## Japan Biomass Safety Workshop

# SAFER BIOMASS HANDLING AND SILO OPERATIONS: PREVENTING FIRE AND EXPLOSIONS

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CANADIAN BIOMASS

## Japan Biomass Safety Workshop

# STARTING WITH THE BASICS: PREVENTION THROUGH HANDLING & STORAGE UNDERSTANDING

WOOD PELLET ASSOCIATION OF CANADA

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# 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

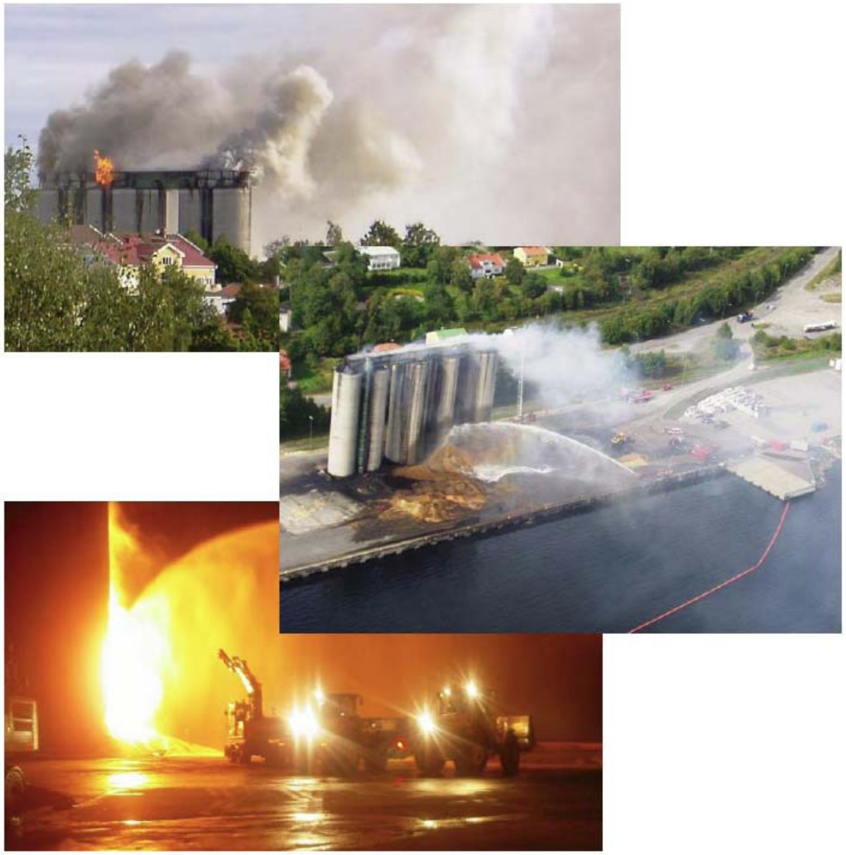
- Six standards and technical specification documents are published or under development.
- ISO 20023 - Solid biofuels — Safety of solid biofuel pellets — *Safe handling and storage of wood pellets in* ***residential and other small-scale applications.***
- ISO 20024 - Solid biofuels — *Safe handling 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.

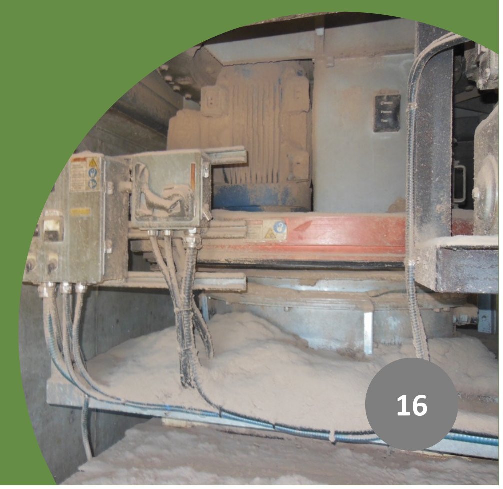
# COMBUSTIBLE DUST: WHEN IS WOOD DUST EXPLOSIVE?

**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

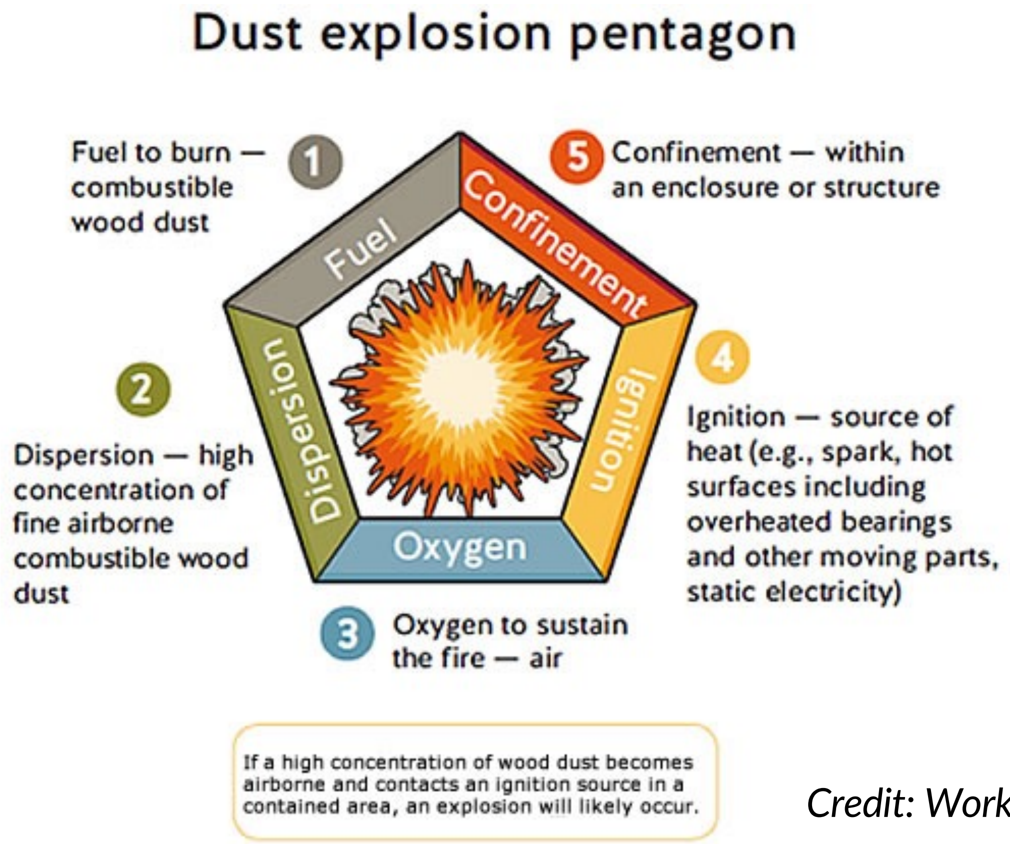


# COMBUSTIBLE DUST: WHAT IS A DUST EXPLOSION?

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.

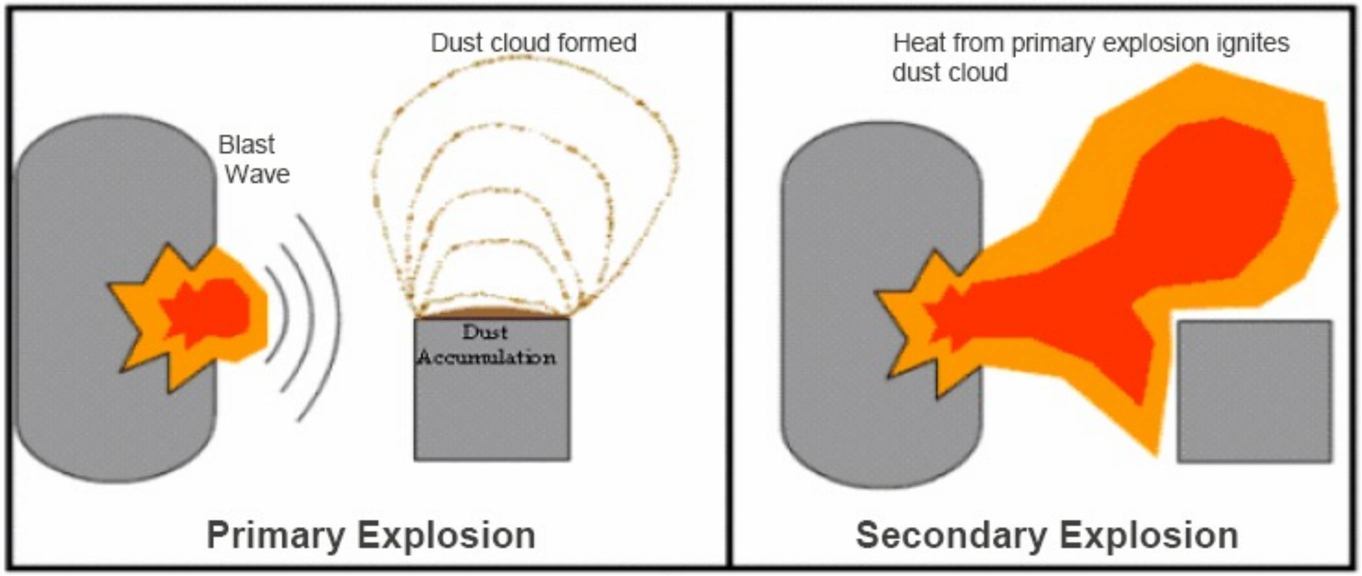
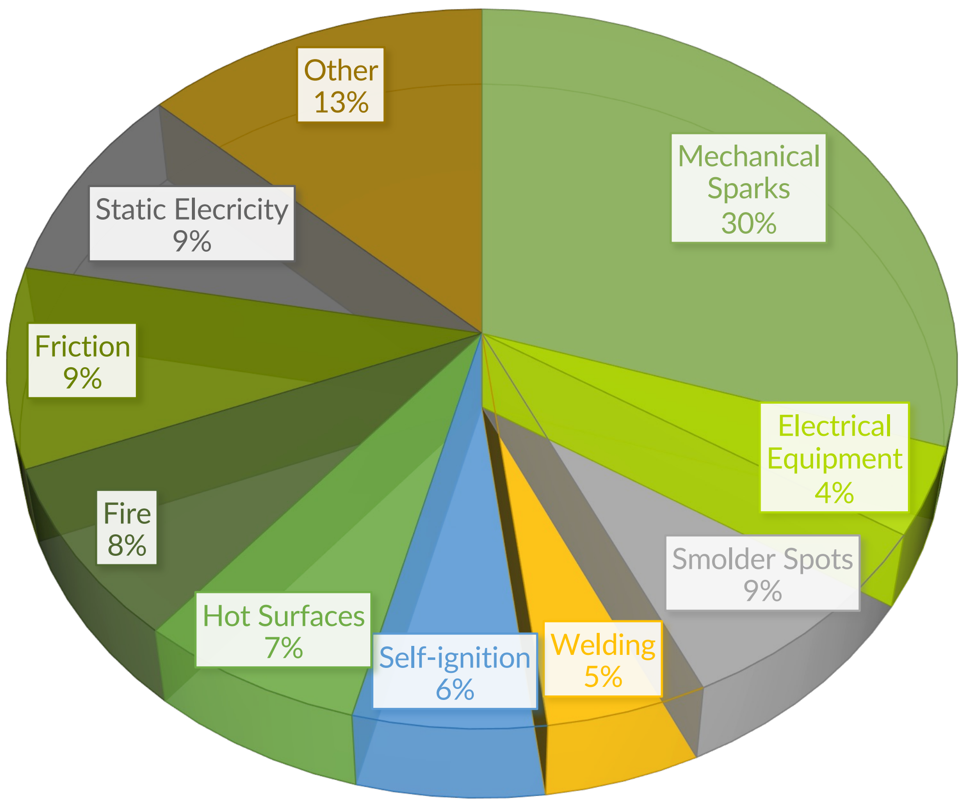



Figure 2

*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.

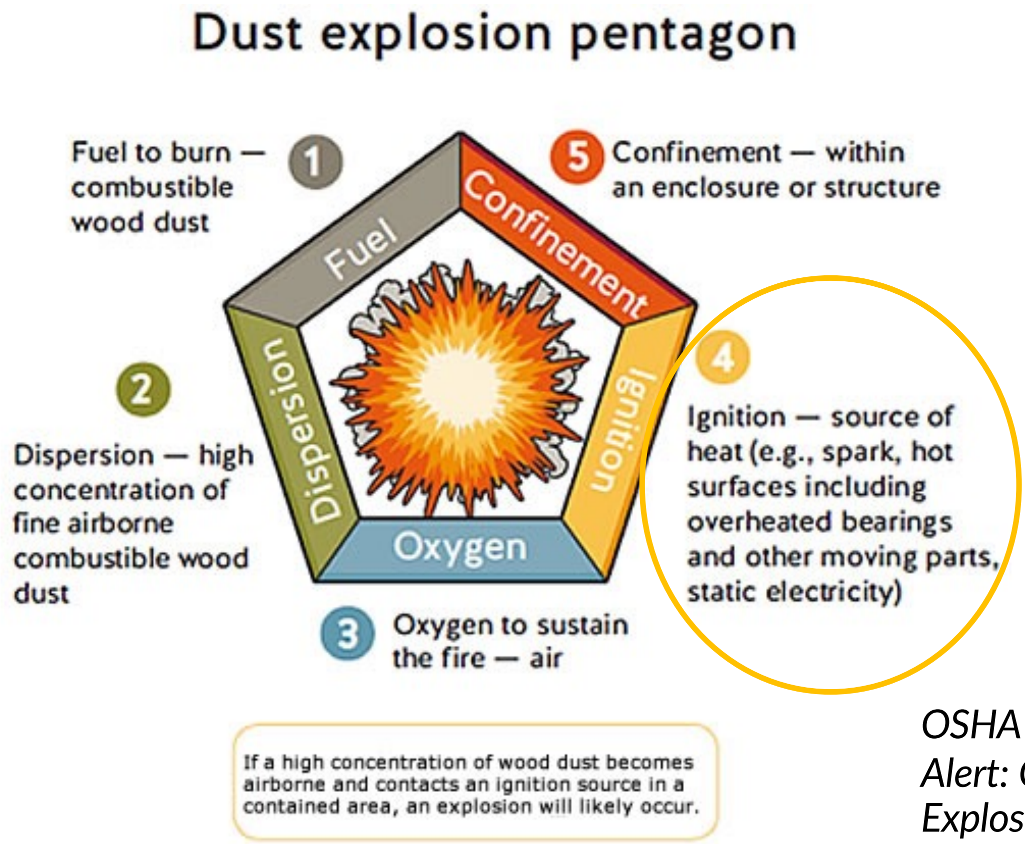
# COMBUSTIBLE DUST: DUST HAZARD ASSESSMENT

- 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.<br>• Suppression systems such as misters can be effective but pose challenges in cold weather.<br>• Ventilation systems such as wall and ceiling fans can provide are circulation and assist in controlling fugitive dust.<br>• 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.<br>• Schedule regular housekeeping.<br>• Pay attention to walls and beams.<br>• Methods include vacuuming, water washing, brooms and compressed air.<br>• Include regular inspections, note deficiencies, and track corrective actions. |

# COMBUSTIBLE DUST: IGNITION CONTROL

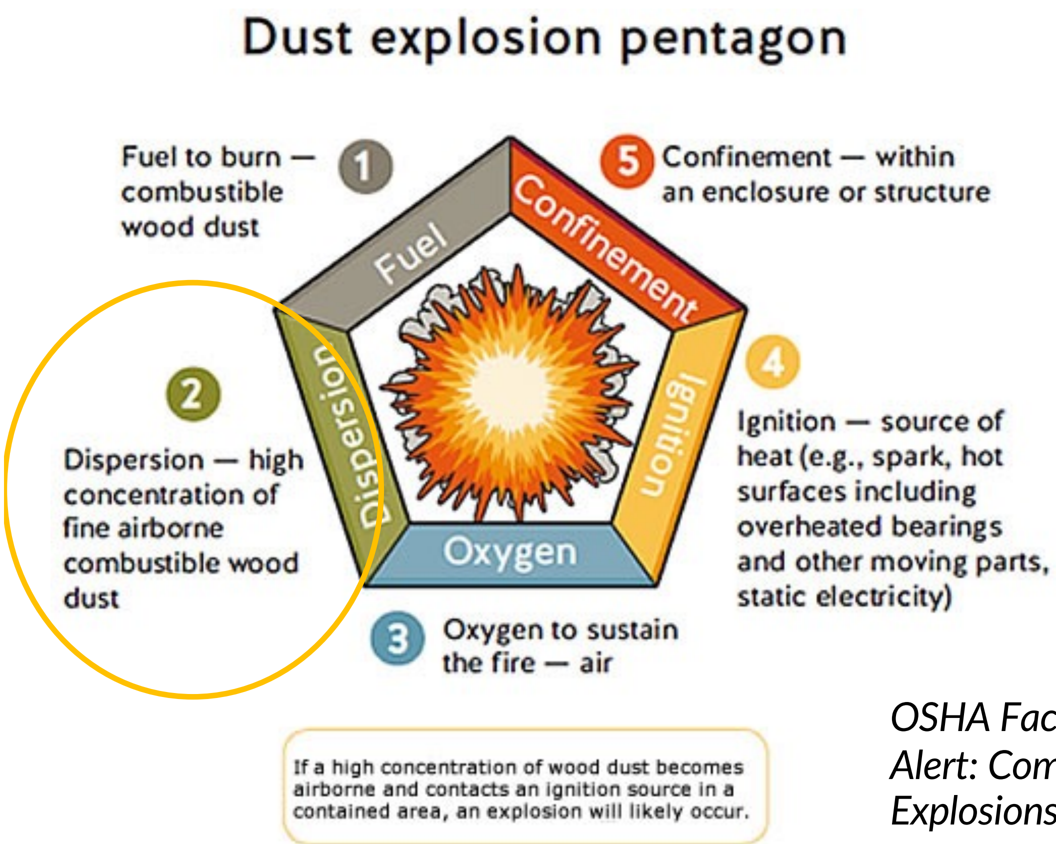



**Need to control**

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

*OSHA Fact Sheet, Hazard Alert: Combustible Dust Explosions*

# COMBUSTIBLE DUST: DISPERSION CONTROL




*OSHA Fact Sheet, Hazard Alert: Combustible Dust Explosions*

- 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.

# 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 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

Thermal runaway
Smoldering combustion

Heat of water adsorption

Chemical Reactions

Chemical oxidation
Pyrolysis
Hydrolysis

Biological degradation

Metabolism and biological oxidation

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.

# 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

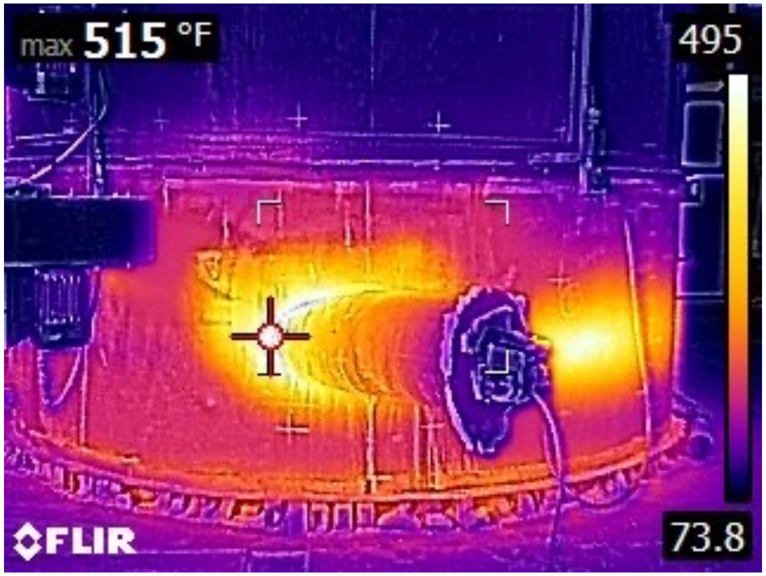
- Temperature monitoring can be completed in real-time with online systems or with routine inspection by trained personnel.

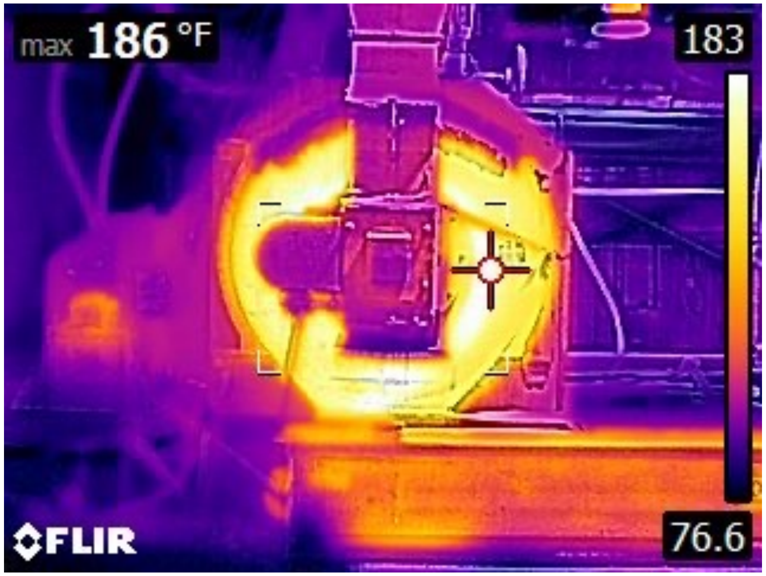


*Thermal imaging camera photos (Courtesy of Shaw Renewables)*

# 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:

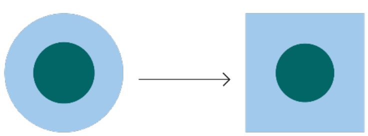
**Minimization**

Remove hazardous equipment no longer in use

**Substitution**

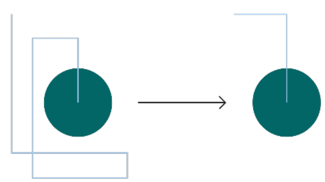
Use alternate material of construction or equipment that is more robust for given application

**Moderation**



Relocate hazardous equipment away from personnel

**Simplification**

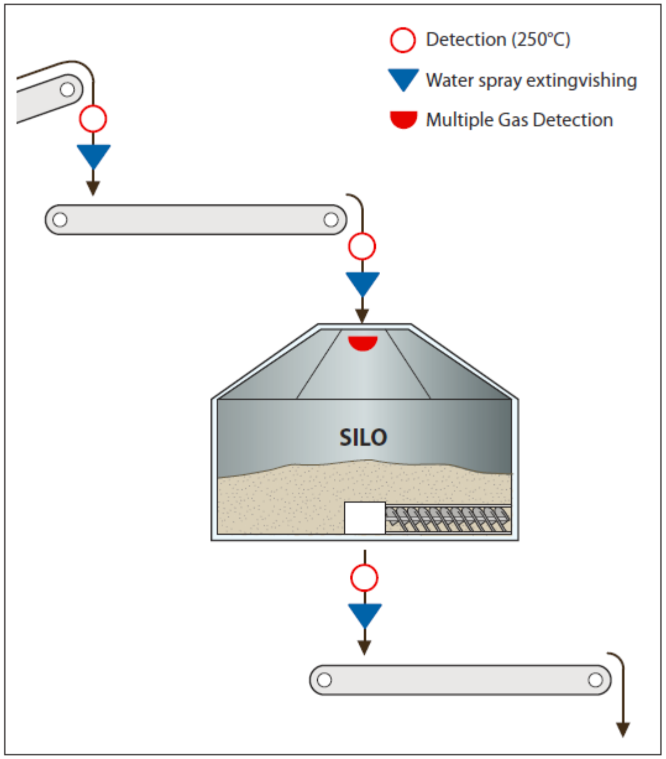


Design processing equipment and procedures to eliminate opportunities for errors and excessive use of add-on safety features

*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)*

Thank you!

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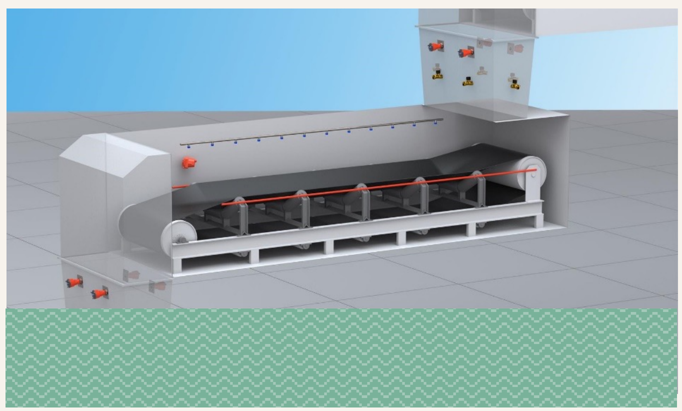
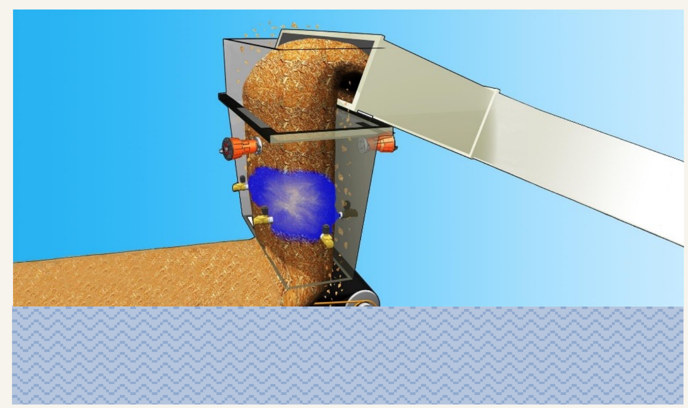
PREVENTIVE PROTECTION SYSTEMS FROM firefly ab SWEDEN

# 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



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# 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)



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# FIREFLY'S INVOLVEMENT IN PELLET SILO TESTS IN SWEDEN

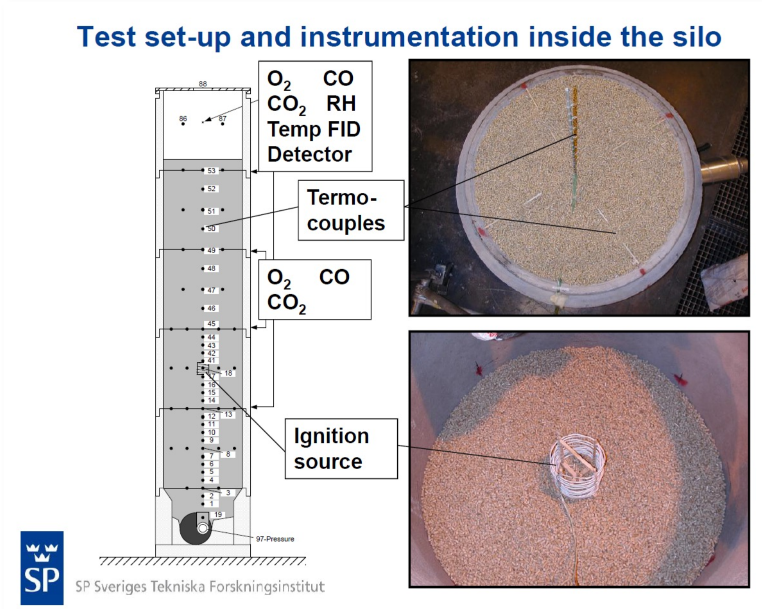
Firefly have been involved in two Silo tests with SP (Swedish National Testing and Research Institute) and Henry Persson

### 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.



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PREVENTIVE PROTECTION SYSTEMS FROM

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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

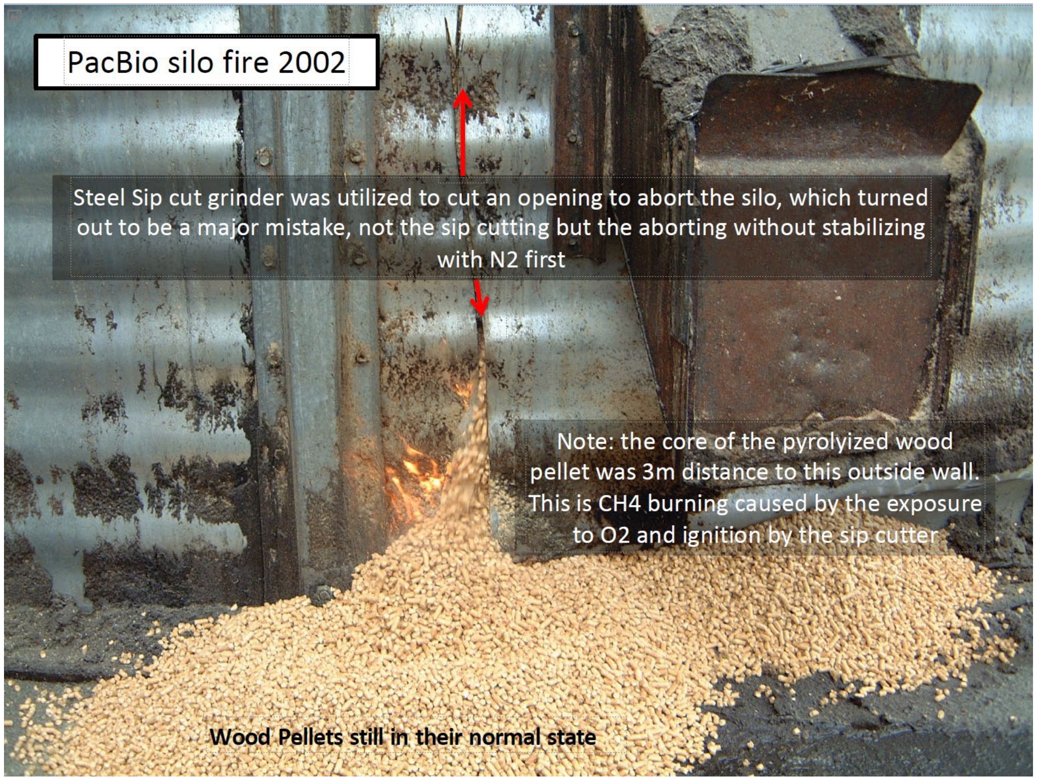
John Swaan
FutureMetrics

# SILO FIREFIGHTING TECHNIQUES & PROCEDURES

# "EXPERIENCES" – RIGHT WAY & WRONG WAY

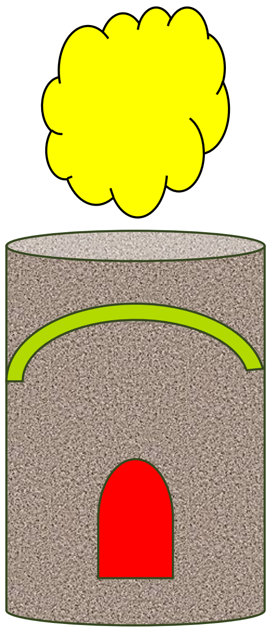
- Yellow-grayish smoke escaping from the silo ventilation ports and into the production building.
- Assuming it to be a normal fire within the silo, aborting the silo was initiated.
- As seen in the picture, the spark from the sip cut ignited the $CH_4$ from the smoldering clump of pellets inside silo.
- 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???

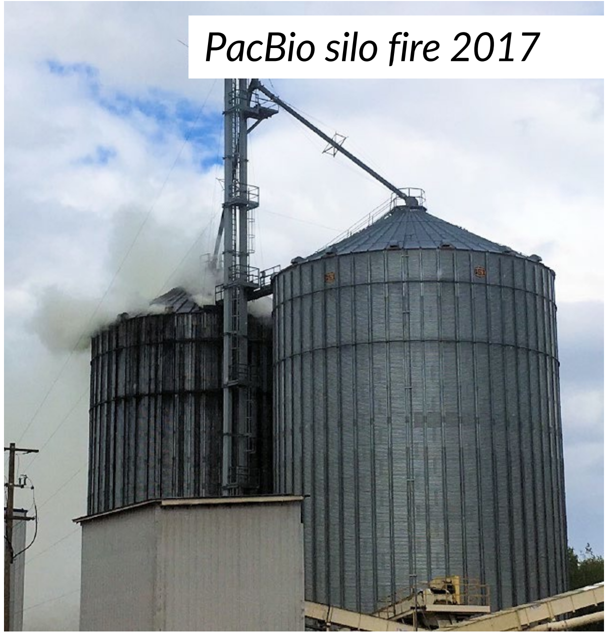
- Pyrolysis of the smoldering pellet generates $CH_4$, $CO$, $CO_2$, $H_2$ gases.
- Lowering (aborting) the level of wood pellets in silo down to the smoldering pellets allowed $O_2$ to make contact with the smoldering pellets releasing $CH_4$, causing the ignition and subsequent explosion.
- Smoldering 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*

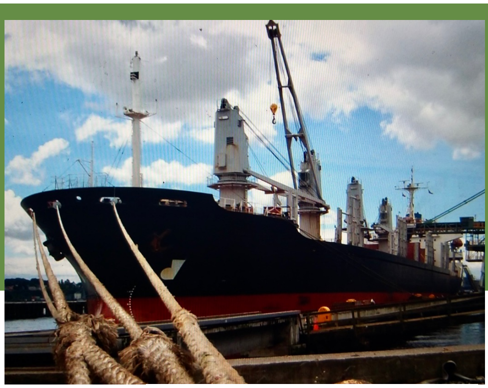
CAUSE OF FIRE: BELIEVED TO BE SELF HEATING

# 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"*

# 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.

# 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 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 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 $N_2$.

**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?

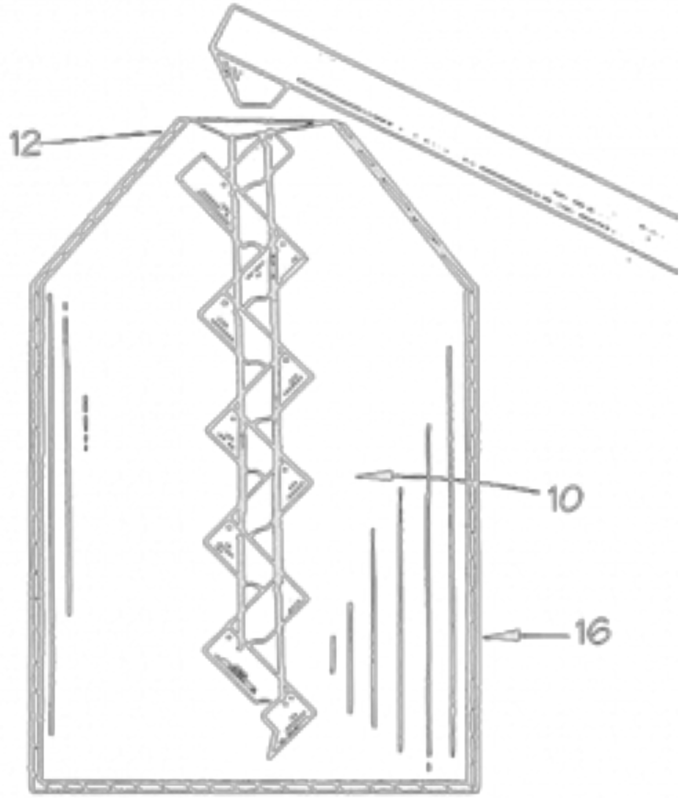
- Wood pellets have been safely stored in silo and/or warehouses for periods of up to 2 years or more, but these wood pellets were manufactured correctly, with low resin (fatty acids) wood species, very minimal fines and well-ventilated storage facilities. (more research required)
- Recommend (if possible) 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.

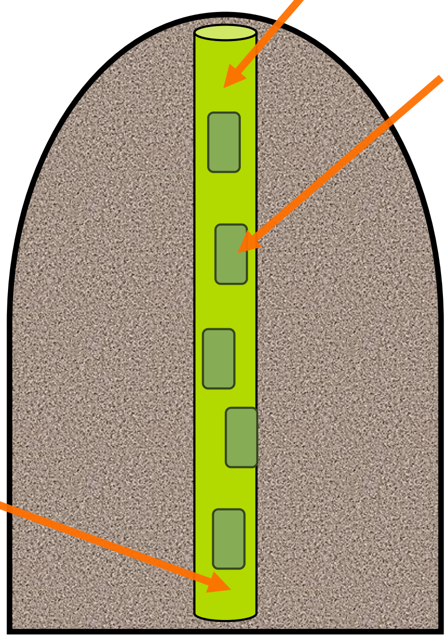
# FINES REDUCTION - GENTLE HANDLING

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 (see FM template – Link ➔ HERE)

## 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
    - 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 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*

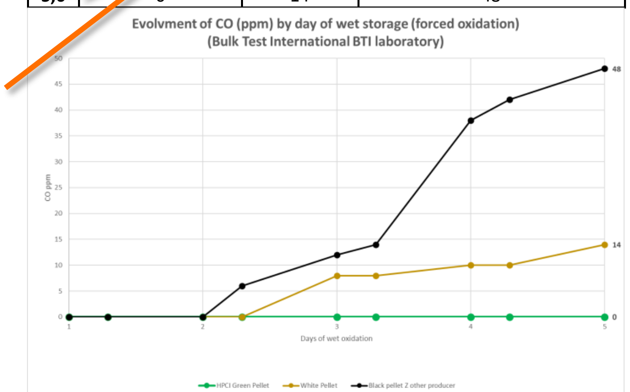
Phase 1 :
Suspending the sample (5 kg) in a container sealed above a volume of water + sodium chloride
Phase 2 :
Over a period of 5 days, with 2 measurements per day capture of CO and O2 fumes.
Oxidation test :
Semi-daily measurement reading
Water uptake test by capillary action :
Total H2O at the end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

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

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

ZERO CO emissions

| 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 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

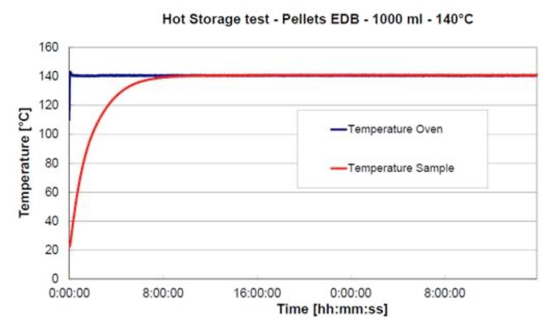
Adinex N.V.
Brouwerijstraat 11
B-2200 Noorderwijk-Herentals
België
Tel. : + 32 14 27 03 90
Fax : +32 14 27 03 99
Web: www.adinex.be
Mail: info@adinex.be
BTW BE 0879.276.393

**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

John.Swaan@FutureMetrics.com

WOOD PELLET ASSOCIATION OF CANADA

## Japan Biomass Safety Workshop

# GETTING DOWN TO TACTICS: DEVELOPING A RESPONSE PLAN


John Swaan
FutureMetrics

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


WOOD PELLET
ASSOCIATION OF CANADA

# GROUP ACTIVITY

- Participants work together to develop a response plan to a silo fire situation.
- Group discussion on plans and sharing of perspectives and experiences.

# 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?

# Japan Biomass Safety Workshop

## GETTING REAL: CASE STUDIES


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


WOOD PELLET
ASSOCIATION OF CANADA

# 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

- Facility/equipment layout
- Incident
- Root cause/why it happened
- Lessons learned

# CASE STUDY #2: SELF-HEATING

- Facility/equipment layout
- Incident
- Root cause/why it happened
- Lessons learned

# CASE STUDY #3: 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 #3: 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](https://doi.org/10.1002/cjce.22815)

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

# CASE STUDY #3: 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 #3: 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](https://doi.org/10.1002/cjce.22815)

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

## Japan Biomass Safety Workshop

# PUTTING IT TOGETHER: NEXT STEPS TO SAFER SILOS

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# SUMMARY OF MEASURES IN EVENT OF SILO FIRE

- Summary of workshop discussions and observations.
- Review of key measures and actions in event of silo fire.
- How workshop information can be used to ensure safer silos.

# SUMMARY OF SILO FIRE RESPONSE

1. Identify the silo and fire types. What is the silo type? Does the silo limit oxygen or can combustible gases escape? When was the fire noticed? How long was it burning? Can its size be determined?
2. Complete an initial risk assessment. Determine if areas in the silo have reduced oxygen concentration or increased carbon monoxide concentration.
3. Consider the risk of a gas or dust explosion. Position the response team away from anywhere that could be affected by an explosion.

*Persson (2013). Silo Fires: Fire extinguishing and preventive and preparatory measures*

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

# SUMMARY OF SILO FIRE RESPONSE

4. Close the silo to minimize any air entrainment. Seal openings and shut off ventilation systems. If oxygen enters the silo, the fire can escalate. Inerting gases could also escape.
5. Make arrangements for nitrogen gas (most preferred) and equipment. Nitrogen is delivered as liquid, so vaporization equipment is also needed.
6. Inject nitrogen from the bottom of the silo. Although silo fires have traditionally been fought from the top, it can be dangerous to have workers up there, and it is more efficient for inerting the atmosphere.

*Persson (2013). Silo Fires: Fire extinguishing and preventive and preparatory measures*

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

# SUMMARY OF SILO FIRE RESPONSE

7. Assemble gas measuring equipment. This equipment is used to measure oxygen levels and $CO_2$ in the headspace and assess explosion risk.
8. Apply foam to the headspace if needed (i.e., if there is an open surface fire in the headspace, the top of silo can burn and propagate into adjacent silos or conveyor systems). Foam can help prevent this, but oxygen entering the process must be minimized. Any personnel at the top of the silo must wear personal protective equipment (PPE).
9. Inert the silo. Use lances to inert the silo and pump nitrogen in. The fire will be extinguished when the silo environment can no longer sustain combustion ("quenched" / "inerted").

*Persson (2013). Silo Fires: Fire extinguishing and preventive and preparatory measures*

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

# SUMMARY OF SILO FIRE RESPONSE

10. Remove the material once the fire is controlled and gas measurements indicate it is suitable to do so.
11. Go slowly. The discharge operation will take a long time. Proceed slowly to prevent any dust clouds or dispersing dust to avoid a dust explosion.
12. Sort discharged material as it exits. Sort the discharged silo contents into two piles—burned material and material that's okay. Assess piles to determine that nothing is smoldering.
13. Continue injecting the nitrogen during discharge. As you remove the material, keep the gas flow so that the oxygen concentration in the silo does not exceed 5% (this will help reduce the risk of an explosion).

*Persson (2013).* *[Silo Fires: Fire extinguishing and preventive and preparatory measures]*

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

# SUMMARIES AND OBSERVATIONS

Factors that elevate fire risk due to self-heating:

1. Co-mingling/mixing of pellets from different sources with variation in their physical characteristics.
2. Accumulation of layers of fines.
3. Long inventory storage times.

- The risk of fires and self-heating can be reduced if silos are equipped.
- Nitrogen inerting systems can be ready/on standby in case of fire, or nitrogen systems can be operated continuously to inert the silos.

# SUMMARIES AND OBSERVATIONS

- Formalized policies and procedures can be implemented to manage process safety risk, including management of change (MOC), mechanical and equipment integrity, and preventative maintenance of interconnected equipment (material handling equipment).
- Additional combustible dust safety measures that can provide a layer of protection include explosion protection, spark detection and deluge at silo infeed.
- Process safety management (PSM) is a framework to systematically manage risk associated with combustible dust fires and explosions.

# REFERENCES AND RESOURCES


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- Reach out to local nitrogen suppliers, and fire protection and equipment companies.

Thank you!

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