUST: DISPERSION CONTROL



- Identify mechanisms of dispersion.
- Consider the characteristics of the dispersed dust.
- Consider opportunities to reduce the level of dispersion.
- Be mindful of any new hazards that might be associated with changes.

OSHA Fact Sheet, Hazard Alert: Combustible Dust Explosions

COMBUSTIBLE DUST: EMERGENCY PROCEDURES

- Establish written emergency procedures and ensure that all personnel are trained.
- Exit routes designed and marked.
- At least one emergency drill completed and documented per year.

COMBUSTIBLE DUST

COMBUSTIBLE GAS: WHAT IS IT?

- Combustible gas consists of mainly **carbon monoxide, hydrogen and methane**, or natural gas. They are produced from incomplete combustion in process equipment.
- Stored wood pellets may also emit combustible gases especially during **self-heating.**
- During **high temperature drying** gases such as carbon monoxide, hydrogen and methane as well as VOCs are formed.
- **Oxygen** must always be present in the air to initiate combustion and explosion.
- The resulting gas is flammable and could be explosive in high concentration.
- If it doesn't get out of the process through ventilation or if ventilation system is off (e.g. power outage) , the gas concentration can be high.

COMBUSTIBLE GAS: WHAT IS IT?

A real silo explosion which most likely occurred due ignition of headspace gases by an electrostatic discharge in an attempt to extinguish a smoldering fire.

Photo: courtesy of Dag Botnen, Hallingdal brann- og redningstenste iks, Norway

COMBUSTIBLE GAS:
WHERE IS THE GREATEST RISK?

- **Dryers** at greatest risk of fire or explosions.
- Sudden, unexpected **power outages and/or power bumps**.
- Scheduled maintenance days during shut down process.
- Dryer component equipment failure such as a **clogged cyclone, infeed airlock/rotary valve jam, or faulty control dampers**
- **Faulty equipment** as plugged or missing deluge nozzles, **faulty solenoid valves** on extinguishing nozzles
- **Distracted operations**, such as when another area of the plant is having issues, which leads to the drying equipment being shut down too fast for protection equipment.

COMBUSTIBLE GAS: REDUCE THE RISK

- Do a complete **risk analysis** to know when combustible gases are emitted most and where they accumulate most.
- Use **alarms and control system** to reduce the risk of fires and explosion.
- Install **monitoring systems** within dryer or combustion system.
- Have **back up power** generation in place.
- Keep your **ducting clean** and make sure ventilation system is effective.

BIOMASS (PELLET, CHIPS AND PKS) SELF HEATING

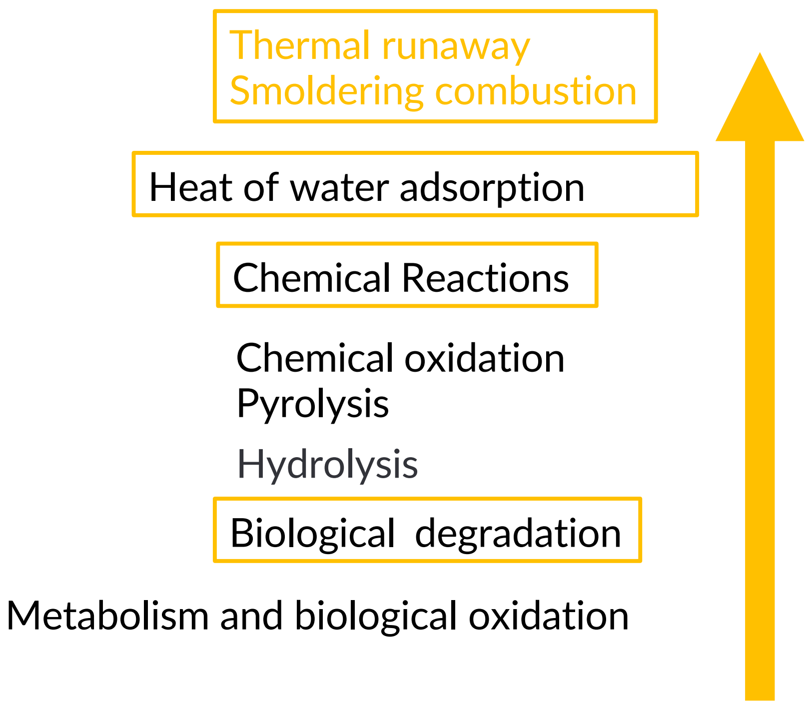
- Propensity of biomass (i.e., wood pellet, wood chips and PKS) to self-heat.
- Properties that influence the propensity of biomass to self-heat.
- Spontaneous combustion of biomass/fire development in a silo.
- Silo fire scenarios (suspected fire versus verified fire).

SELF HEATING: CAUSES AND DETECTION

Self-heating processes may be due to:

- Biological metabolic reactions (microbiological growth) exothermic chemical reactions (chemical oxidation).
- Heat-producing physical processes (e.g. moisture absorption), and it may occur both for dry and wet biofuels.
- It may become problematic if a pile or silo is so large that the heat generated cannot be easily dissipated to the surroundings.

SELF HEATING AND THERMAL RUNAWAY: CAUSES AND DETECTION



Factors that influence self-heat are:

- Oxygen concentration in the bulk
- Moistening of bulk
- Relative humidity

Contributing factors are:

- Pellet temperature and moisture content.
- Conduction and convection of heat and moisture in the pile.
- Physical properties (broken pellets and dust).

SELF HEATING: CAUSES AND DETECTION

- At temperatures above 50°C, the rate of chemical decomposition exceeds biological decomposition.
- Temperature of wet biomass will gradually increase and stabilize at 100°C until moisture is driven off and biomass is dry. Once dry, temperature can rapidly increase particularly in enclosed silo or bins with no air circulation.
- Temperature could eventually rise to the point where pyrolysis (spontaneous ignition) occurs within biomass pile. Thermal runaway due to exothermic oxidation begins at approximately 190°C.
- If pyrolysis spreads to the surface of pile or an area of high oxygen concentration, flaming combustion will occur. Several serious incidents have resulted from self-heating leading to combustion of biomass in silos. Once ignition occurs in a pile or silo it is difficult to extinguish and can smolder for days or weeks.

SELF HEATING: CAUSES AND DETECTION

Self heating can be seen as the first step in a process that might finally result in spontaneous combustion. These steps can be defined as:

1. **Self-heating:** an increase in temperature due to exothermal reactions in the fuel.
2. **Thermal runaway:** self-heating which rapidly accelerates to high temperatures.
3. **Spontaneous combustion:** visible smoldering or flaming by thermal runaway.

SELF HEATING: CAUSES AND DETECTION

- The most important prevention measure to take is **temperature monitoring of the storage** at several different locations in the bulk.
- For detection of any activity of the bulk, **CO concentration** should be measured in the air above the pellet surface.
- One of the first signs of an on-going self-heating process is often a **sticky and irritating smell**.
- If such smell is sensed, **pyrolysis is already taking place** in fuel bulk and fire fighting operation has to start.

SELF HEATING AND SILO FIRE

Fire in a silo containing wood chips; Lancaster, PA, December 2015; Lancaster Online.

PARAMETERS AFFECTING SELF HEATING

- The property of biomass to self-heat is determined by many factors, which can be divided into two main types, properties of the biomass (intrinsic factors) and environment/storage conditions (extrinsic factors).
- Some of these parameters are: wood pellet moisture content, storage humidity and water exposure, pellet age and storage temperature.
- Heterogeneous piles contain biomass of different particle sizes and moisture levels and have an increased risk of self-heating and ignition, as air flow through the pile can be poorly distributed, leading to "hot spots" and localized ignition.
- Self-heating is also affected by the chemical composition of the biomass, with fuels higher in lignin and fatty acid showing a larger propensity for self-heating.

IS IT SELF HEATING OR AN EXTERNAL SOURCE?

- Temperature increase could be due to self-heating or an external ignition source such as sparks, friction, overheating or smoldering material fed in when loading material into the silo.
- Self-heating is also affected by the chemical composition of the biomass, with fuels higher in lignin and fatty acid showing a larger propensity for self-heating.

INDOOR STORAGE IN HEAPS

- Indoor heaps are typically very large. Ignition due to an external source may be identified more easily than spontaneous ignition/self-heating.
- Signs of self-heating:
  - #1 “white smoke” water vapour/moisture on surface.
  - #2. “condensation areas” caused by the water vapour condensing on the surface of the pellets and causing them to disintegrate to dust.

Credit: Ingvar Hansson, Swedish Civil Contingencies Agency

INDOOR STORAGE IN HEAPS

- Temperature monitoring on and close to the surface can be measured with a probe installed in pellet bulk or incorporated into surrounding infrastructure (e.g., dividing walls)
- Gas analyzers and sensors can also be used.
  - If indoor storage is significantly ventilated, they may not be helpful for early detection.
- Insert CO probe at potential/suspected locations (0.5 to 1.0 m into pellet bulk).
  - High CO values suggest self-heating ignition (self-contained breathing apparatus must be worn).
- Use separating concrete walls to reduce ignition spread.
- Temperature and humidity conditions should be controlled in pellet storage.

Reference: IEA Bioenergy (2013) Health and Safety Aspects of Solid Biomass Storage, Transportation and Feeding

INDOOR STORAGE IN HEAPS

- Firefighting foam can help in indoor storage heaps.
  - Compressed Air Foam System (CASF) is well-suited.
- Benefits:
  - Applied more gently than water and reduced risk of dust cloud formation.
  - Sustained surface coverage which helps reduce spread.
  - Requires less water so fewer pellets are damaged.
- More effective for fires on mobile equipment (e.g., loader) with risk of fire spread to fuel, plastics, rubber.

Reference: IEA Bioenergy (2013) Health and Safety Aspects of Solid Biomass Storage, Transportation and Feeding

PREVENTION OF BIOMASS IGNITION

- Mechanical integrity of material handling equipment.
- Hot work program.
- Management of change (MOC).
- Deflagration isolation.
- Silo monitoring.
- Inherently safer design (ISD).

MECHANICAL INTEGRITY OF MATERIAL HANDLING EQUIPMENT

- Material handling equipment includes drag chain conveyors, bucket elevators, rotary valves, bearings, fans.
- An upset condition (including a fire or explosion) can arise if there is a failure, breakdown, or malfunction of any component of the material handling process.
- Metal or foreign material that enters the process (either from infeed-contamination or equipment failure) poses an ignition source risk.
- Important techniques for observing operating conditions and proactively detecting issues include vibrational analysis, temperature monitoring, visual monitoring, formalized preventative maintenance.
- Vibrational analysis can be completed in real-time with installed online systems, or with routine inspection by trained personnel.
- Some equipment may also have vibration switches installed that will initiate an automatic shutdown.

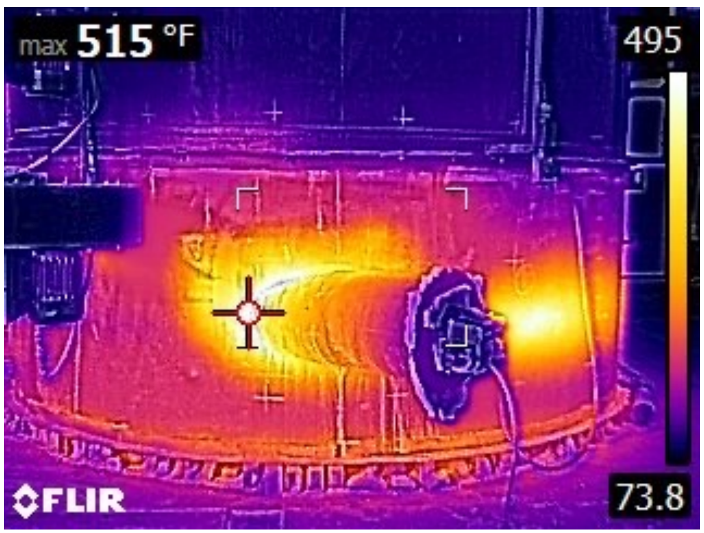
MECHANICAL INTEGRITY OF MATERIAL HANDLING EQUIPMENT

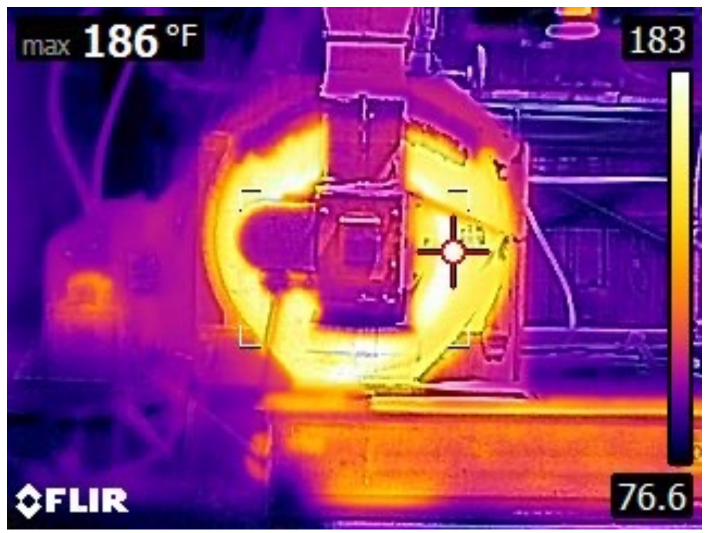
- Temperature monitoring can be completed in real-time with online systems or with routine inspection by trained personnel.

Thermal imaging camera photos (Courtesy of Shaw Renewables)

MECHANICAL INTEGRITY
OF MATERIAL HANDLING EQUIPMENT

- Infrared (IR) video cameras can also be used, along with visual cameras.





IR imaging camera photos (Courtesy of Shaw Renewables)

MECHANICAL INTEGRITY OF MATERIAL HANDLING EQUIPMENT

- Preventative maintenance plans for all equipment should be formally documented.
- As part of preventative maintenance, visual monitoring can be conducted during shifts by operations personnel.
- Preventative maintenance plans should include regular cleaning, inspections and replacements of hydraulic lines, belts, fan motors, fuel and oil levels, fire suppression systems, bearings and sensors.

HOT WORK PROGRAM

- Hot work is a temporary operation that involves open flames, or producing heat or sparks; includes welding, brazing, cutting, grinding, or other processes or equipment that produces sparks.
- Hot work programs should be formalized, and written, include activities such as:
  - Examine if hot work can be avoided.
  - Shutdown the process when completing the hot work.
  - Clean and remove combustible material from area.
  - Designate a person as “spark watch” (ensures safe conditions are maintained during hot work).
  - Have fire extinguishing equipment and fire-resistant blankets nearby.

MANAGEMENT OF CHANGE (MOC)

- Management of Change is the program to manage risks related to changes and modifications of design, equipment, procedures, and organization.
- MOC process should include (NFPA 664, 2020):
  - Occupancy and process changes, including storage arrangements and heights, process equipment, process materials, production rates.
  - Modifications to any fire protection and alarm systems (including water supplies, automatic sprinkler protection, alarm equipment).
  - Exposure changes (such as yard storage and changes to neighbouring facilities).
  - Changes in personnel.
  - New construction or modifications to existing infrastructure.

DEFLAGRATION ISOLATION

- Pressure and flame from a deflagration (explosion) can propagate through a process to interconnected equipment (NFPA 652, 2019).
- Deflagration isolation interrupts or mitigates the flame and pressure between equipment connected by pipes or ducts (NFPA 69, 2019).
- Deflagration isolation methods include:
  - Flap valves
  - Chemical isolation
  - Mechanical valves
- Common locations for isolation methods include hammer mills, dust collectors, bucket elevators, drag chain conveyors, and cyclones.

Example of chemical isolation system. Figure courtesy of Fike (used with permission)

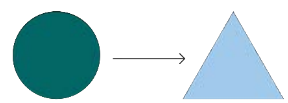
INHERENTLY SAFER DESIGN (ISD)

- ISD focusses on elimination of hazards and treatment of hazards at the source, rather than relying on only add-on equipment and procedures; most preferred and effective risk reduction measure.
- How do we think about ISD? Four keywords/principles:

Minimization

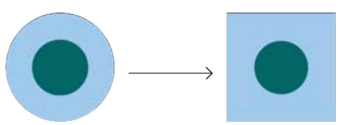
Remove hazardous equipment no longer in use

Substitution



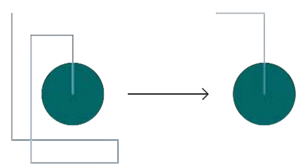
Use alternate material of construction or equipment that is more robust for given application

Moderation



Relocate hazardous equipment away from personnel

Simplification

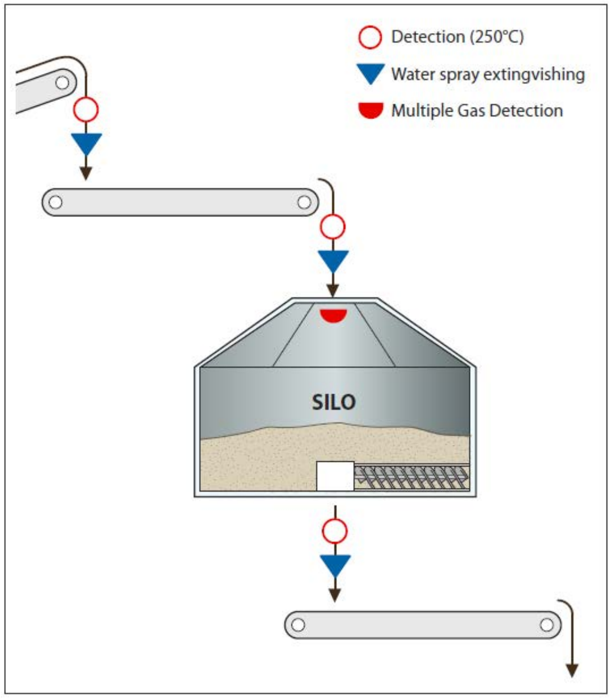


Design processing equipment and procedures to eliminate opportunities for errors and excessive use of add-on safety features

Credit: Obex Risk Ltd. (2023)

SILO MONITORING

- Prevention systems that comprise silo monitoring can provide early warnings of smolders in silos, include:
  - IR-detection systems on conveyor systems before and after the silo.
  - Gas detection in the silo headspace.
  - Temperature sensors inside the bulk material.
- Silo design should also be considered (e.g., air tightness, ventilation system, emergency discharge, explosion protection).



Credit: Henry Perrson (2019)

PREVENTING AND MANAGING UPSET CONDITIONS

- Upset conditions can occur and escalate to larger incidents, such as:
  - Deluge malfunctions
  - Conveyor plug-ups or breaks
  - Dust collector plug-up
- How upset conditions can occur
- How to prevent upset conditions
- What to do if upset conditions happen

UPSET CONDITION
AUTOMATIC DELUGE MALFUNCTION

- How could happen:
  - The deluge is critical for managing risk associated with fire.
  - Malfunction could occur due to a faulty sensor (including a false positive), clogged nozzles or broken pipes, pump malfunction, failure of heat tracing and frozen lines.
- To prevent:
  - Clean sensors regularly and complete preventive maintenance on entire system.
- If happens:
  - Site dependent. The process should be shut down until equipment is repaired.
  - Your operation may still have another manual deluge system that could be used.

UPSET CONDITION
DUST COLLECTOR PLUG UP

- How could happen:
  - The cyclone can be clogged if the fibre being collected by the cyclone is too wet.
  - The cyclone can also become clogged if another piece of equipment shuts down.
  - If the cyclone shuts off, the restart is attempted and the rotary valve is closed, material will build up.
  - Clogging can also arise if rotary valve malfunctions.
- To prevent:
  - Complete regular preventive maintenance on rotary valve to prevent mechanical malfunction. Consider the moisture content of the fibre and manage as required.
- If happens:
  - Site dependent. Stop the incoming flow, stop and lock out the feeder, open access door above the feeder, unplug the blockage.

UPSET CONDITION
CONVEYOR PLUG UPS AND BREAKS

- How could happen:
  - Conveyor issues can arise due to bearing failures and mechanical malfunctions.
  - For belt conveyors, the conveyor could rip or break, or rollers could malfunction. Augers can also break.
- To prevent:
  - Complete regular preventive maintenance to prevent mechanical malfunction.
- If happens:
  - Slip sensors (magnetic sensors) on the auger on the tail/non-drive end of the conveyor/auger will notify the operator that it is not turning.
  - The operator may receive an automatic alarm on the HMI screen.
  - Follow relevant site-specific shutdown procedures and determine the root cause. This may be site-specific and dependent on on-site protocols.

UPSET CONDITION
DRAG CHAIN BREAKAGE

- How could happen:
  - Drag chain breakage can occur due to foreign material jam or misalignment.
- To prevent:
  - Complete preventive maintenance on drag chains, which may include checking alignment and checking for broken links.
- If happens:
  - Operators may receive a slip sensor alarm notification, or the motor would shut down because of high amperage (overloaded).
  - Stop all conveyance into the conveyor and evaluate the situation. If there is a lack of material flow, some systems may need to be shut down.
  - Inspect and determine root cause and call maintenance or welder, depending on issue.

UPSET CONDITION
FIRE IN VENTILATION SYSTEM

- How could happen:
  - Combustible dust may be found in dust collector pipes. A spark can propagate from elsewhere in the plant (for example, a spark is caused by a bearing failure, which is then drawn through the air into a pipe).
- To prevent:
  - Complete preventive maintenance, including on fans to ensure in good working order. Complete housekeeping, including regular cleaning of the pipes and dust collector to remove dust.
- If happens:
  - Isolation valves that are installed on the pipes will automatically close if there is a fire or deflagration.
  - Explosion panels on dust collectors will relieve pressure, and a sprinkler system head in dust collector will spray water to extinguish a fire.

UPSET CONDITION
FIRE IN MOBILE EQUIPMENT

- How could happen:
  - Mobile equipment, such as a loader, may be used to transport pellets.
  - Combustible dust can accumulate on the mobile equipment on hot surfaces (e.g., motor).
  - Could lead to smoldering material propagating through the process during transportation or cause a fire or explosion on the mobile equipment.
- To prevent:
  - Complete preventive maintenance to ensure the mobile equipment is in good condition.
  - Establish a safe working procedure to conduct routine blowdowns to remove dust.
- If happens:
  - Fire suppression systems on mobile equipment may be automatically or manually activated if there is a fire or deflagration.

Thank you!

Kayleigh Rayner Brown, MASc, P.Eng.

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WOOD PELLET
ASSOCIATION OF CANADA

Japan Biomass Safety Workshop

SAFER BIOMASS HANDLING AND STORAGE: PREVENTING FIRE AND EXPLOSIONS

WOOD PELLET
ASSOCIATION OF CANADA

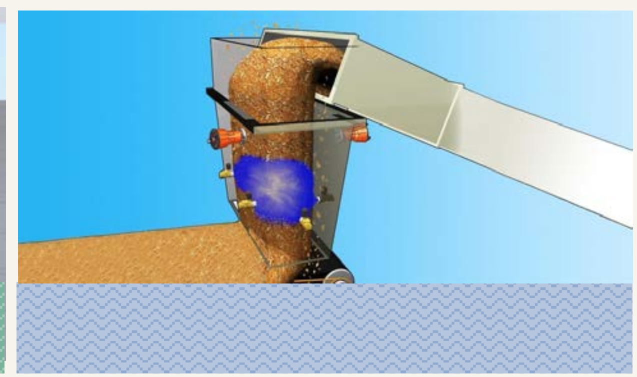
FutureMetrics LLC ™

ITOCHU

PREVENTIVE PROTECTION SYSTEMS FROM firefly ab SWEDEN

Short Introduction to Firefly

Anders Bergström, Firefly AB



FIREFLY – SHORT INTRODUCTION

- Firefly AB – a Swedish company founded in 1973
- Designing and manufacturing high-tech fire protection systems for the process industry
- We conduct risk assessments and consulting assignments
- Head office in Stockholm, subsidiaries in Poland and Italy and agents/distributors worldwide
- Service centers located in all continents of the world
- We are active in over 80 countries

FIREFLY'S INVOLVEMENT IN STANDARDIZATION GROUPS

We are involved in many different standardization groups.

Some examples:

- CEN/TC 142/WG 10 Chip and dust extraction systems
- ISO/TC 199/WG Safety of Machinery Fire prevention and protection
- ISO/TC 300/WG 6 Safety of solid recovered fuels (ISO 21912)
- ISO/TC 238/WG 7 Safety of solid biofuels (ISO 20024)

FIREFLY'S INVOLVEMENT IN PELLET SILO TESTS IN SWEDEN

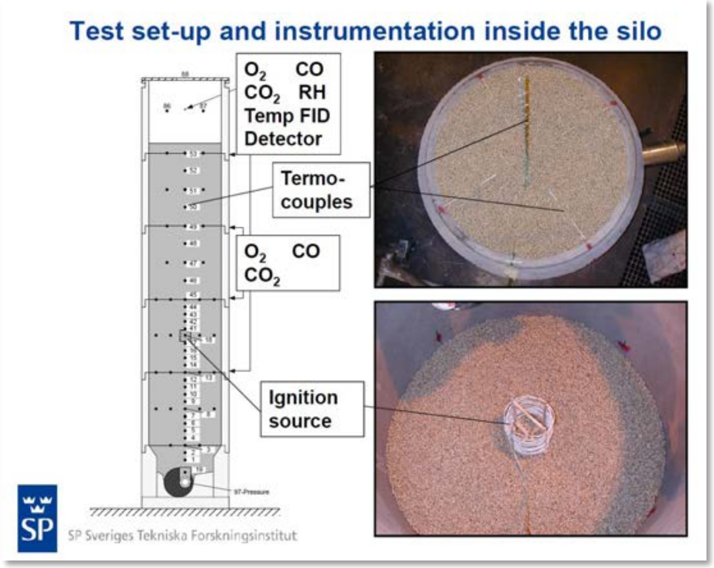
Firefly have been involved in two Silo tests with SP (Swedish National Testing and Research Institute) and Henry Persson

2006 – Four Silo Fire Experiments

- A series of four Intermediate scale silo tests were conducted
- Purpose to provide guidelines regarding fire fighting of silo fires
- Possible detection methods were studied in the experiment

2013 - Large-scale silo storage test

- Performed within European project SafePellets.
- Silo capacity: 3000 ton Wood Pellets
- The main purpose to monitor possible self-heating and off-gassing
- Also to evaluate this data with various gas/fire detection systems.



PREVENTIVE PROTECTION SYSTEMS FROM

firefly ab

SWEDEN

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CHANGING THE WORLD OF INDUSTRIAL FIRE PROTECTION

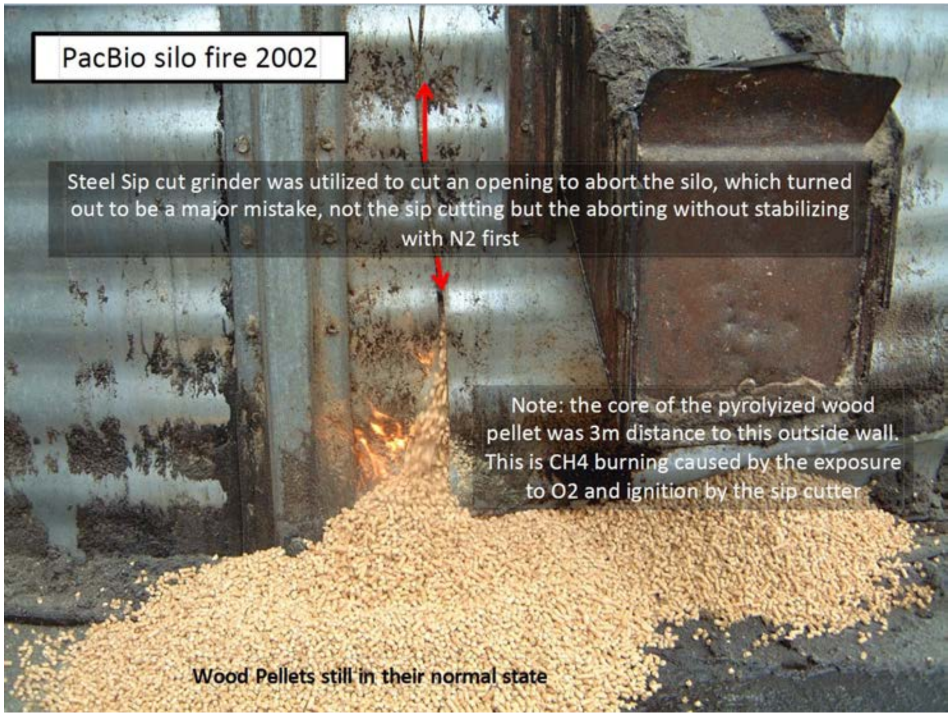

Japan Biomass Safety Workshop
IF A FIRE HAPPENS: EFFECTIVE APPROACHES TO FIRE SUPPRESSION
WOOD PELLET ASSOCIATION OF CANADA
John Swaan
FutureMetrics
JL SUZHOU

SILO FIREFIGHTING TECHNIQUES & PROCEDURES

“EXPERIENCES” – RIGHT WAY & WRONG WAY

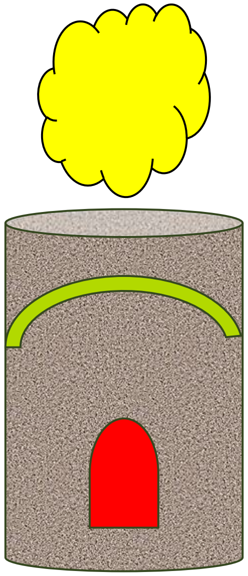
- Yellow-grayish smoke escaping from the silo ventilation ports and into the production building.
- Assuming it to be a normal fire within the silo, aborting the silo was initiated.
- As seen in the picture, the spark from the sip cut ignited the CH_4 from the smoldering clump of pellets inside silo.
- No attempt to close off the ventilation and pellets continued to be evacuated till an explosion blew the top of the silo off.

CAUSE OF FIRE: EXTERNAL HOT MATERIAL



SO WHAT CAUSED THE EXPLOSION???

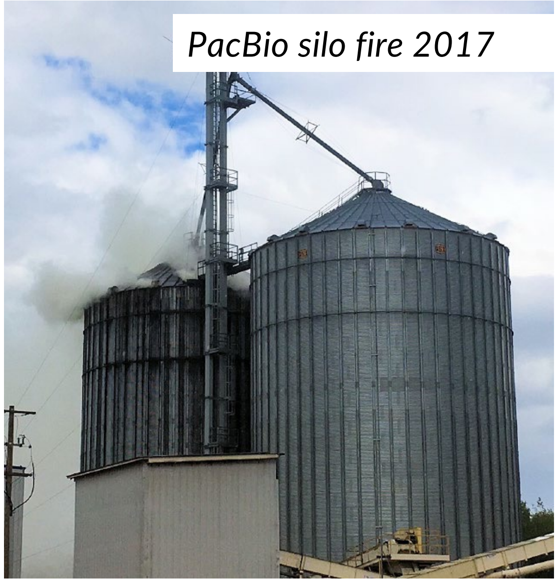
- Pyrolysis of the smoldering pellet generates CH_4, CO, CO_2, H_2 syngas.
- Lowering (aborting) the level of wood pellets in silo down to the smoldering pellets allowed O_2 to make contact with the smoldering pellets releasing CH_4, causing the ignition and subsequent explosion.
- Smoldering pellets glue together and become clumps that cause bridging and blockage when aborting the silo.



"EXPERIENCES" – RIGHT WAY & WRONG WAY

Lessons learned from the 2002 silo fire:

- The Swedish SP Technical Institute conducted experiments and produced a report, "Silo Fires" by Henry Persson, on how to correctly deal with wood pellet silo fires.
- Best practices for dealing with wood pellet fire incidents found N_2 injection to be the most effective to stabilize the smoldering pyrolysis of the pellets before safely discharging silos, minimizing personnel danger and damage to the silo(s) and/or surrounding faculties.
- Volume and flow rates for N_2 injection were also calculated and verified.
- Restricting O_2 and injecting N_2 into the silos head space proved to have positive results, although utilizing medium or high-density foam spray was identified as an option to assist with N_2 losses from the top of the silo and potential fire.



PacBio silo fire 2017

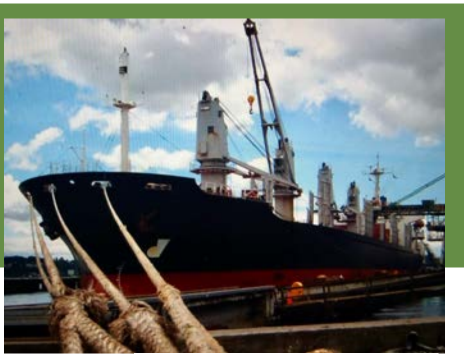
CAUSE OF FIRE: BELIEVED TO BE SELF HEATING

SILO FIRE RESPONSE PLAN

Setup for N_2 injection to a silo with no prior injection system:

- Call out to N_2 supplier.
- Bring in a mobile N_2 vaporizer unit.
- Fabricate injection lances and install them into the (bottom) sides of the silo.
- Setup and connect an N_2 distribution manifold.
- Calculate the feed rate and volume of N_2 required.
- Attempt to apply foam spray on the top of silo.
- Seal off silo ventilation, if possible, to eliminate gas leakage.
- Gas monitors (CO, O_2) to monitor levels to gauge when safe to start aborting the silo (O_2 level below 10% or lower).

FIRE INCIDENT ON A VESSEL (SHIP)



MV Herdla - 2005

- Vessel loaded at Neptune Terminals, Port of Vancouver.
- 24 hours later, vessel went to another port of call and a tar-like liquid was noticed leaking from the vent pipes under the hatch cover.
- Cause of fire: broken hatch light cover allowed fines to build up around the light element, and when the hatch lights were mistakenly turned on several hours after loading while loading other hatches with other commodities, the fines ignited, and pyrolysis of the pellets beneath the hatch light began.
- Several sailors were airlifted to a hospital suffering from overexposure to CO.
- Upon entering a neighbouring hold, the ships ventilation system had not been isolated from the holds containing wood pellets.
- Upon discharge, a column of pyrolyzed material ~1m in diameter by 3m deep below the hatch light, which was no longer active, was dug out, and the balance of the cargo was utilized at a Belgium power station.

CAUSE OF FIRE: BROKEN HATCH LIGHT MISTAKENLY TURNED ON

EFFECTIVE APPROACHES TO FIRE SUPPRESSION

PLAN FOR THE LONG DISTANCE, TAKE TIME TO DEVELOP A PLAN OF ACTION

Inerting the silo with nitrogen has been proven to be the best solution to gain control of a smoldering fire of wood pellets before aborting (discharging) the silo.

- Liquid nitrogen is easier to vaporize than carbon dioxide, more accessible and more economical.
- No risks of static electricity during injection.

WARNING: DO NOT USE

- Water inside the silo as it could form explosive H_2 through water gas shift. In the case of hoppered silos, water finding its way down along the outside walls of the silo into the hopper area will cause the pellets to swell and become very difficult to abort. Foam spray or N_2 in silo head space only!
- CO_2 as it can lead to the formation of high volumes of CO and H_2.

Strongly recommend studying the "SILO FIRE" report of Henry Persson and the Enplus Safety Module 12.

"the most difficult scenario for fire and rescue service (fire brigade) to handle is deep smoldering fires since such fires are extremely difficult to access"

Key Resource:

"Silo Fires- Fire Extinguishing and Preventive and Preparatory Measures" by Henry Persson

IN THE CASE OF A SILO FIRE: PREPARING A SILO FOR NITROGEN INJECTION

- Shut down all ventilation systems and close all ventilation hatches (seal where possible) top and bottom of the silo (take caution when on top of the silo). Pressure relief only or rubber sheet.
- Call for a nitrogen supplier and mobile vaporizer and gas distribution manifold system c/w hoses etc.

IN THE CASE OF A SILO FIRE: PREPARING A SILO FOR NITROGEN INJECTION

If not already equipped with N_2 injection nozzles and/or lances within the bottom of the silo floor or hopper(s) and silo head space.

- Fabricate lances: 4 perforated pipe lances, place 1 within each quarter section of the silo, length – long enough to reach half of the silos radius of the silo - 20mm - 24mm diameter lance (pipe) with 3 - 4mm openings spaced every 25mm for 1 - 2m depending on the silos radius and desired flow rate capacity
- Prepare the silo to receive injection lances, take caution not to create sparks when boring and/or cutting the lance holes and minimize O_2 introduction.
- Drive the lances into the silo by either mobile equipment or drilling drivers. Once inserted (no perforated holes exposed outside the silo), seal and ground the lance.
- Install a lance or open pipe in the silo's head space if safe to do so.
- Alternative to N_2 in the headspace would be medium or high-density foam but requires a foam station on top of silo.
- Connect hoses from the manifold and commence with N_2 injection.

FIRES IN WAREHOUSE WOOD PELLET STORAGES:

- Fire incidents of wood pellets stored in warehouses have been minimal, however there have several incidents on record in both the US and Europe.
  - Seldom has it been caused by self-heating because of the stockpiles ability to allow off-gasses to ventilate from top plus two sides. However there has been incidents in warehouses where self-heating was the cause.
  - Most wood pellet warehouse storage incidents have been of an external ignition source, conveyor failures or outside hot material sources.
- RECOMMENDED FIRE PROTECTION FOR WAREHOUSES:
  - Consider installing hatches or openings along the lower part of the side walls of the warehouse to be able to drive lances into the pile of wood pellets.
  - Install a foaming station and overhead deluge sprinkler system to be able to spray a medium or high density foam over the entire warehouse.

PREPARING A WAREHOUSE FOR NITROGEN INJECTION

If not already equipped with N_2 injection nozzles and/or lances within the bottom of the warehouse floor.

- Fabricate lances: 20mm - 24mm diameter lance (pipe) with 3 - 4mm openings spaced every 25mm perforated pipe lances in sections (6m). Pointed tip on the section to be driven into the stock pile and threaded ends on the sections required to place the lance near the centre of the warehouse from each side. Utilize thermal imaging camera to locate the hot spot (smoldering pyrosis column or ball) to assit with placing the lance(s) where it will be most affective to stabilize the incident.
- Should the warehouse not have access hatches or openings in the walls, prepare the warehouse to receive injection lances, take caution not to create sparks when boring and/or cutting the lance holes and minimize O_2 introduction.
- Drive the lances into the warehouse as close to the bottom of the pile as possible by either mobile equipment or drilling drivers. Once inserted (no perforated holes exposed outside the warehouse), seal and ground the lance.
- Should the warehouse not be fitted with an overhead spray foam deluge system, when safe to do so spray a medium or high-density foam over the stock pile in the warehouse to minimize the loss of N2.
- Connect hoses from the manifold and commence with N_2 injection.

NITROGEN FLOW RATE & VOLUME—CALCULATIONS

- Calculate the m^2 volume of the silo.
- Flow rate of the nitrogen should be no less than $5kg/m^2$, preferably up to $10kg/m^2$ during the initial firefighting operation, depending on the porosity of the pellets.
- Consult with the gas supplier's technical support team (gas experts are normally on staff or consult with gas suppliers).
- Flow rate of N_2 into the (silo) headspace (should injection be possible) is lower than the bottom flow rate at $1 – 3kg/m^2$ to avoid leakage.
- Total volume of nitrogen required and consumed will depend on the leakage (ventilation systems and hatches), but a guideline based on experience of actual silo fires, a total of gas consumption of $5 – 15kg/m^3$ can be expected in relation to the gross volume of the silo.

OBSERVATIONS AND MEASUREMENT OF GASES BEFORE SAFE TO DISCHARGE THE SILO

- Should there be no gas monitors, or they have been damaged, a line (top of silo) and gas pump must be installed in a safe location to monitor gas levels, CO and O_2.
- Measure these gas levels before N_2 injection begins for a reference to determine N_2 concentration level.
- Declining gas concentrations of mainly CO is a sign that the fire intensity has reduced
- Once gas concentrations stabilize to relatively low levels of CO below 1% and oxygen below about 5%, N_2 flow could be reduced to 1 kg/m^2.

SAFE DISCHARGE OF THE SILO AND/OR WAREHOUSE

WARNING: DO NOT attempt discharging the silo till the exothermal fire is STABILIZED

Reaching a stabilized fire incident before discharge may take several days or more depending on the size of the silo and N_2 leakage.

- Develop a plan for the discharge of the silo or warehouse, select a safe area where the potential for open fire and oxidizing gases can be managed and out of danger to personnel and other infrastructures.
- Monitor the gas concentrations during discharge as the falling bridged material may disrupt the inert stability level within the silo.
- Monitor discharge material handling equipment for temperature and/or fire as the oxidizing material may burst into fire.
- Prepare to have water suppression available for the material handling systems and dosing of discharged material in the safe area.
- Monitor the atmospheric gases at the discharging areas, all personnel and/or fire brigade working within the discharge area(s) will require SCBA/SABA (breathing apparatus equipment).
- Clumps formed by the pyrolysis (smoldering) of the fire incident may bridge and/or disrupt the flow of material discharge, which will necessitate manual clearing.

SILO AND WAREHOUSE FIRE PREVENTION—METHODS & PRACTICES

PELLET QUALITY AWARENESS

Process temperatures (drying & cooling), moisture levels and fines.

- Wood Pellet process manufacturing temperatures – that affect self-heating.
  - High drying temperatures will case harden (trap) moisture inside fibre particles.
  - Pellet cooling – short residence time at high air volume extraction will case harden moisture within the pellets, which generates excess CO when pellets begin to oxidize.
  - Higher moisture levels and/or a mixture of MC will accelerate self-heating.
  - Excessive fines will create layers while cascading (free falling) into silos and/or warehouses, these layers of fines reduce the porosity of the wood pellets reducing the ability of gases to ventilate, escalating the potential of self-heating.
- Awareness of the supplier's wood pellet manufacturing process is an important criterion when choosing a supplier.

SILO AND WAREHOUSE PROTECTION

For New Silo construction or retrofit, nitrogen injection and/or purging system is the most effective silo fire prevention method.

Silo

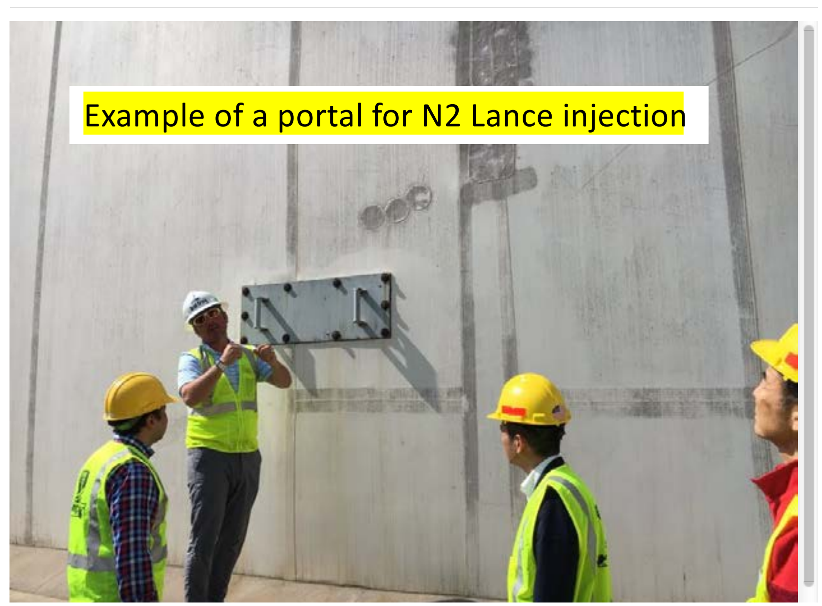
- Install N_2 injection system – nozzles in the bottom of the silo hopper or flat bottom.
- Install the injection nozzles so as not to interfere or be damaged under normal operating conditions.
- Consult with a local fire suppression systems company and/or engineer (ensure the engineer is knowledgeable about dealing with wood pellet fire incidents).
- Should the local authority and/or fire brigade insist on water sprinklers, install a foam spray station on the top of the silo(s). However, try to educate them on the advantage of N_2.

SILO AND WAREHOUSE PROTECTION

For New Silo construction or retrofit, nitrogen injection and/or purging system is the most effective silo fire prevention method.

Warehouse

- Portals along the outside of the warehouse should be installed for lances to be inserted in case of a fire incident (thermal cameras may be utilized to seek out the smoldering hot spot to better penetrate the lances).
- Foam spray deluge system is a good solution to provide somewhat of a seal to minimize the loss of N_2



SILO/WAREHOUSE TEMPERATURE AND GAS MONITORING

- Multiple temperature cables with multi-level readings do not always provide adequate readings to pinpoint a self-heating incident occurring, but will usually give an indication when self-heating activity is occurring.
- Installation of quality gas and humidity monitors is critical as rising levels of CO and humidity is usually the first signs of self-heating.
- Protection from external hot matter (failed bearings, rubber belting, etc.) requires hot spot detectors mounted at the material handling receiving transitions to abort any suspect material (Firefly – GreCon).

PRODUCT ROTATION

Should wood pellets be stored for periods exceeding a month or more?

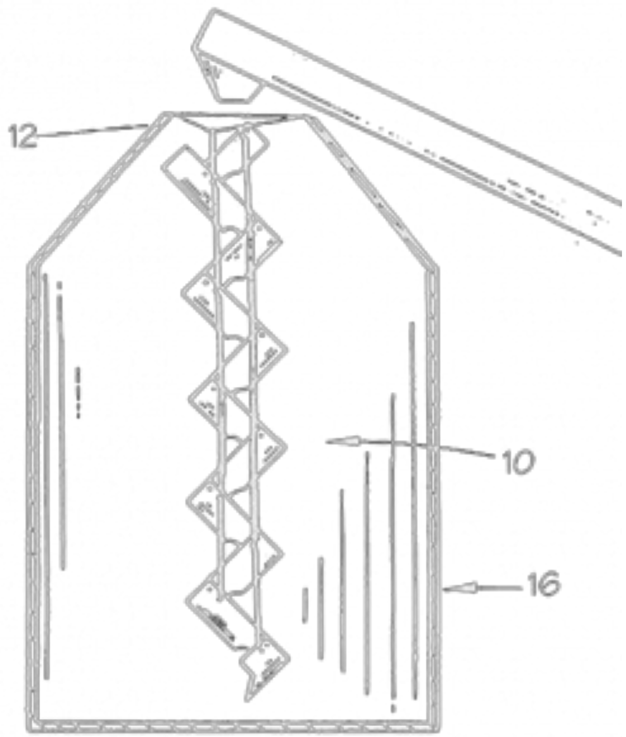
- Wood pellets have been safely stored in silo and/or warehouses for periods of up to 2 years or more, but these wood pellets were manufactured correctly, with low resin (fatty acids) wood species, very minimal fines and well-ventilated storage facilities. (more research required)
- Recommend (if possible) rotating co-mingled wood pellets once a month or less.
- Should the gas concentrations begin to become suspect, then N_2 injection is required rather than rotating the product, as self-heating may have already advanced to a fire-smoldering state.

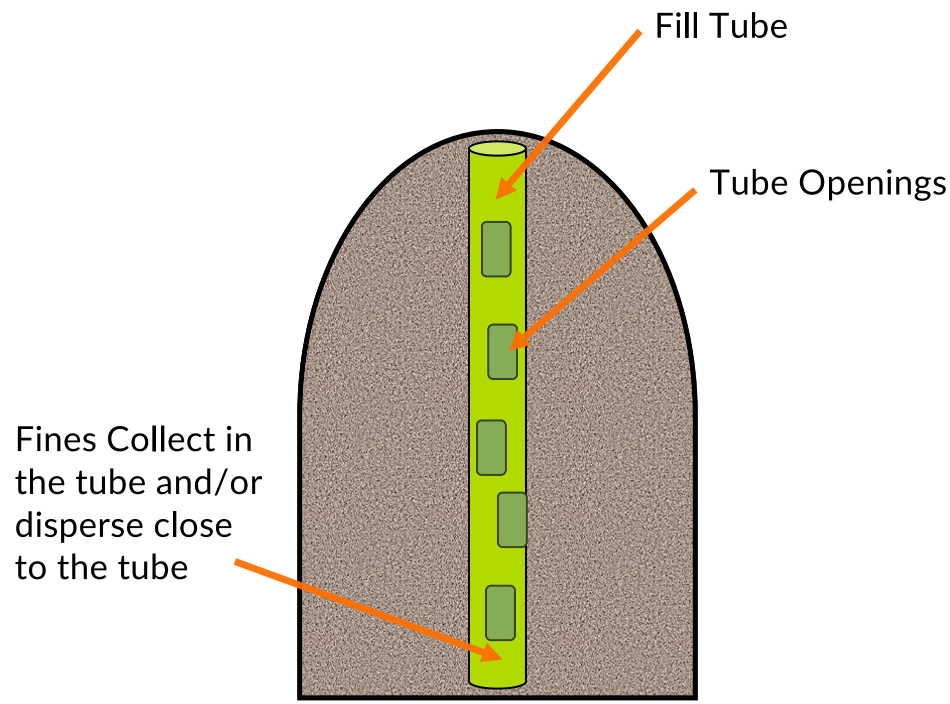
FINES REDUCTION - GENTLE HANDLING

Self-heating prevention by reducing fines distribution in the silo and warehouse

- Fines distributed by cascading in layers over the pellets as the silo or warehouse is being filled, will reduce the porosity of the pellets and accelerate self-heating due to reduced ventilation capacity to release oxidizing heat and moisture.
- Gentle handling equipment has had positive results in reducing self-heating by reducing the free-fall of pellets and confining the fines to the center of the pile in the silo.
- Warehouses can utilize a slide system allowing pellets to roll down the pile instead of free falling.
- Another method for warehouses is to index the drop close to the pile.

EXAMPLES OF GENTLE HANDLING EQUIPMENT (AKA BEAN LADDERS)





Reference Peeples Industries – Dome Technology Silo Installation

PREVENTATIVE AND PREPARATORY MEASURES

Silo Protection Systems & Protocols

Silo Firefighting Protocol – Incident Response Template

- Develop an Onsite Silo Fire Handbook

Silo Protection Systems - Review

- Gas monitors, temperature sensors, humidity sensor
- Hot spot detectors – wood pellet material handling equipment
- Nitrogen injection system –onsite vaporizer
- Nitrogen purge system – small nitrogen generator (PSA)
- Foaming station – top of silo and/or warehouse

PERSONNEL SAFETY

Silo Fire Awareness – Training

- Recommend all personnel study the following reports:
  - Silo Fire Report by Henry Persson https://www.msb.se/siteassets/dokument/publikationer/english-publications/silo-fires-fire-extinguishing-and-preventive-and-preparatory-measures.pdf
  - WPAC Safety Report
  - Enplus Safety Report

Firefighting Procedure Training

- Recommend all personnel study the Silo Fire Handbook developed for onsite silo(s) and/or warehouse.
- Regular practice drills should be scheduled.

COMMUNICATIONS

Local Fire Brigade Awareness and Training

- **No Water** to be sprayed on top and/or within the silo, but rather nitrogen injection to inert the fire incident before aborting the silo and/or warehouse.
- Share the Silo Fire Handbook with the local fire brigade.

Local Authorities – Regulators

- Should there be pressure to install a sprinkler system within the silo, compromise with a foam spray deluge and foam spray generator mounted on the of the silo.

Insurance Agent(s)

- Same as above – educate them

Nitrogen Supplier and Gas Expert

Reach out and encourage all parties that may be involved in a silo fire incident to become informed.

Are there advantages to thermally treated pellets with respect to storage and handling safety?

YES!

Steam-treated (aka steam exploded) pellets produced using the continuous process have several advantages:

✓ **They do not self-heat or self-ignite.**

✓ **They do not offgas carbon monoxide (CO).**

✓ **The produce much less dust in handing (lower explosion risk).**

STEAM-TREATED PELLET PRODUCTION

Steam-treated pellet production with the continuous process is proven at scale at the Européeanne de Biomasse (EdB) 125,000 tonne per year plant in France.

John Swaan at a stockpile of steam treated pellets produced by EdB and used to replace coal in the Paris district heating system.

CO PRODUCTION DURING STORAGE

1. CO production during storage :

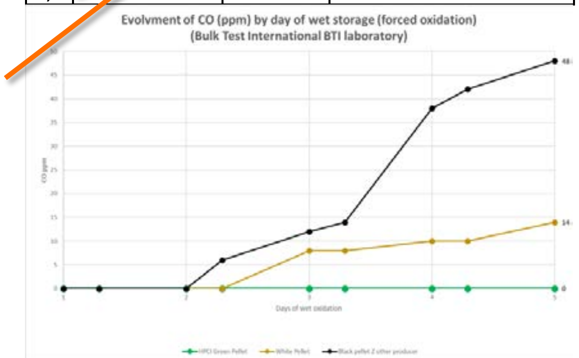
BULK TESTING Int

Surveyors & experts in raw materials

Phase 1 :
Suspending the sample (5 kg) in a container sealed above a volume of water + sodium chloride
Phase 2 :
Over a period of 5 days, with 2 measurements per day capture of CO and O2 fumes.
Oxidation test :
Semi-daily measurement reading
Water uptake test by capillary action :
Total H2O at the end of the test - initial H2O of the biofuel

Equipment : container, gasket, grid, etc...

CO ppm emission measurement (BTI test)			
Day	**HPCI Green Pellet**	**White Pellet**	**Black pellet Z other producer**
1,0	0	0	0
1,3	0	0	0
2,0	0	0	0
2,3	0	0	6
3,0	0	8	12
3,3	0	8	14
4,0	0	10	38
4,3	0	10	42
5,0	0	14	48



Steam-treated pellets produced by EdB using the Valmet continuous process.

ZERO CO emissions

Steam treated pellets produced using the batch process (Zilkha).

Theory for high CO emissions in the batch process – some wood fibers were not transformed in the batch process and are trapped in the pellets with moisture and thus CO emissions are magnified.

SELF-HEATING TEST

1. **Self-heating test :**

ADINEX
EXPLOSION SAFETY CONSULTANTS
Adinex N.V.
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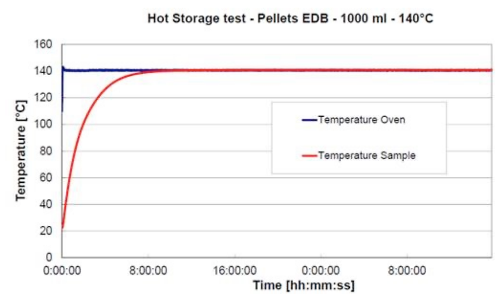
Hot storage test – 140°C – 10 cm – "EDB Pellets" (original part)
A hot storage test was carried out at a constant temperature of 140°C and at a cubic volume of 1 liter (10 cm wide).
No exothermic reaction and no ignition was observed at an oven temperature of 140°C (mesh container metallic, 1000 ml).
The maximum temperature of 140°C was reached after 4 p.m.
Sample temperature did not reach 200°C within 24 hours.
By consequently, the auto-ignition temperature of the "Pellets EDB" sample (fraction original) - 1000ml cubic wire mesh basket is above 140°C.

Appendix 3 shows a graph of the storage test temperature history at hot :
Annexe 3: Hot storage test – 140 °C – 10 cm – "Pellets EDB" (fraction originale)



No self-heating

The following classifications can be assigned to the "EDB Pellets" sample in accordance with UN Transport of Dangerous Goods* and CLP Regulation**:

- Classification according to UN: **No self-heating substance of the Division 4.2.**
- Classification according to CLP [2009]: **No self-heating substance**

**"Recommendations on the transport of dangerous goods Part III Section 33.3 division 4.2 – United Nations New York and Geneva 2003"*

Thank you!

John Swaan

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WOOD PELLET
ASSOCIATION OF CANADA

Japan Biomass Safety Workshop

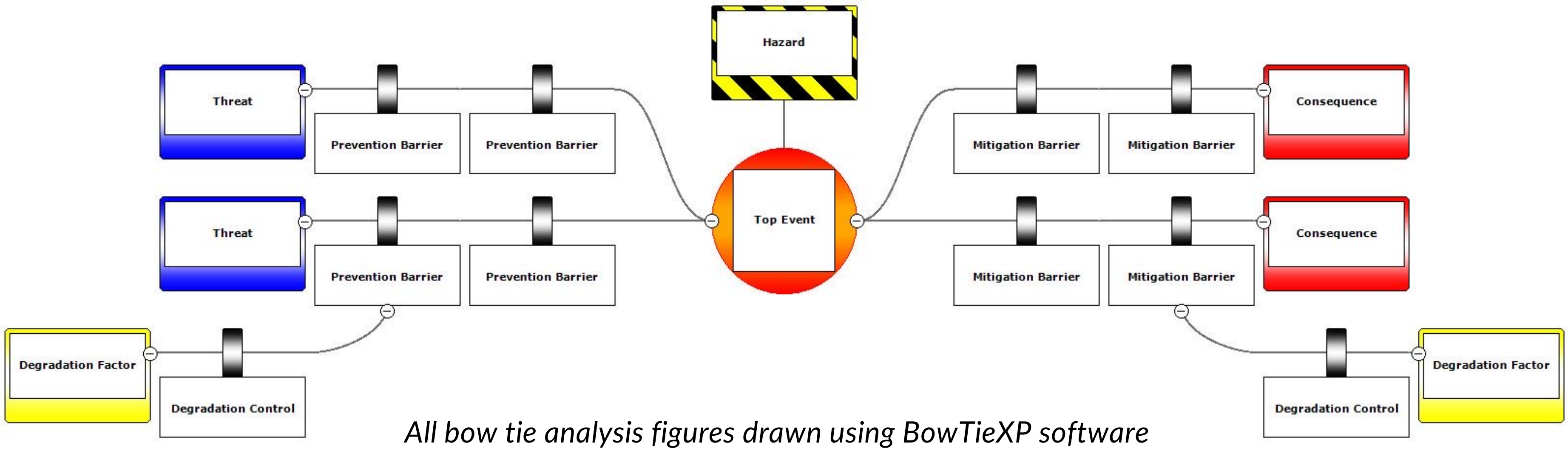
ANALYZING THE HAZARDS: MOVING FROM REACTIVE TO PROACTIVE

WOOD PELLET ASSOCIATION OF CANADA

Kayleigh Rayner Brown, MASc, P.Eng.
Obex Risk Ltd.

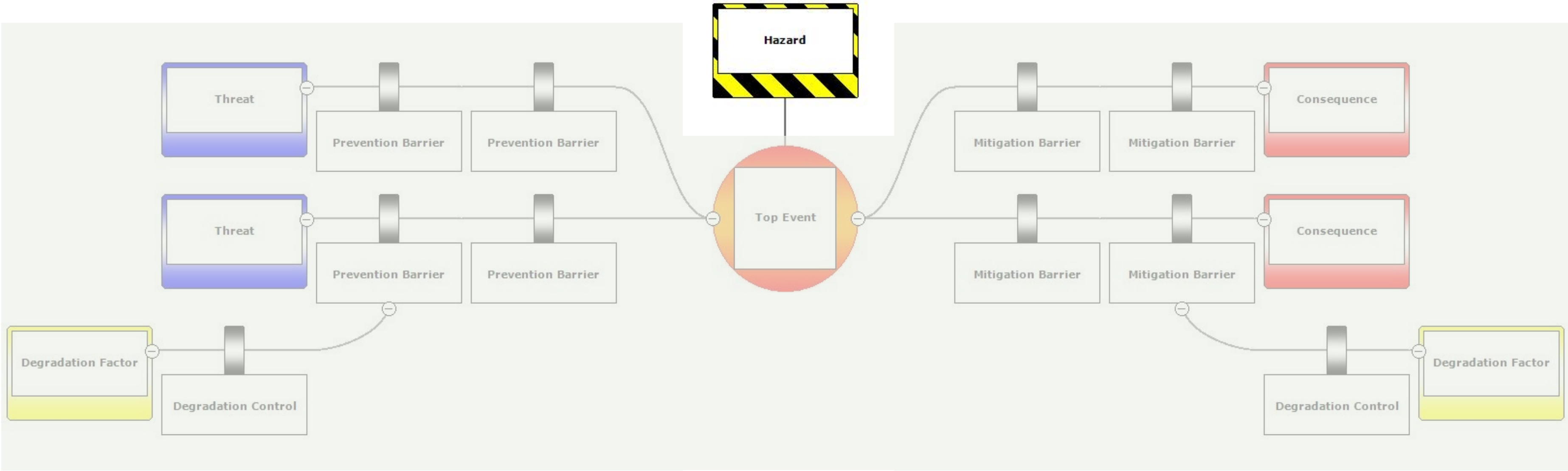
BOW-TIE ANALYSIS INTRODUCTION

Visual hazard analysis tool that systematically analyzes and communicates how hazardous events can occur and cause negative consequences



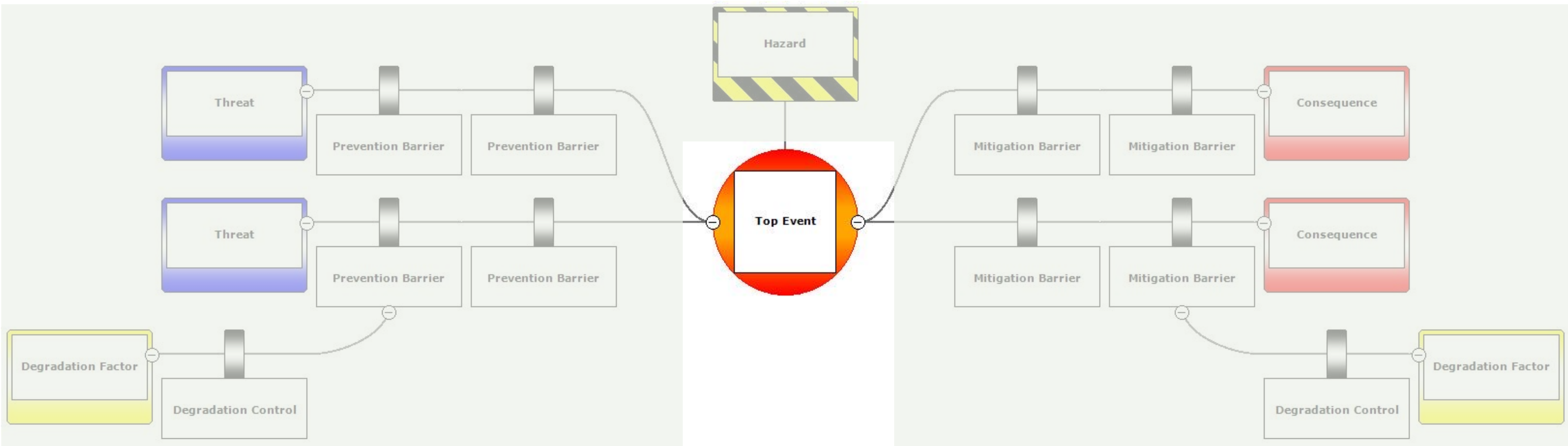
All bow tie analysis figures drawn using BowTieXP software

BOW-TIE ANALYSIS ELEMENTS: HAZARD



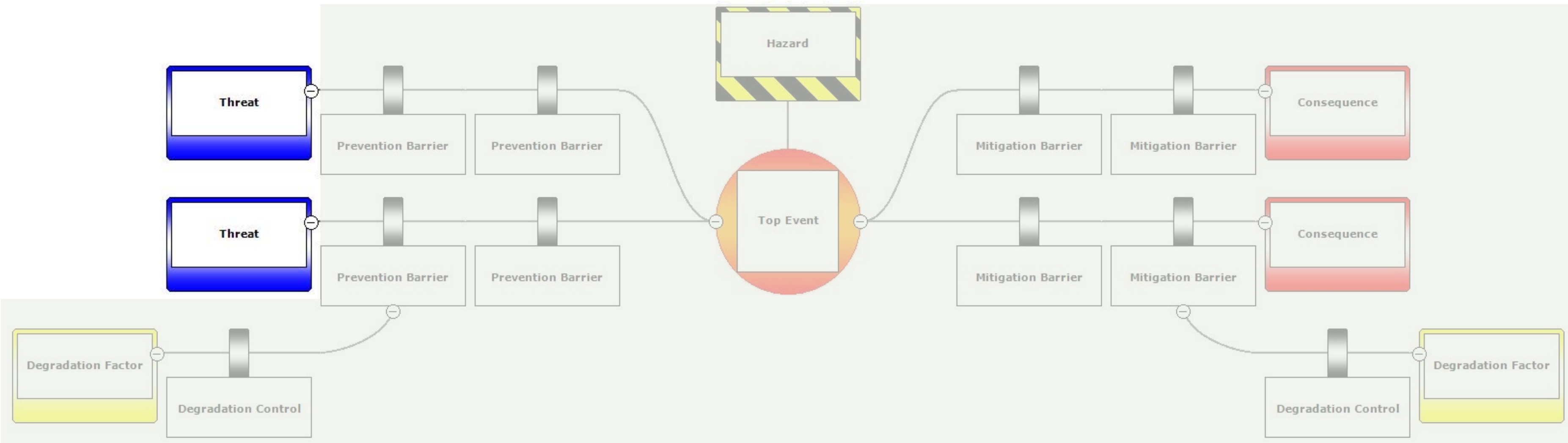
Hazard: An operation, activity or material with the potential to cause harm to people, property, the environment or business.

BOW-TIE ANALYSIS ELEMENTS: TOP EVENT



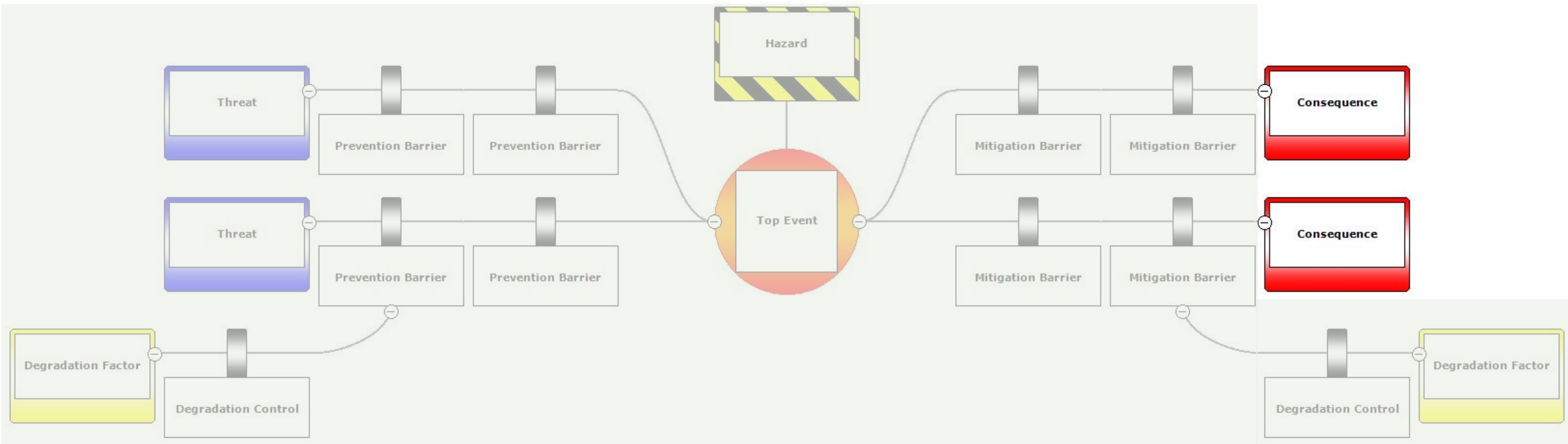
Top Event: The central event corresponding to the loss of containment or loss of control of the hazard.

BOW-TIE ANALYSIS ELEMENTS: THREATS



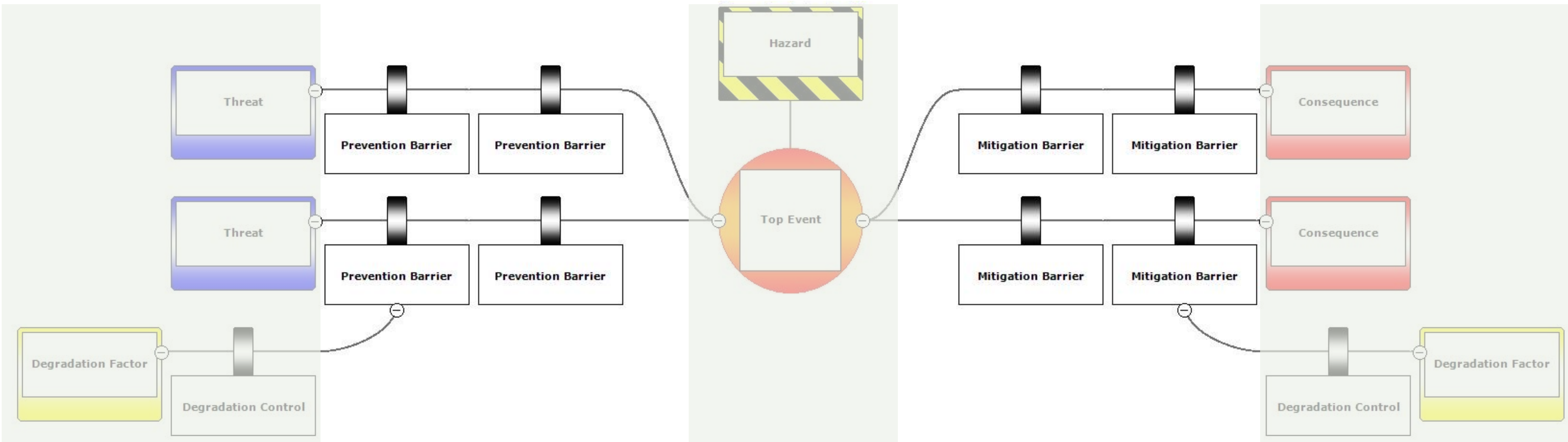
Threats: Possible initiating events that can lead to the top event.

BOW-TIE ANALYSIS ELEMENTS: CONSEQUENCES



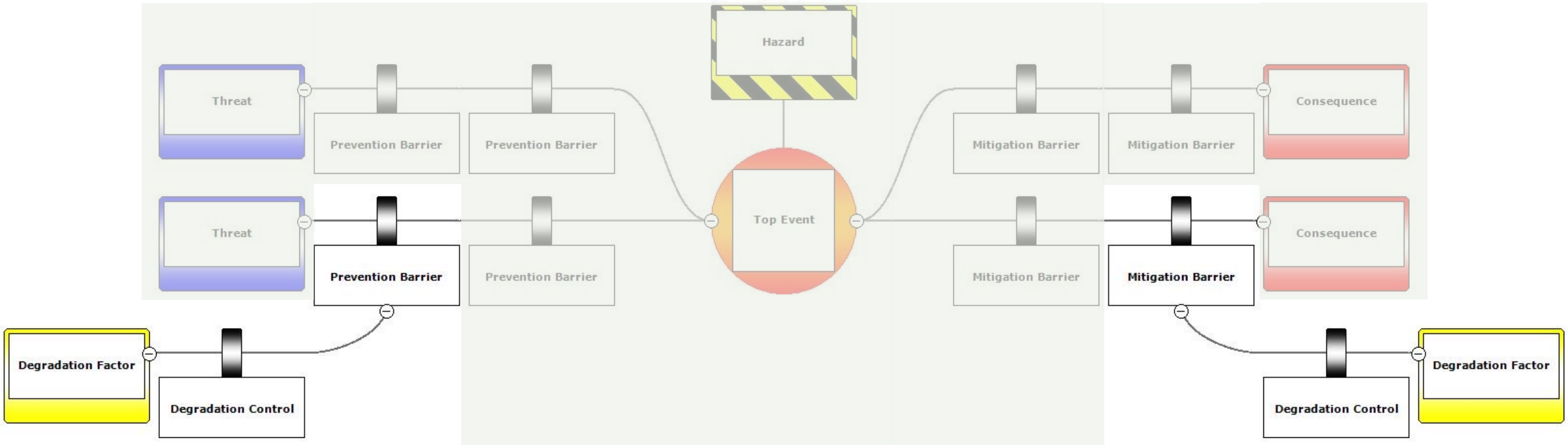
Consequences: The undesirable result of the top event; health and safety effects, environmental impacts, loss of property and business interruption.

BOW-TIE ANALYSIS ELEMENTS: BARRIERS



Barriers: Control measures that can prevent a threat from developing into a top event (prevention barriers) or can mitigate the consequence of a top event after it has occurred (mitigation barriers).

BOW-TIE ANALYSIS ELEMENTS DEGRADATION FACTORS AND CONTROLS

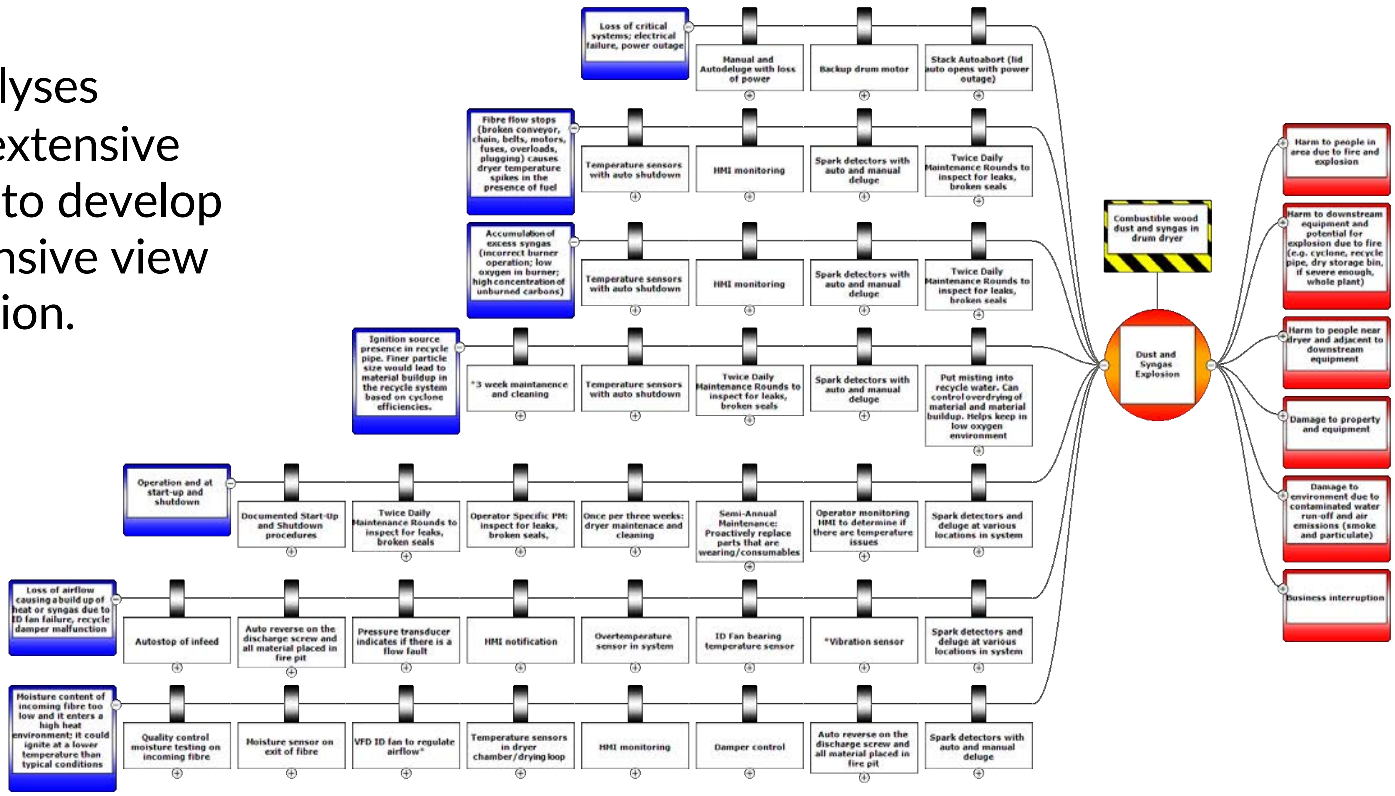


Degradation Factors: A situation, condition, defect or error that compromises the function of a barrier by defeating it or degrading its effectiveness.

Degradation Controls: Measures that help prevent the degradation factor from impairing the barrier.

BOW-TIE ANALYSIS EXAMPLE: COMBUSTIBLE DUST & GAS IN DRUM DRYER

Bow-tie analyses summarize extensive information to develop a comprehensive view of an operation.



INHERENTLY SAFER BOW-TIE ANALYSIS FOR COMBUSTIBLE DUST HAZARDS

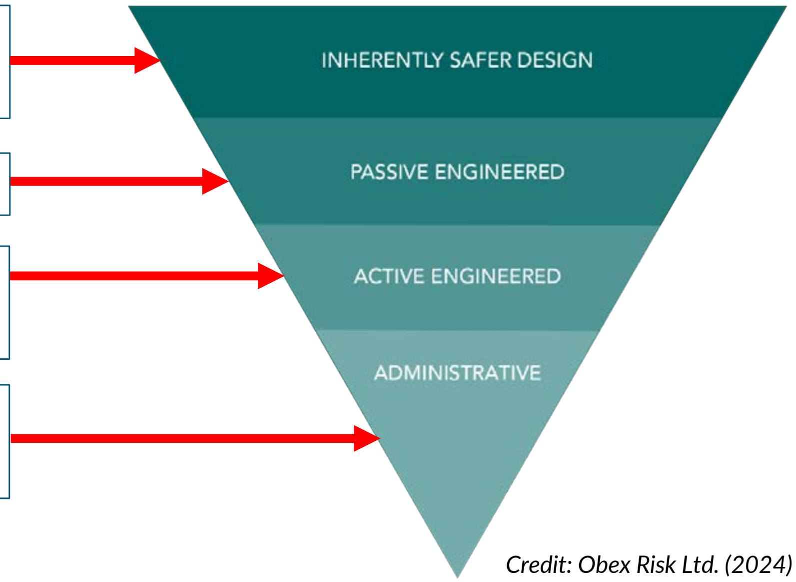
Effective risk reduction involves implementation of inherently safe design (ISD), engineered equipment, and procedural measures

ISD (minimization): Minimization of number of elbows in ventilation system to reduce combustible dust accumulation

Passive engineered: Installation of flap valve

Active engineered: Installation of gas sensor and alarm system

Administrative: Wearing of personal protective equipment (PPE) by personnel



Amyotte and Khan (2021); Rayner Brown et al. (2022)

Credit: Obex Risk Ltd. (2024)

BOW-TIE ANALYSIS FOR ASSESSMENT AND MANAGEMENT OF COMBUSTIBLE DUST HAZARDS

- Completed bow tie analyses for each of the major pellet production steps (raw fibre storage, dryer, hammer mill, pelletizer, cooler, silo)
- Identified critical controls, such as:
  - Spark detection and deluge systems
  - Preventative maintenance programs
  - Hot work programs
- Completed critical control management, including:
  - Assigning roles and responsibilities
  - Establishing measures to ensure reliability and effectiveness (e.g., inspection, testing, maintenance, calibration)

WPAC (2024)

KEY OUTCOMES

- Effectively identifies areas for improvement.
- Shifts from reactive to proactive—advances the understanding of what can go wrong and how to prevent it.
- Improves understanding of reliability of controls.
- Enhances employee participation and safety culture.
- Improves sharing of information.
- Adds to existing safety management framework to develop more robust system to deal with hazards at plant.

PROCESS SAFETY MANAGEMENT (PSM)

- Bow tie analysis is part of process safety management (PSM)
- PSM is the use of management principles and systems to identify, understand, avoid, and control process hazards to prevent, mitigate, prepare for, respond to, and recover from process-related incidents.
- PSM helps protect people, property, business and the environment.

- Canadian wood pellet industry beginning to implement PSM following CSA Z767 *Process safety management* standard framework.

CLOSING REMARKS

- Bow-tie analysis is a powerful tool to analyze process hazards systematically.
- Bow-tie analysis evaluates how combustible dust ignition can occur so key prevention measures can be implemented.
- Systems must be in place to ensure the reliability of critical controls.
- Bow-tie analysis is part of process safety management, which provides a framework for managing all aspects related to protecting operations, including management of change, training, process and equipment integrity.

Thank you!

Kayleigh Rayner Brown, MASc, P.Eng.

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Japan Biomass Safety Workshop
GETTING DOWN TO TACTICS:
DEVELOPING A RESPONSE PLAN
WOOD PELLET
ASSOCIATION OF CANADA
John Swaan
FutureMetrics

SILO OR WAREHOUSE FIRE RESPONSE PLAN REVIEW

- Review of Developing Silo or Warehouse Fire Response Plan "Site Fire Handbook"(7 page) handout.
  1. Purpose
  2. Scope
  3. Personal Protective Equipment Required
  4. Regulation and Reference Material
  5. Definitions
  6. Procedures
  7. Communication Methods
  8. Associated Documents
  9. Revisions Table

SILO FIRE RESPONSE PLAN

- Review the following silo fire response plan.
- Complete the form to support the development of a plan for your own operation.

RESPONSE PLAN REVIEW

- Any questions about the response plan?
- Any questions about training personnel on a silo fire response plan?
- Any questions about how to coordinate, educate and engage with workers, first responders and any other relevant personnel that would be involved with a silo fire?
- Any questions about who to contact?
- Do you have resources that can be provided to first responders/fire department on silo fires? Do you need more information?
- Any questions about setting up nitrogen supplies and systems?
- Any questions about gas monitors, including maintenance and calibration?

Thank you!

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Japan Biomass Safety Workshop

GETTING REAL: CASE STUDIES

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WOOD PELLET
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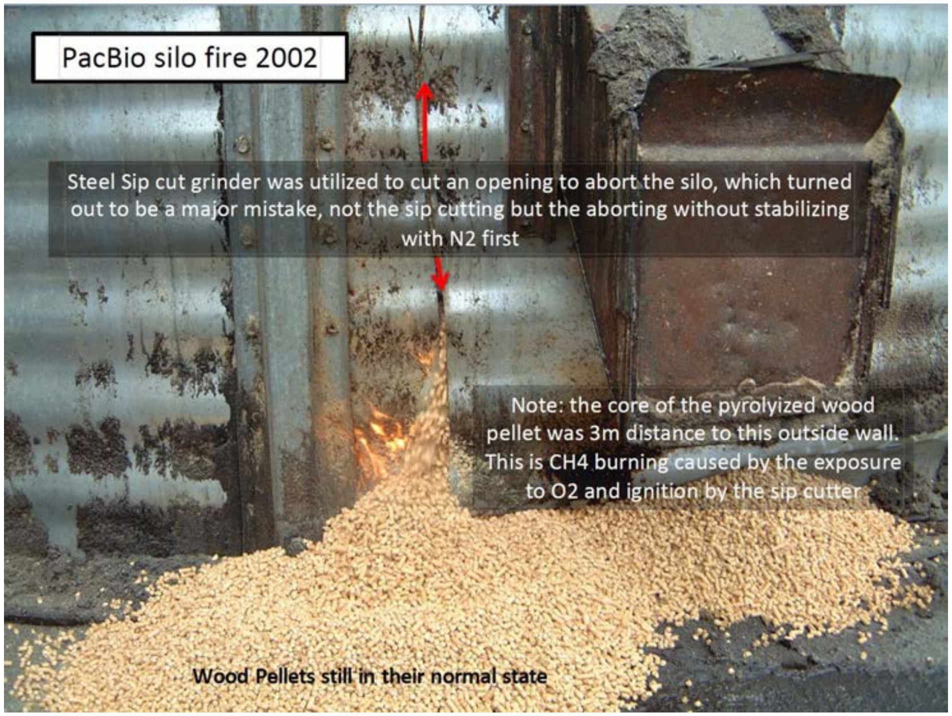
CASE STUDIES

- Highlight real-life silo fire examples including
  - Responses
  - Action plans
  - Preventative measures
- Training for workers in plants and local fire departments.
- Revisit case studies highlighted previously and elaborate on key takeaways.

CASE STUDY #1: IGNITION SOURCE PROPAGATION

- Hot work (welding) without fire watch.
- Molten steel transported into the silo.
- Pyrolysis initiates an exothermal event.
- Began to abort the silo without stabilizing exothermal event.
- Syngas's from the pyrolysis Ing material ignites when exposed to this material and supplied with oxygen.
- The eruption of the syngas destroys the silo.
- Lesson Learnt – It's the syngas's that caused the explosion, not the dust.

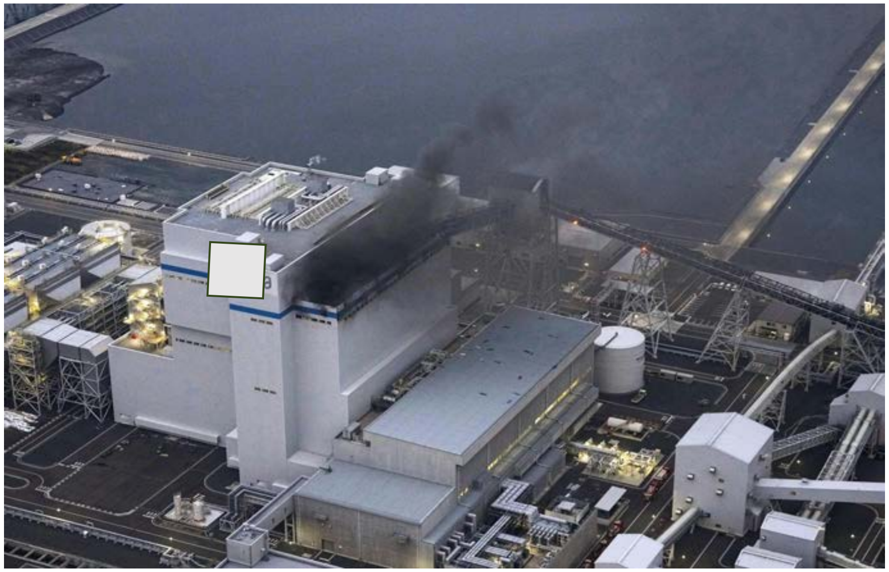


CASE STUDY #2: SELF-HEATING

- Silo Fire at PacBio Prince George, BC – 2017.
- Assumed to have caused by Self-Heating.
- Root cause/why it happened:
  - Pellets stored in the silo for over 3 months due to shipping issues.
  - Faulty temperature sensors & no gas monitoring.
- Lessons learned:
  - N2 injection inerting the silo and stabilizing the product before aborting the pellets from the silo.

CASE STUDY #3 – POSSIBLE CAUSE OF FIRE SYNGAS OR DUST OR BOTH

- If external mechanical failure (conveyance): could be dust explosion & fire carried on to the boiler
- If self-heating: could be syngas explosion followed by dust explosion & fire



CASE STUDY #4: MECHANICAL FAILURE

Facility/equipment layout:

- Sawdust and wood chip storage silo.
- Carpentry facility with two storage silos (~10 m tall and ~5.5 m diameter); metal shell construction.
- Baghouse and filter system on top of silo.
- Inside silo, large vertical screw moved sawdust and wood chips to rotary valve and transferred the material for use at onsite thermal power plant.

Russo, P., De Rosa, A., Mazzao, M. (2017). Silo explosion from smoldering combustion: A case study. The Canadian Journal of Chemical Engineering. *https://doi.org/10.1002/cjce.22815*

Dust Safety Science (2023). Case Study – Insufficient Venting During Sawdust Silo Explosion Leads to Fatality

CASE STUDY #4: INCIDENT

- Smoke and flames appeared at bottom of silo.
- Attempted to douse fire through manhole on top of silo.
- When manhole at bottom opened to discharge burned material, it is believed it caused the chimney effect—draw oxygen through the top manhole down to bottom and caused smoldering combustion inside.
- Resulted in explosion that blew off silo roof; four firefighters injured, one fell off elevated surface platform and died in hospital.

Russo, P., De Rosa, A., Mazzao, M. (2017). Silo explosion from smoldering combustion: A case study. The Canadian Journal of Chemical Engineering. https://doi.org/10.1002/cjce.22815

Dust Safety Science (2023). Case Study – Insufficient Venting During Sawdust Silo Explosion Leads to Fatality

CASE STUDY #4: ROOT CAUSE/WHY IT HAPPENED

- Ignition source: believed vertical screw inside conveyor (broke, heated up).
- Pyrolysis gases built up in headspace.
- Deflagration vents installed on upper silo, but poorly placed bag filers blocked them and reduced venting efficiency.
- Corrosion on silo contributed to fracture due to explosion.
- Insufficient explosion venting resulted in fatality.

Russo, P., De Rosa, A., Mazzao, M. (2017). Silo explosion from smoldering combustion: A case study. The Canadian Journal of Chemical Engineering. https://doi.org/10.1002/cjce.22815

Dust Safety Science (2023). *Case Study – Insufficient Venting During Sawdust Silo Explosion Leads to Fatality*

CASE STUDY #4: LESSONS LEARNED

1. Measures needed to stop the fire or deflagration, such as temperature sensors, gas detectors, water foam sprinkler systems, and gas inerting systems.
2. Equipment maintenance must be completed to prevent mechanical failure and potential ignition sources; corrosion must be inspected and addressed to ensure equipment integrity.
3. Best-practices for attacking a silo fire (as previously outlined and as described by Persson (2013)) should be followed to minimize the risk of dust or gas explosion.
4. Deflagration venting must be adequately designed; obstructions increases the area needed to relieve the explosion pressure.

Russo, P., De Rosa, A., Mazzao, M. (2017). Silo explosion from smoldering combustion: A case study. The Canadian Journal of Chemical Engineering. https://doi.org/10.1002/cjce.22815

Dust Safety Science (2023). Case Study – Insufficient Venting During Sawdust Silo Explosion Leads to Fatality

Thank you!

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WOOD PELLET
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Safer Biomass Handling and Storage

A PATH FORWARD

WOOD PELLET
ASSOCIATION OF CANADA

Integrated Learning Session (Moderated by Gordon Murray)
May 9, 2024

CONFIDENTIAL ONLINE FEEDBACK

1. Scan this QR code or click the Mentimeter link in the chat
2. Enter your responses

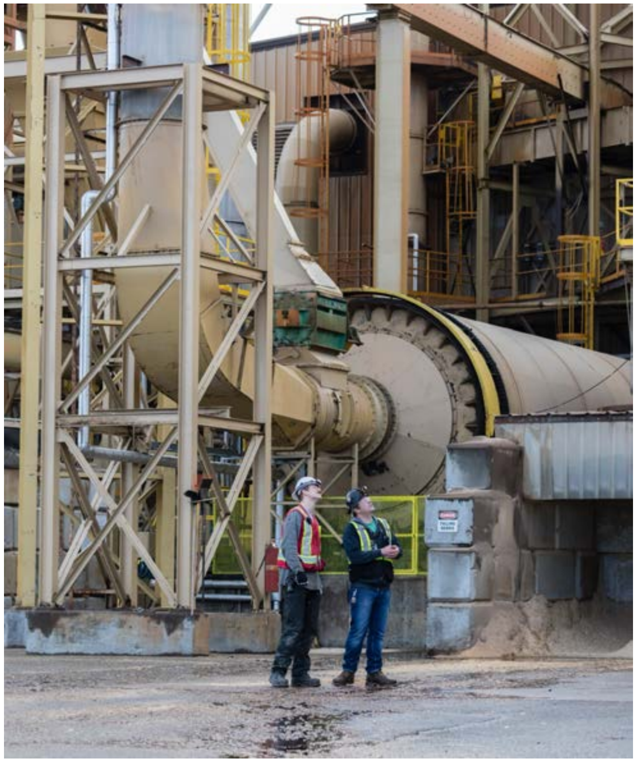
All feedback is anonymous. Your responses will be kept confidential.

Mentimeter

QUESTION 1

What do you think is the biggest risk to safe biomass storage and handling?

- Combustible gas
- Mechanical integrity
- Dust accumulations
- Training
- Self-heating and storage
- Conveyors
- Ventilation and piping



QUESTION 2

What are some other risks that we did not cover in the previous question?

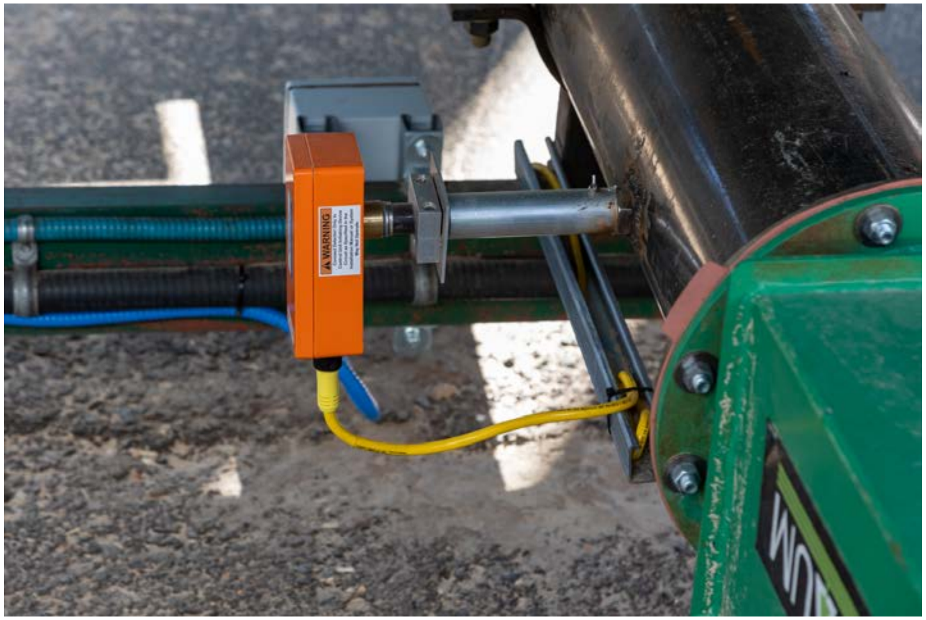
QUESTION 3

What solutions and risk reduction measures are you most interested in learning more about?

- Fire protection (e.g., detection and deluge)
- Preventative maintenance
- Fibre pile management
- Nitrogen injection
- Gas and temperature sensors
- Bow tie analysis

QUESTION 4

What are some other solutions and risk reduction measures that we did not cover in the previous question?



QUESTION 5

How do you think incidents can be avoided in the future?

QUESTION 6

What could the industry do together to help prevent incidents and raise awareness?

QUESTION 7

How can the industry work together (for example - an industry working group)?

QUESTION 8

Who else needs to be involved to help drive safety initiatives?

QUESTION 9

What suggestions do you have to obtain leadership buy in?

QUESTION 10

Which additional resources would be the most beneficial to you?

- In-person workshops
- Technical reports
- Summary documents
- Online learning
- Site specific visits
- Bow-tie analysis
- Information from equipment vendors

Thank you!

Gordon Murray

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Japan Biomass Safety Workshop

IN CLOSING – SAFETY IS EVERYONE'S RESPONSIBILITY

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