Final Technical Report

Safer Operation of Direct Heated Belt Dryers

Final Report

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Table of Contents

Abbreviations

BBRG	UBC Biomass and Bioenergy Research Group
BSFSC	BC Forest Safety Council
BDWG	WPAC Belt Dryer Working Group
much	Moisture content
% webs	wet basis
% db	dry basis
IR	Infrared
ISD	Inherently Safer Design
TGA	Thermogravimetric Analysis
WPAC	Wood Pellet Association of Canada

Executive Summary

Most Canadian wood pellet plants use rotary drum dryers for moisture removal. However, some new pellet plants began using direct-heated belt dryers. Belt dryers generally provide more flexibility in feedstock type and have lower operating temperature and thus result in lower emissions of volatile organic compounds. The operators of direct-heated dryers have experienced several safety incidents over the past few years. The Wood Pellet Association of Canada (WPAC) held a symposium on Belt Dryer in November 2020 and a Belt Dryer Working Group (BDWG) was formed after the symposium to review the current practices and discuss controls and procedures for safer operations of direct-heated belt dryers. The working group also reviewed the positive aspects in safety, operations, and efficiency of indirect-heated systems.

One of the main recommendations by BDWG was the removal of infeed contaminants and the urge to ensure clean feedstock enters dryers. According to belt dryer manufacturers, the assumption is that the infeed fibre arrives at the belt dryer free of contaminants and thus the risk assessments and design of the internal safety controls are based on this assumption. As pellet plants diversify their infeed fibre to wider sources besides local sawmills and more external feedstock such as bush grind and hog fibre are added to the infeed mix, the content of contaminants increases. Some pellet plants' infeed systems are not designed to process the full range of infeed types and remove contaminants completely from the infeed. Moreover, a homogenous infeed particle distribution ensures a homogeneous drying result at the dryer side.

Belt dryer manufacturers strongly recommend the use of indirect-heated belt dryers as opposed to direct-heated belt dryers as the best, most efficient and broadly tested option to reduce the fire and explosion risks for biomass.

The BDWGs reviewed the various equipment and safety controls located on the infeed of direct-heated belt dryers and explored if there are any additional controls or equipment that might be appropriate to raise the safety level and to help eliminate contaminants entering into the drying process.

Overall and valid for both systems of direct and indirect-heated belt dryers is the protection of the equipment of any external ignition sources, air- and material side.

The group also reviewed the various safety controls currently being used in direct-heated belt dryers and explored if there are any additional controls or technologies that might be appropriate to raise the safety levels and reduce production downtime. Since the infeed material does have contamination and the dryer manufacturer's risk analysis is based on clean infeed, it was strongly recommended that plants use additional controls besides the ones provided by the dryer manufacturers. Such additional controls include spark detection and suppression in the burner channel, below belt internal deluge, Infra-Red (IR) thermal detection above and below belts, and controlling contaminants from entering the burner.

Another topic reviewed was safety systems associated with direct-heated belt dryers primarily using Bow Tie analysis. The analysis assessed combustible wood dust hazards and controls that are present in a direct-heated belt dryer. Through Bow Tie analysis, the group was able to

systematically identify barriers and controls and their degradation or failure. Current procedures and maintenance activities were also discussed to eliminate fire events inside the dryers. It is highly recommended that all producers review and update their procedures looking for any missing step on infeed fibre quality and dryer operation using the bow ties developed. Assessing the current controls, housekeeping, and maintenance schedules for effectiveness at eliminating or minimizing ignition sources or sparks will help to reduce or eliminate fire events.

In spite of all indicated measures mentioned, a residual risk in the operation of direct-heated dryers remains compared to indirect-heated systems working under similar conditions and material composition.

1. Introduction

1.1. Background

Pellet operators are obtaining their infeed fibre from wider sources besides local sawmills. There has been a significant shift from controlled feedstock from a connected sawmill (planer shavings & dried residuals relatively free of contaminants) to large variations of feedstock from external sources. As operations increase the amount of external feedstock such as bush grind and hog fibre, the content of contaminants increases. Many pellet infeed systems are not designed to process the amount of external infeed types and remove the potentially larger amounts of contaminants (see Table A. 1 for some examples of infeed material and contaminants).

Most Canadian wood pellet plants use rotary drum dryers to remove moisture from biomass feedstock. Recently, however, Canada's newest pellet plants, particularly in British Columbia, have begun using belt dryers to potentially reduce emission and fire incidents. As direct-heated belt dryers have become more common, the pellet industry has experienced several safety incidents over the past few years. The increase of fire incidents in direct-heated belt dryers and incidents associated with the dryers prompted the Wood Pellet Association of Canada to organize a Belt Dryer Safety Symposium in collaboration with BC Forest Safety Council and media partner Canadian Biomass Magazine.

Over 70 participants, representing pellet producers, dryer manufacturers, insurance companies, universities, fire detection equipment suppliers and WorkSafeBC attended the event held virtually on November 25, 2020. The symposium included presentations and summaries of fire events from some of the operations of direct-heated belt dryers in British Columbia. At the end of the symposium, participants recommended to form a Belt Dryer Working Group (BDWG) to review the current practices and share lessons learned among plant operators for safer uses of direct-heated belt dryers in pellet the industry.

The objective of this brief report is to summarize BDWG's learnings gained from incidents and implementing in-house controls and safe operating procedures.

1.2. Belt Dryer Working Group

The belt dryer working group (BDWG) was composed of 25 members with representatives from Wood Pellet Association of Canada (WPAC), BC Forest Safety Council (BSFSC), dryer manufacturers (Stela and Prodesa), pellet producers, safety equipment suppliers, consultants, academia, and technology providers. The group was broken down into four subgroups of (1) infeed product quality and contamination control, (2) dryer operations, (3) safety systems and controls, and (4) procedures and maintenance practices. See Appendix B for a detailed list of members of the BDWG.

1.3. Project Scope

The scope of safety and protection around dryers and material analysis in this project starts with the arrival of infeed fibre in the plant yard and ends at the outfeed of the dryer. This part of the process includes the equipment designed to remove contaminants from the infeed biomass material such as magnets and rock scalpers, fibre storage and conveying devices up to and including the dryer itself. The scope does not include hammermills located after the dryer, the pellet press, and post-production pellet handling and storage. The analyses cover current equipment for contamination removal, dryer safety controls related to fires, fire warnings, and fire suppression devices. The report communicates to the pellet industry current safety devices and procedures to prevent harm to people and damage to assets.

2. Pellet Plant Process Flow

Several plants provided block diagrams representing their process flow (Appendix C). Upon its arrival at the plant, the biomass is separated into piles in open and closed storage, depending upon the available facilities. Typically, dry planer shavings and clean dry sawdust are stored under a shed. Some of the biomass feedstock arriving at the plant contains contamination that needs to be separated from infeed fibre. Contaminants like rocks, ferrous and non-ferrous metals and any other undesired items that may cause sparks inside the drying unit are separated and removed from the infeed materials. Elimination of contaminants in the infeed fibre is important because the manufacturers stated that their assumption is that the infeed fibre arrives at the belt dryer free of contaminants. The manufacturers' risk assessments and design of the internal safety controls are based on the assumption that material is clean and does not contain foreign material that may cause spark or overheating. Both biomass and air flow should be free from sources that may introduce sparks into the dryer.

3. Equipment and Controls

3.1. Standard equipment

The standard equipment used to eliminate contaminants before entering the dryers includes:

- Scalpers/Grizzly Rolls/Disk Screens: this equipment removes large, oversized material which can include rocks, metal, and other foreign items. These types of devices are common in forest product manufacturing. The equipment is relatively easy to maintain. This equipment allows smaller contaminants to remain in the infeed flow.
- Density Separators: a density separator removes higher density material from the infeed. Heavy contaminants such as rocks, metal and man-made items fall out of the flow of the infeed fibre in the separator. Smaller lighter contaminants can still make it into the infeed fibre stream based on the set-up and feed speed of the density separators. Density separators either work based on screen vibration or by using an air flow or a combination of the two.
- Rock Drops/Vibration Screens: drops and vibratory screens remove contaminants and larger items as they pass over rock drops or screens. Screen opening sizes are managed to allow the optimum sized particles to stay in the infeed stream while larger contaminants are separated out. Smaller rocks, pieces of metal and small man-made items can fall through the screens and stay in the infeed streams.
- Magnets: magnets are deployed in various infeed locations to remove ferrous metals. Non-ferrous metals remain in the infeed streams. The existence of metals in the feed is one of

the most critical contributors to creating sparks and fires in the dryer. The ferrous objects must be completely removed before the feed enters the dryer and come in contact with feed rollers.

3.2. Additional Infeed Equipment

- Green Hammermills: hammer mills are used to reduce the infeed fibre size to optimize dryer efficiencies. Magnets located on green hammermills help to remove ferrous metals.
- Loader Driver Visual Screening of Fibre: loader operators visually inspect incoming fibre loads for contaminants. The operators identify the suppliers who deliver contaminated feedstock to the plant and report this to the supervisor.
- Small & Dry Particle Diversion: Small and/or dry particles may bypass in feed equipment and dryer. This bypass helps to minimize loading clean and overdried material on the dryer. Thus, increasing throughput and efficiency.

3.3. Controls used in other industries

- Equipment for Contaminant Identification and Removal: an on-line device is used in panel manufacturing prior to the press. This technology identifies contaminants such as rocks, metal, and other high-density foreign materials. The real-time detection and elimination capabilities of such systems were discussed for potential consideration as an infeed control.
- Optical Chip Analyzer for Contaminant Identification and Removal: Optical chip analyzer was discussed to determine if this type of technology can be used to identify and remove contaminants from belt dryer infeed systems.

4. Infeed Fibre Quality:

UBC Biomass and Bioenergy Research Group (BBRG) analyzed infeed material received from participating pellet plants in BC. The infeed material is comprised of six types of material: sawdust, shavings, chips, hog grind (sawmill residue), mixed fibre, and bush grind (forest residue). The images and descriptions of each group of infeed fibre are presented in Appendix A.

The sampled materials were tested for moisture content, ash content, bulk density, minimum smoking temperatures, drying time at 90°C, and net calorific value. Table 2 lists these values for the tested material. It summarizes the range of moisture contents, ash content, bulk density, and the range of on-set smoking temperature.

Sawdust and hog grinds originating from sawmills had the highest range of moisture contents 44%-54% w.b. (wet mass basis) for sawdust and 32-63% w.b. for hog grind. As expected, shavings were the least moist infeed. Bush grind and hog grind had the largest ash content 3.0% and 4.7%, respectively. It is not clear how much of this ash is biogenic and how high much of the dirt is from contamination with soil. Bulk density varied from a low of 41 kg/m^3 (4 lb/ft^3) to 366 kg/m^3 (22 lb/ft^3). This wide range of bulk density shows the challenge that a loader operator would have in preparing uniform loads for the dryer. A low bulk density feedstock occupies a larger space (volume). Smoking temperature is when a particle of feedstock exposed to hot air or in direct contact with a hot surface starts making smoke prior to burning. The smoking temperature reported in Table 2 was measured using a Thermogravimetric Analysis (TGA) method, where a small sample of biomass is heated gradually. The increase in temperature and the reduction in mass is followed closely. The temperature at which the biomass starts smoking is recorded as the smoking temperature. The onset of smoking temperature is lower than the ASTM E2021-06 ignition temperature. The lowest smoking temperature was 154ºC. Exceeding temperature at any point within the dryer may be a sign that fire may be imminent.

Table 1 lists the composition of six types of infeed materials from four plants in BC. The data is an indication of the significant shift from clean dry infeed material to alternative infeed stock with higher potential amounts of contaminants. The data shows that the share of feedstock from sawdust and shavings is as low as 12% in Plant 4. Hog was 58 w.t.% share of the infeed. The remaining infeed was chipped probably from the pulp log. Two plants, Pants 1 and Plant 2 did not receive any wood chips but most of their infeed was sawdust and shavings.

Table 1. The range of the percentages of six types of infeed materials used in 4 pellet plants

Feedstock Type	Plant 1	Plant 2	Plant 3	Feedstock Type	Plant 4
Shavings	29.7%	22.8%	35.1%	**Shavings Sawdust**	12.0 %
Sawdust	45.6%	18.6%	20.2%		
Hog	3.3%	0.0%	9.4%	**Hog**	58 %
Grind – Bush, Yard, Mix	11.0%	2.4%	33.5%	**Grind – Bush, Yard, Mix**	0.01 %
Logs – Chipped, Ground	0.0%	36.5%	0.0%	**Chips Other**	30 %
Other	9.0%	19.7%	1.8%		

Table 2. Moisture, ash, bulk density, and minimum smoking temperature of the received and analyzed samples

Process line	Type	m.c. (% wb)[1]	Ash (% db)[2]	Bulk density (kg/m^3)	Smoking temperature (°C)[3]
Woody biomass feedstock at plant gate	Sawdust	44-54	0.2-2.5	195-254	155-171
	Shavings	9-12	0.3-0.8	41-117	154-170
	Chips	12-39	0.4-0.5	178-303	155-168
	Hog grind	32-63	0.4-4.7	198-366	154-170
	Bush grind	21-45	0.2-3.0	137-276	165-177
Infeed to the dryer	Feedstock mix	33-45	0.3-1.5	197-377	158-172

[1] *we mass basis*

[2] *dry mass basis*

[3] *Smoking temperature is the minimum temperature at which feedstock particles start to devolatilize and generate visible smoke.*

Table 3 lists the mass fraction of particles of the infeed material that passed through a 0.5 mm screen. According to dryer manufacturers, particles less than 0.5 mm are not desired because these particles are easily entrained in the drying air and tend the fall through the dryer belt perforations. The data in Table 3 show that a large fraction of hog grind and shavings may be smaller than 0.5 mm. According to our measured data, the particles less than 0.5 mm in size constitute 4.1% to 13.3% of the mass of the infeed to the dryer. It is not clear what percentages of these small particles originated from the infeed and what percentage were created during handling and hammer milling.

Table 3. Fraction of particles <0.5 mm. According to dryer manufacturers, particles smaller than 0.5 mm are not desired for the belt dryer.

Process line	Type	Mass fraction of particles smaller than 0.5 mm (%)
Woody biomass feedstock at plant gate	Sawdust	10.4 - 15.2
	Shavings	5.7 - 23.7
	Chips	0.7 - 3.8
	Hog grind	6.0 - 13.3
	Bush grind	3.4 - 4.7
Infeed to the dryer	Feedstock mix	4.1 - 13.2

Table 4 lists the manufacturers' specified particle size. According to the manufacturers, the maximum limit is set to avoid clogging the dryer screw conveyor. The minimum limit is set to avoid large pressure drops, which will result in higher energy consumption, and to minimize dust agglomeration and emissions.

Table 4. The desired particle size specified by dryer suppliers (mm)

Supplier	Minimum (mm)	Optimum (mm)	Maximum (mm)
Stela	0.5	Not specified	50-70
Prodesa	Not specified	8-10	60

4.1. Blending Analysis

To demonstrate the variability introduced through the blending larger range of material, a blending analysis was performed. Wood pellet plants may only use sawdust and shavings (blend 1) or a wide range of infeed that include sawdust, shavings, chips, hog, bush grind and other mixed feeds (blend 2), which is the case in many plants as shown in Table 3. As you can see in Figures 1 and 2, the range of moisture content, as well as size fraction < 0.5 mm of Blend 2, is larger than Blend 1. This increase in variability in moisture and particle sizes results in uneven drying because moisture does not distribute evenly when different infeed materials with different moisture contents are blended. The non-homogenous particle size and large variability in the amount of fine particles may also increase the risk of fire because fine particles are easier to be ignited by sparks.

Table 5. Blend compositions 1 and 2 used in the blending analysis

	Blend 1	Blend 2
Sawdust	75.00%	16.70%
Shavings	25.00%	16.70%
Chips	0.00%	16.70%
Hog Grind	0.00%	16.70%
Bush Grind	0.00%	16.70%
Mixed Feeds	0.00%	16.50%

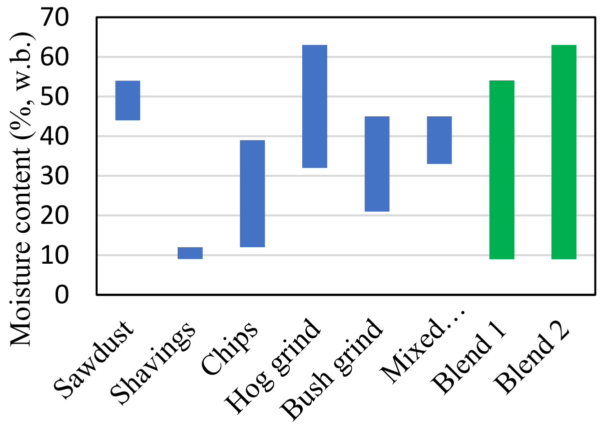

Figure 1. Moisture content (%, w.b.) ranges of infeed materials and two blends. Blend 1 contains 75% sawdust and 25% shavings. Blend 2 contains equal portions of sawdust, shavings, chips, hog, bush grind and mixed feeds

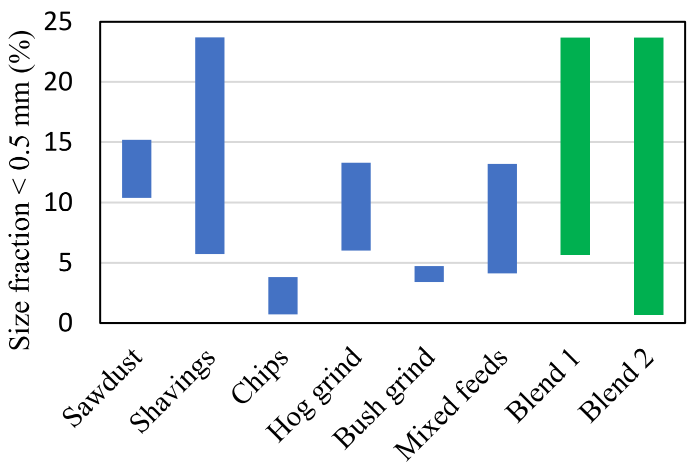

Figure 2. Percentage of size fraction with particle less than 0.5 mm of infeed materials and two blends. Blend 1 contains 75% sawdust and 25% shavings. Blend 2 contains equal portions of sawdust, shavings, chips, hog, bush grind and mixed feeds.

Figure 3 is a plot of cumulative fractions of sieve sizes used to fractionate two samples of in-feed. The y- axis gives the cumulative mass fractions from 0 to 100%. The x-axis lists the sieve sizes. The top orange curve is the mass fraction distribution for in-feed before the green hammer mill.

The lower blue lines give the mass fraction distribution for in-feed after the green hammer mill. For particle before green hammer mill, about 50% of the particles are larger than 8 mm. This percentage drops to less than 40% for particles on a sieve size of 8 mm. About 22% of particles are larger than 16 mm. This percentage number drops to less than 8% for particles after the green hammermill. No particles are larger than 32 mm after the green hammermill.

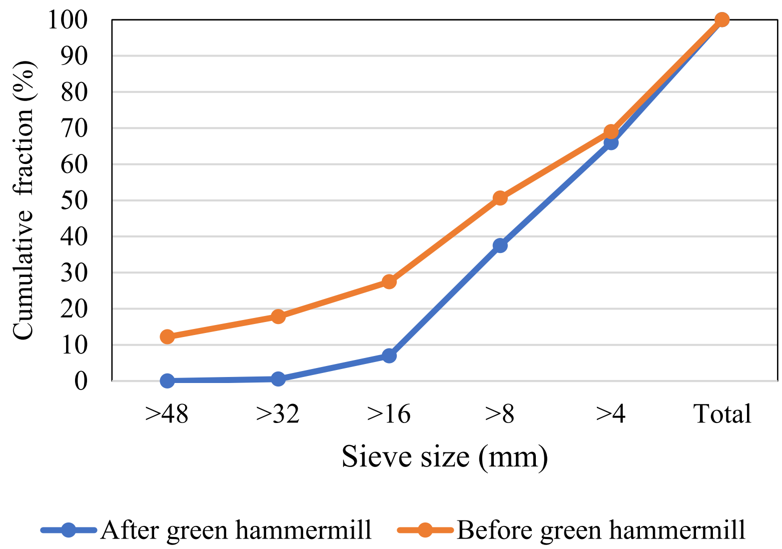

Figure 3. Cumulative mass fraction distribution of a sample of particles before and after green hammermill.

Having a good understanding of infeed quality, contamination levels and fibre composition helps the operation with their production rates, pellet quality and general safety. The BDWG determined that increased knowledge and management of infeed quality can play a significant role in the overall success of the operation including safety. Developing and implementing effective operational controls such as a formal infeed fibre quality control program as well as well maintained equipment controls can minimize infeed fibre contaminants.

5. Dryer

The scope of the working group was direct-heated belt dryers. Direct-heated belt dryers have an elevated risk of fire events than over indirect-heated belt dryers. The sparks generated by the burners are the main source of fires in these dryers. The working group reviewed the relevant equipment and safety controls to help minimize or eliminate sparks or ignition sources inside the belt dryers. The recommendations were included in the developed bowtie for dryer operation (Appendix F). They also explored if there were others controls not currently in use that might help to eliminate sparks and ignition sources. Reference is made to the basic protection against external ignition sources in general.

5.1. Standard Controls (Typically supplied by the manufacturer)

- Preventing hotspots by optimal air turbulence

Turbulence is introduced to reduce hotspots and create even heating. Turbulence is created by installing a series of barriers, ducting, air screens/grates, zigzagging grates, air drops and switchbacks. High energy sparks are able to make it past these controls to the fibre layer.

- Spark capturing/elimination technology

Spark capturing/elimination components minimize the possibility of sparks travelling through the dryer. This is accomplished mostly with air grates that remove the energy of the spark while allowing the air to flow through. As with air turbulence sparks are able to make it past these devices to the fibre layer.

- Increasing the length of the burner outfeed channel

Lengthening the burner outfeed channel to extend the reach to the biomass layer will help to achieve an optimal mixture of air and to reduce the spark energy. Lengthening does not eliminate all high-energy sparks.

- Internal deluge systems

Dryer deluge systems (dry pipe) installed above the belt are activated in response to a rising temperature or a detection of ignition events. This deluge system reacts to fire events that have already started and does not prevent the event from happening. This system can only minimize the damages of a fire incident.

- Belt alignment control:

The dryer belt alignment is controlled and monitored to eliminate belt friction and uncontrolled dust passing on the belt edges.

- Monitoring of the material distribution screw:

Monitoring the distribution screw amperage can provide an indication of plugged or choked material supply onto the belt.

5.2. Optional Controls

- Spark detection and suppression in burner channel. This control is included as a standard control in some direct-heated belt dryers.

Spark detection with suppression/extinguishment between burner and dryer belt is currently under development and being assessed in a few operations.

- Below belt internal deluge

Deluge systems (dry pipe) installed below the belt use rises in temperature to detect ignition events and trigger a deluge to extinguish the event. This controls reacts to fire events that have already started and does not prevent the event from happening. This system can only minimize the damages of a fire incident.

- Infra-Red (IR) thermal detection above and below belts

IR cameras detect hot spots or smolders and activate water deluge or fast-acting water mist above and below belts, it may also involve operator manual activation of water deluge.

- Controlling contaminants from entering the burner

Control the intake of air-borne particles from entering the burner with a screen. This control helps to minimize burner sparks, but it does not eliminate the risk if housekeeping activities are not maintained and the screens are not regularly cleaned out.

The elevated risk of fire events in direct-heated belt dryers due to sparks generated in the burners can not be adequately addressed with the standard or optional controls supplied by the manufacturers. Operations should continue to explore further controls such as spark detection and suppression in the burner channels. After all control measures for direct-heated belt dryers, a residual fire risk will remain. Fire risk can be lowered effectively by using the indirect-heated dryer.

6. Risk Management and Control

6.1. Safety systems including prevention and mitigation

The working group discussed and reviewed safety systems associated with direct-heated belt dryers, primarily using Bow Tie analysis that assessed combustible wood dust hazards and controls that are present in a direct-heated belt dryer. The Bow Tie analysis allowed the group to systematically identify barriers and controls and how these safety systems can degrade or fail. In addition, the measures that must be taken to ensure that safety controls will perform as intended when needed were explored.

The analysis was performed over 6 sessions (1.5 hours per session) and involved a diverse group of subject matter experts (SMEs), including representatives from numerous explosion protection equipment suppliers, wood pellet facilities, as well as health and safety associations (HSA). It should be noted here that the dryer manufacturers also conduct their risk analysis and management according to EU-regulations and it is based on ISO standards (Machine Directive 2006/42/EG; Riskmanagement system acc. ISO12100:2010 and risk assessment acc. Iso 13849-1:2015).

Numerous safety systems were identified, including deflagration isolation (e.g., chemical isolation), ensuring contaminants in in-feed are minimized, relocating dust-generating activities away from the burner and effective combustible dust housekeeping programs to remove dust in surrounding areas, as well as fixing leaks/sources of dust.

Degradation factor controls that were identified include prescribed preventative maintenance and inspections of safety systems, identifying as many opportunities to automate as possible, and considering the use of micro-mist deluge systems that could extinguish fires quickly with very little residual water. A link to the Bow Tie diagram and the breakdown in table format is given in Appendix F.

6.2. Key controls

The hierarchy of controls is the preferred order of risk reduction measures, including for the prevention of fires and deflagrations in belt dryers.. In order of preferred consideration, the controls are: inherently safer design (ISD), passive engineered, active engineered and administrative. Effective combustible dust risk reduction involves the use of ISD, as well as passive and active equipment and procedural measures (Amyotte and Khan, 2021). The hierarchy of controls is shown in Figure 4.

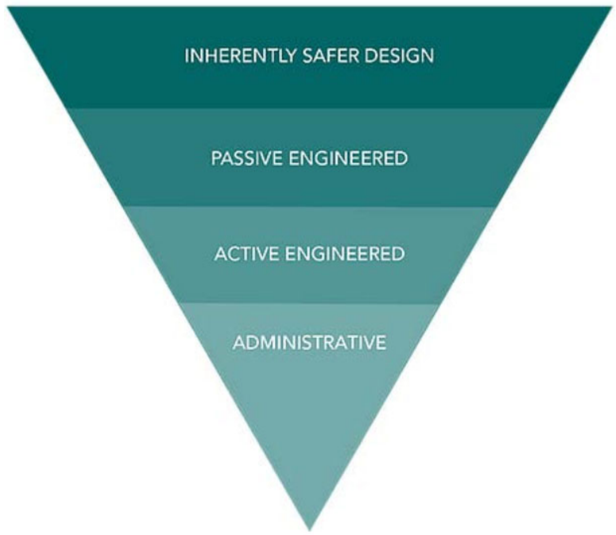

Figure 4. Hierarchy of controls

Inherently safer design (ISD) focuses on the treatment and elimination of hazards at the source. ISD is based on four principles: minimization, substitution, moderation, and simplification. Examples of ISD in the wood pellet production include designing equipment to minimize dust accumulations (minimization), replacing bucket elevators and other mechanical conveying systems with dense-phase pneumatic transport (substitution), performing size reduction processes on moist material prior to drying and optimizing particle size for the drying process (moderation), and designing equipment to withstand maximum possible overpressure (simplification) (Amyotte et al., 2009;.NFPA 652, 2019).

Passive engineered systems in wood pellet plants include explosion venting and passive explosion isolation flap valves.

Active engineered systems include spark detection and infrared (IR) temperature monitoring which are connected to sprinkler deluge or misting systems, current and load monitoring systems for measuring and responding to belt alignment, wear and defects, and belt load , and active chemical isolation systems for preventing deflagration propagation.

Administrative systems include safe work procedures, preventative maintenance, and housekeeping programs, including the cleaning and removal of combustible dust accumulations at/in the dryer and its surroundings.

7. Controls, Procedures, Maintenance, and Cleaning Practices

The working groups reviewed the various safety systems inside & outside of the dryer with a focus on the systems used to manage the equipment and processes.

7.1. Controls

The groups discussed a number of controls including temperature sensors, ID fans' amperage, IR cameras, spark and deluge detection, visual cameras and auto shut down. Various controls not previously mentioned are listed below:

- Tracking amperage of ID fans where a drop in amps indicates a hole in the belt. A drop of amperage may require an operator to check the belt for holes or any other damage.
- Visual cameras located above or below the belt allow operators to monitor belt levels and ignition events.
- Auto shutdown before and after dryer during events in the dryer.
- Temperature monitoring in stacks to trigger a water deluge in the stack or under the belt.
- Temperature monitoring in the dryer upper chamber to trigger a water deluge in the dryer
- Belt cleaning devices, such as blowers, high-pressure water cleaning and/or brushes on belt return to minimize fugitive dust and help with housekeeping activities.
- Spark detection should be installed on infeed systems to the dryer to detect fire/smolder in fibre entering dryer,
- An extra Green hammermill is located before dryers are used to ensure that infeed fibre is evenly sized to prevent hotspots in the dryer

7.2. Procedures & Maintenance

Various procedures and maintenance activities were discussed to eliminate fire events inside the dryers. The procedures reviewed by the group include:

- When the dryer goes down for scheduled maintenance for two or more hours, the dryer must be completely empty of infeed materials,
- If the belt stops for any reason, the burners should be automatically shut off,
- Any "empty" running of the dryer must be prevented – the dryer should only be heated with completely material filled belt surface
- Exterior fire risks, such as smolders coming into the dryer, should be mitigated before the dryer,
- Direct-heated dryers should be cleaned more frequently and have shorter maintenance cycles. Indirect-heated dryers will have significantly longer cycles than direct-heated dryers.
- Plants should consider sharing operational and incident data with suppliers,
- Trends on infeed and product moisture should be monitored and recorded by operators,
- Operators should perform trend analyses on motor loads, temperature, and pressure data collected from sensors,

- Temperature differential differences across the belt and material layer are an indicator of gaps in the belt.

The maintenance steps and topics reviewed by the group include:

- Belt/dryer/fans cleaning should be performed every two to three weeks– not more than 500h (includes pressure washing or the use of fire hose),
- Visual inspection of burner chambers and heat shields should be done daily during the commissioning and first weeks of operation, and weekly during the first months. After that, the frequency of the cleaning works can be decided. It is recommended that burner chambers and heat shields be cleaned of fibre and particulates every three months or more often – not longer than 2000h.
- Stack cleaning should be performed every six months– not longer than 4000 hours
- When cleaning an emphasis should be made to remove all accumulations of combustible dust in all areas

Additional discussions included:

- Comments by dryer manufacturers regarding fans left running during fire events: 'fans are to be protected by the safety system and not used as part of the safety system',
- Comment by dryer manufacturer: temperature probes are primarily meant for the operation of the dryer itself. Temperature probes were confirmed not to be solely used to trigger emergency shutdown/deluge as the points of measurement vary; they have a set delay (3 sec, 5 sec, 10 sec …) and generally are too slow to protect from fire events. Temperature delay set points determine the amount of data generated and gathered and may be set to gather less data (due to server size limitations) and are too slow to identify and/or react to events. As an additional safety system, some manufacturers have recently included a temperature sensor in the belt dryer to control and prevent fire events. So, there are two temperature sensors, a T sensor for the process and a T sensor for safety.
- IR cameras can help to mitigate a dryer fire event much faster if the cameras are set to auto shutdown the system and trigger deluge when identifying a smolder or fire event,
- Dryer suppliers vary in their ability to monitor/gather and track information from the dryers based on the client's willingness to share data. Providing access to monitor the systems and share operational information with manufacturers may aid in the development of improved controls
- Discussion on worker competencies and human factors and how these relate to events and/or reacting to events identified the importance of education, training, and competency of operators. Standard training provided by equipment suppliers was outlined. Suppliers commented that operators did not fully understand the value of additional and periodic training that is offered by the suppliers.

Operational controls, housekeeping and maintenance schedules vary by operation. Assessing your current controls, housekeeping, and maintenance schedule for effectiveness at eliminating or minimizing ignition sources or sparks will help to reduce or eliminate fire events. Assessing these controls on an annual basis and as part of a fire event investigation will help improve the overall safety of the operation.

References

Amyotte, P.R., Pegg, M.J., Khan, F.I. (2009) Application of inherent safety principles to dust explosion prevention and mitigation. *Process Safety and Environmental Protection*. 87, 35-39.

Amyotte and Khan (2021). The role of inherently safer design in process safety. *The Canadian Journal of Chemical Engineering*. 99 (4), 853-871.

NFPA 652 (2019) Standard on the Fundamentals of Combustible Dust. NFPA (National Fire Protection Association), Quincy, MA.

Appendix A. Infeed Samples

Table A. 1. Infeed Samples Description and Specifications

Name and Image	Description
Sawdust 	A sawmill residue that is produced from sawing, milling, planing and routing processes. It is composed of small chippings of wood. In general, sawdust is clean and contains mostly white wood. It may contain some bark and small pieces of chips. **Some specific characteristics:** • Calorific value is between 17.9 - 19.4 (MJ/kg) • Moisture content is between 44 – 54 (% wb) • Ash content is between 0.2 – 2.5 (% db) • Bulk density is between 195 - 254 (kg/m^3)
Hog grind 	A sawmill residue that is produced from debarking and scalping oversized materials from sawmill in-feed. It has a high content of bark and soil minerals. More contaminated hog, stored for a long period, is named “legacy hog grind.” **Some specific characteristics:** • Calorific value is between 18.8 – 20.2 (MJ/kg) • Moisture content is between 32 – 63 (% wb) • Ash content is between 0.4 – 4.7 (% db) • Bulk density is between 198 - 366 (kg/m^3)
Shavings 	A sawmill residue that is produced from planning wood. It usually comes after the kiln-drying process. The very thin pieces are dry and a by-product of planers. **Some specific characteristics:** • Calorific value is between 18.2 – 19.2 (MJ/kg) • Moisture content is between 8 – 12 (% wb) • Ash content is between 0.3 – 0.8 (% db) • Bulk density is between 41 - 117 (kg/m^3)
Bush grind	A forest residue that is chipped in the logging area. It has high fraction of oversize materials, such as branches, bark pieces and chips. When the forest was burned in a wildfire, the resulting forest residue is named “fire kill bush grind”. **Some specific characteristics:**

- Calorific value is between 18.9 – 19.0 (MJ/kg)
- Moisture content is between 21 – 45 (% wb)
- Ash content is between 0.2 – 3.0 (% db)
- Bulk density is between 137 - 276 (kg/m^3)

Wood chips

Produced from whole log or lumber chippers.
If the log is kiln-dried, it is named “kiln-dried chips.”
If it is micro-ground, the resulting chip is called “micro grind.”

Some specific characteristics:

- Calorific value is between 18.6 – 19.6 (MJ/kg)
- Moisture content is between 12 – 39 (% wb)
- Ash content is between 0.4 – 0.5 (% db)
- Bulk density is between 178 - 303 (kg/m^3)

Mix pile, green infeed, or infeed mix

A mixture of coarsely ground materials before entering the dryer. This in-feed mixture consists of sawdust, shavings, chips, hog and forest residues.

Some specific characteristics:

- Calorific value is between 18.3 – 19.3 (MJ/kg)
- Moisture content is between 33 – 45 (% wb)
- Ash content is between 0.3 – 1.5 C (% db)
- Bulk density is between 197 - 377 (kg/m^3)

Contaminants

A variety of foreign objects, which are mixed with the in-feed materials. The examples are rocks, lighters, batteries, aluminum foils, sandpapers, etc. The contaminants may be removed by the destoners, scalpers and magnets.

Appendix B. Belt Dryer Working Group Members

Participant	Company
Jamie Colliss, Chair	Drax North America
Jeff Mycroft, Chair	Fike Canada Inc.
Fahimeh Yazdan Panah	Wood Pellet Association of Canada (WPAC) & UBC
Bill Laturnus	BCFSC
Tyler Bartels	BCFSC
Shahab Sokhansanj	UBC, Biomass and Bioenergy Research Group
Hamid Rezaei	UBC, Biomass and Bioenergy Research Group
Jun Sian Lee	UBC, Biomass and Bioenergy Research Group
Ian Tencarre	Drax North America
Dylan Leclerc	Drax North America
Thomas Laxhuber	Stela Laxhuber GmbH
Yves-Marc Schade	Stela Laxhuber GmbH
Elena Duato	Prodesa
Alvaro Valle	Prodesa
Nathan Bond	Skeena Bioenergy Ltd.
Travis McCue	Canfor
Tim Heneks	Dustcon Solutions Inc.
Jay Juvenal	CV Technology
Luc Cormier	Jensen Hughes
Jorgen Dehlbom	Firefly ab
Chris Zuberec	BFL Canada
Kayleigh Rayner Brown	Obex Risk Limited (Bow Tie Facilitator)
Jeramy Slaunwhite	Rembe GmbH
Chris Cloney	DustSafeyScience
Paul Amyotte	Dalhousie University

Appendix C. Process Flow Diagrams

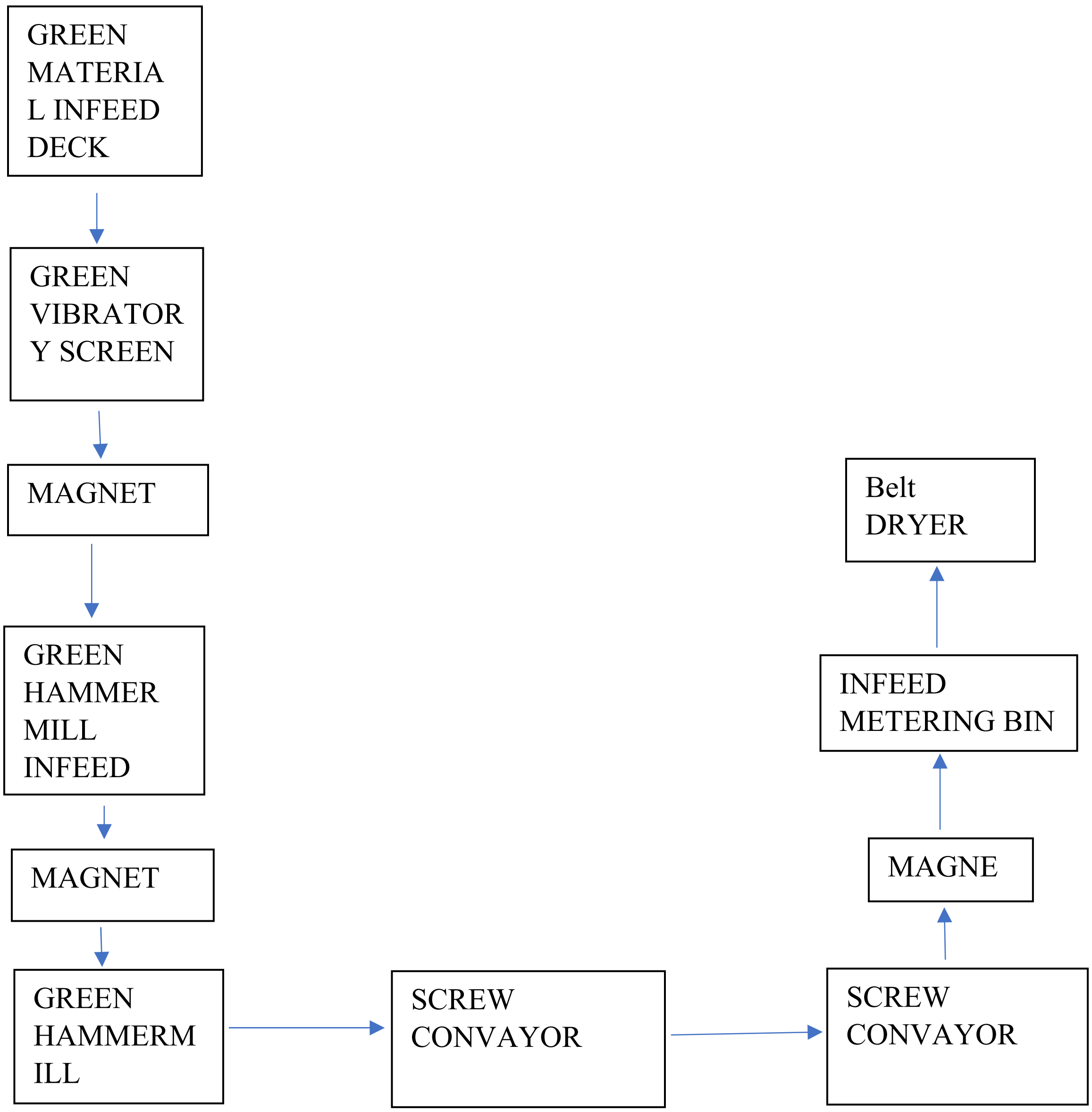

Figure C. 1. Plant 1 process flow diagram

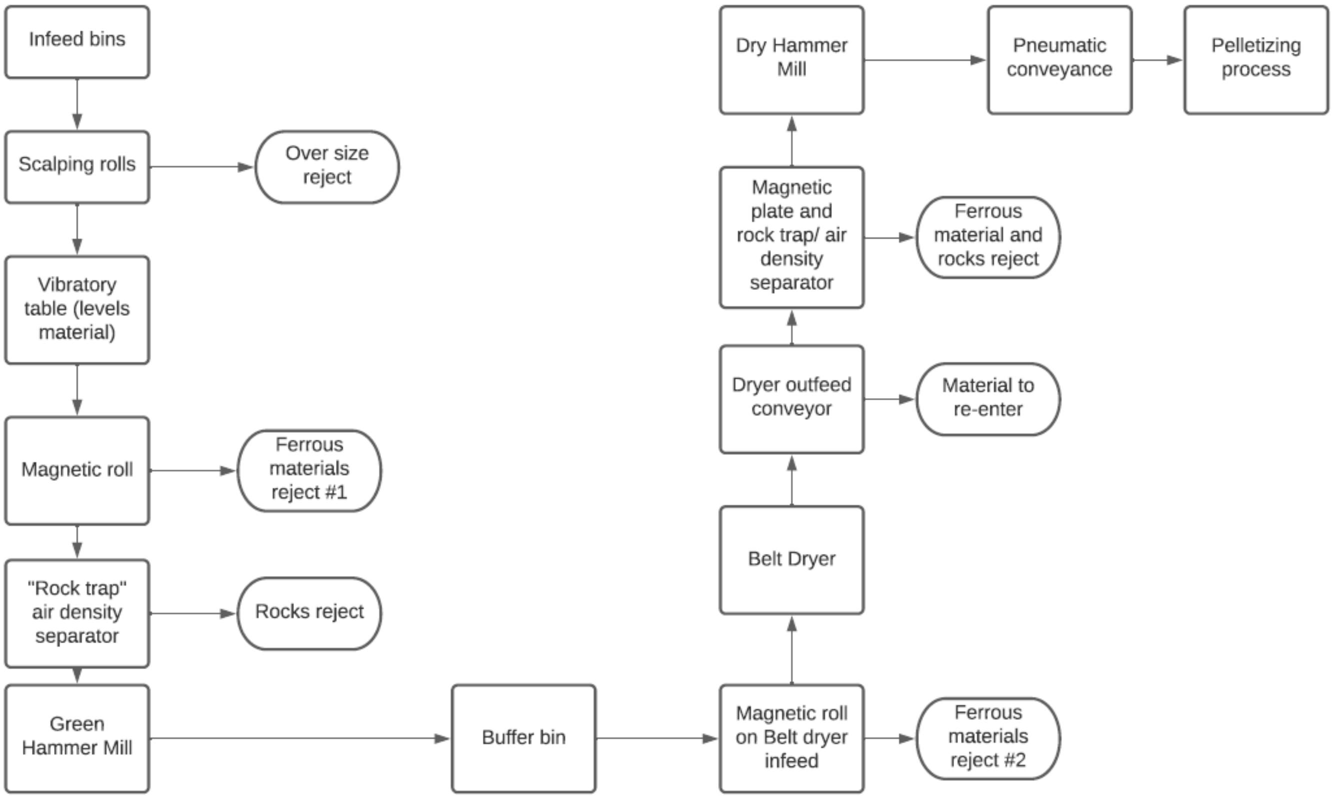

Figure C. 2. Plant 2 process flow diagram

Appendix D. Direct-heated Dryer Pictures

Figure D. 1. Stela's Direct-heated Belt Dryer

Figure D. 2. Stela's Indirect-heated Dryer with Hot Water Heat Exchanger Deck

Figure D. 3. Prodesa's Direct- heated Belt Dryer (Skeena Bioenergy). View of the burner channel

Figure D. 4. Prodesa Indirect-heated Belt Dryer

Figure D. 5. Prodesa Indirect- heated Belt Dryer

Appendix E. Stela and Prodesa Dryer Specifications

Table E. 1. Stela's indirect-heated (hot water) RecuDrybelt dryer specifications

Product	Microchips/sawdust
Dryer input capacity	39,6 ton/h
Initial moisture	52%
Product bulk weight	250 kg/m3
Fresh air parameters	0ºC; 980 mbar;98%RH
Heating medium	Hot Water-Glycol 30%
Nominal heat capacity	13 MW
Dryer type	BTU 1/6200-60 RecuDry ; 372 m2
Dryer output capacity	20,9 ton/h
Water evaporation	18,7 ton/h
Final moisture	9%
Demand of electricity	490 kW
Type thermal oil - air heat exchanger	water - air heat exchanger
Drying temperature	110ºC
Control range retention time in active zone	Residence time: 5 - 30 min
Compressed air for wet cleaning system	na
Water for wet cleaning system	1 – 2m³ per week @ 3-4 bar. one cycle approx. 60min
Condensate to sewage	up to 5 m3/h
Bed depth	70-180 mm
Maximum dust loading of the exhaust air	10 - 15 mg/Nm3

Table E. 2. Prodesa indirect-heated (thermal oil) belt dryer specifications

Product	Microchips/sawdust
Dryer input capacity	39,64 ton/h
Initial moisture	52%
Product bulk weight	250 kg/m3
Fresh air parameters	0ºC; 980 mbar;98%RH
Heating medium	Thermal oil 160ºC
Nominal heat capacity	21 MW
Dryer type	Belt dryer 304 m2
Dryer output capacity	20,9 ton/h
Water evaporation	18,7 ton/h
Final moisture	9%
Demand of electricity	364 kW
Type thermal oil - air heat exchanger	thermal oil - air heat exchanger
Drying temperature	110ºC
Control range retention time in active zone	Residence time: 5 - 60 min
Compressed air for wet cleaning system	25 litres/min @ 6 bar
Water for wet cleaning system	40-60 litres/min @ 3-4 bar. One cycle every 8-12 hours
Waste water	3-5 m3/h water+solid waste. One cycle every 8-12 hours
Bed depth	30-210 mm
Maximum dust loading of the exhaust air	10 - 15 mg/Nm3

Appendix F. Bow Tie Analysis

The bow tie analysis was facilitated by Kayleigh Rayner Brown (Obex Risk Limited), an experienced Bow Tie Facilitator. A bow tie analysis was completed to assess combustible wood dust hazards and controls that are present in a direct-heated belt dryer. The group elected to perform a bow tie analysis due to a number of reasons. The intuitive structure of bow tie analysis allows for systematic identification of the different safety systems used in belt dryers to manage combustible dust hazards. The assessment of degradation factors and controls was another important and valuable component of the work. This allowed the group to systematically identify how these safety systems can degrade or fail, and the measures that must be taken to ensure that they will perform as intended when needed.

The bow tie analysis was conducted for the hazard "Combustible wood fibre in direct-heated belt dryer" and top event "Combustible wood dust deflagration." The resulting bow tie provides extensive information on:
how a deflagration could occur in a direct-heated belt dryer, what the potential outcomes of a deflagration are, the barriers that are in place to prevent a deflagration or mitigate the effects of one, and how the barriers can fail and the controls that are in place to ensure they are more reliable (degradation factors and controls).

Numerous safety systems were identified, including deflagration isolation (e.g., chemical isolation), ensuring contaminants in in-feed are minimized, relocating dust generating activities away from burner and effective combustible dust housekeeping programs to remove dust in surrounding areas, as well as fixing leaks/sources of dust. Degradation factor controls that have been identified include prescribed preventative maintenance and inspections of safety systems, identifying as many opportunities to automate as possible, and considering the use of micro mist systems that could extinguish fires quickly with very little residual water.
An identified area for enhanced focus is a training program on explosion protection systems, including application, installation, and maintenance. For additional information on using bow tie analysis to analyze combustible wood dust hazards in wood pellet plants, it is recommended that interested parties complete the WPAC Safety Foundation Webinar Series, including the webinar "Bow Tie Analysis Part I: Using Bow Tie Analysis to Assess Combustible Dust Hazards and Controls."
Link to the bow tie on Combustible Wood Dust Deflagration

A tabular representation of the complete bow tie analysis was also completed for the hazard of combustible wood fibre in direct-heated belt dryer and top event combustible wood dust deflagration. This table includes the degradation factors and controls that were identified during the analysis.

Tabular representation of the complete bow tie analysis

Appendix G. Presentations

Below are the presentations made during the Belt Dryer Symposium on some previous events as well as some presentations made during the BDWG meetings by belt dryer manufacturers and safety equipment manufacturers.

Drax - WPAC Belt Dryer Symposium Presentation Nov 25, 2020

Skeena - WPAC Belt Dryer Symposium Presentation Nov 25, 2020

Stela - Belt Dryer Working Group Presentation

Prodesa - Belt Dryer Working Group Presentation