

The Hierarchy of Controls for Biomass Pyrolysis Dust

1. Elimination (Most Effective)

Physically remove the hazard

Examples

- Reduce/eliminate process steps where dust is generated (e.g., fewer conveyor drops, pre-processing off site)
- Enclosed material transfer
- Process design to maintain continuous material flow, preventing stagnation and accumulation
- Remove non essential components from Hazardous area zones
- Remote operation and automation to reduce personnel presence in hazardous zones

2. Substitution

Replace the hazard with a less hazardous alternative.

Examples

- Use feedstock with higher moisture content to reduce fines creation (balance with efficiency and product specs)
- Process feedstock into pellets or briquettes (less dusty form) (balance with efficiency and product specs)
- Substitute an inert gas (e.g., nitrogen, CO₂) for air where chemically feasible
- Replace pneumatic conveying where possible with low-velocity conveying (screw or dense phase)

3. Engineering Controls

Isolate people from the hazard through physical design changes. Operate independently of human action.

Examples:

- **Dust Containment:**
 - Enclosed systems, enclosed chutes/socks at transfer points.
 - Proper bag filter discharge design to prevent dust accumulation
- **Dust Collection (LEV):** Capture dust at source (mills, transfer points, cyclones, filters)
- **Inerting Systems:** Use inert gases in process equipment where chemically feasible
- **Dust suppression:** Add water/mist at dust generation points (makes dust heavier, less likely to disperse)
- **Explosion Protection:**
 - Explosion Vents (for deflagration relief)
 - Explosion Suppression Systems (chemical agents).
 - Explosion Isolation Systems (rotary valves, fast-acting gates, chemical isolation)
 - Spark Detection & Extinguishing Systems in ducts
- **Ignition Source Control:**
 - Proper Grounding & Bonding of all equipment (static electricity control)
 - Remove all possible equipment out of the hazardous area zones, where relocation isn't possible, install Hazardous Area Classified (e.g., ATEX, NFPA) equipment, such as sensors, motors, plugs, cabinets, etc
 - Foreign Material Detection/Removal (magnets, metal detectors)
 - Bearing temperature monitoring, detection of hot spots before they become ignition sources
- **Fire Suppression:** Fixed water sprayers/misting systems (designed for dust type/size)
- **Monitoring & Detection Systems:** Pressure, temperature, smoke, and CO detectors linked to alarms and automatic shutdowns
- **Fail-Safe Design:** Ensure all safety critical components are designed to default to the safest state in case of power failure (e.g., isolation valves close, safety shut-downs engage)

4. Administrative Controls

Procedures and training to manage risk. Dependent on human behavior.

Examples:

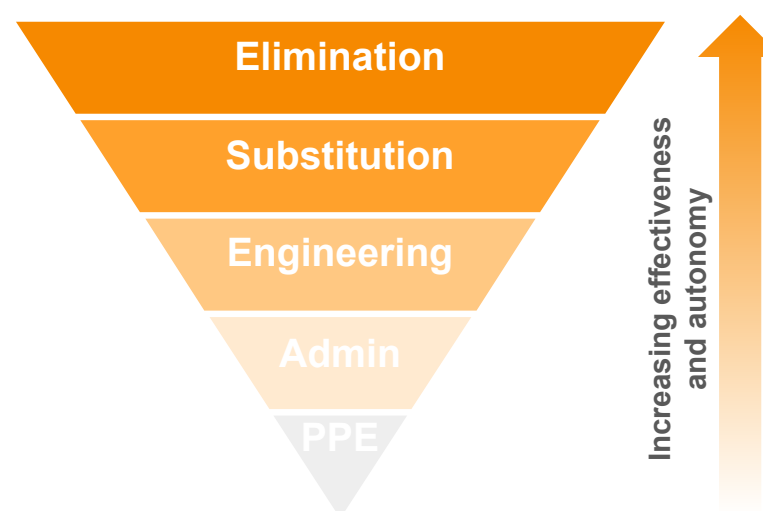
- **Rigorous Housekeeping Program:** Scheduled cleaning (especially high/hard-to-reach areas), documented procedures, **NEVER use compressed air**. Use ATEX/explosion-proof vacuums.
- **Hot Work Permit System:** Strict control over welding, cutting, grinding.
- **Preventive Maintenance (PM):** Regular inspection/lubrication of bearings, motors, conveyors to prevent friction/overheating.
- **Safe Operating Procedures (SOPs):** Detailed instructions for all tasks involving combustible dust.
- **Training:** Comprehensive training for all personnel on dust hazards, MIE (Minimum Ignition Energy), Kst (deflagration index), Pmax (maximum explosion pressure), emergency procedures, and hazard recognition
- **Signage:** Clear hazardous area markings.
- **Change Management:** Strict procedures for modifying equipment or processes.
- **Detection Systems:** Pressure, temperature, smoke, CO detectors linked to alarms/shutdowns.
- **Access Control:** Limit entry to high-risk zones and confined spaces to authorized personnel only.
- **Management of Change (MOC):** A formal system to review and approve changes before they happen.
- **Emergency Response Planning & Drills:** Train site-specific emergency drills for hazardous scenarios.
- **Safety Critical Equipment (SCE) Verification:** Schedule and document functional testing of all SCE.
- **Daily pre-shift inspections:** Documented visual checks for dust accumulation, leaks, abnormal conditions
- **Near-miss reporting system:** Encourage reporting of "close calls" (dust puffs, hot bearings, etc.)

5. Personal Protective Equipment (PPE) (Least Effective)

Protects the individual after exposure. Last line of defense.

Examples:

- Respirators (N95, P100) for dust exposure.
- Flame-Resistant Clothing (FRC).
- Eye protection, gloves, hard hats.



5 Step Implementation Process

- 1. Minimize the Hazard:** Before the system is built or during a retrofit, apply Elimination and Substitution to reduce the hazards.
- 2. Quantify the Remaining Risk:** Perform the Dust Hazard Analysis (DHA)
- 3. Define the Zones:** Use the DHA data to accurately perform a Hazardous Area Classification.
- 4. Isolate and Manage the Risk:** Apply Engineering Controls (based on DHA data) to isolate the hazard and then Implement Administrative Controls and PPE to manage human behavior and procedures.
- 5. Verify and Maintain:** Implement a continuous monitoring and maintenance schedule. Perform regular safety audits to confirm that Administrative and Engineering Controls remain effective.