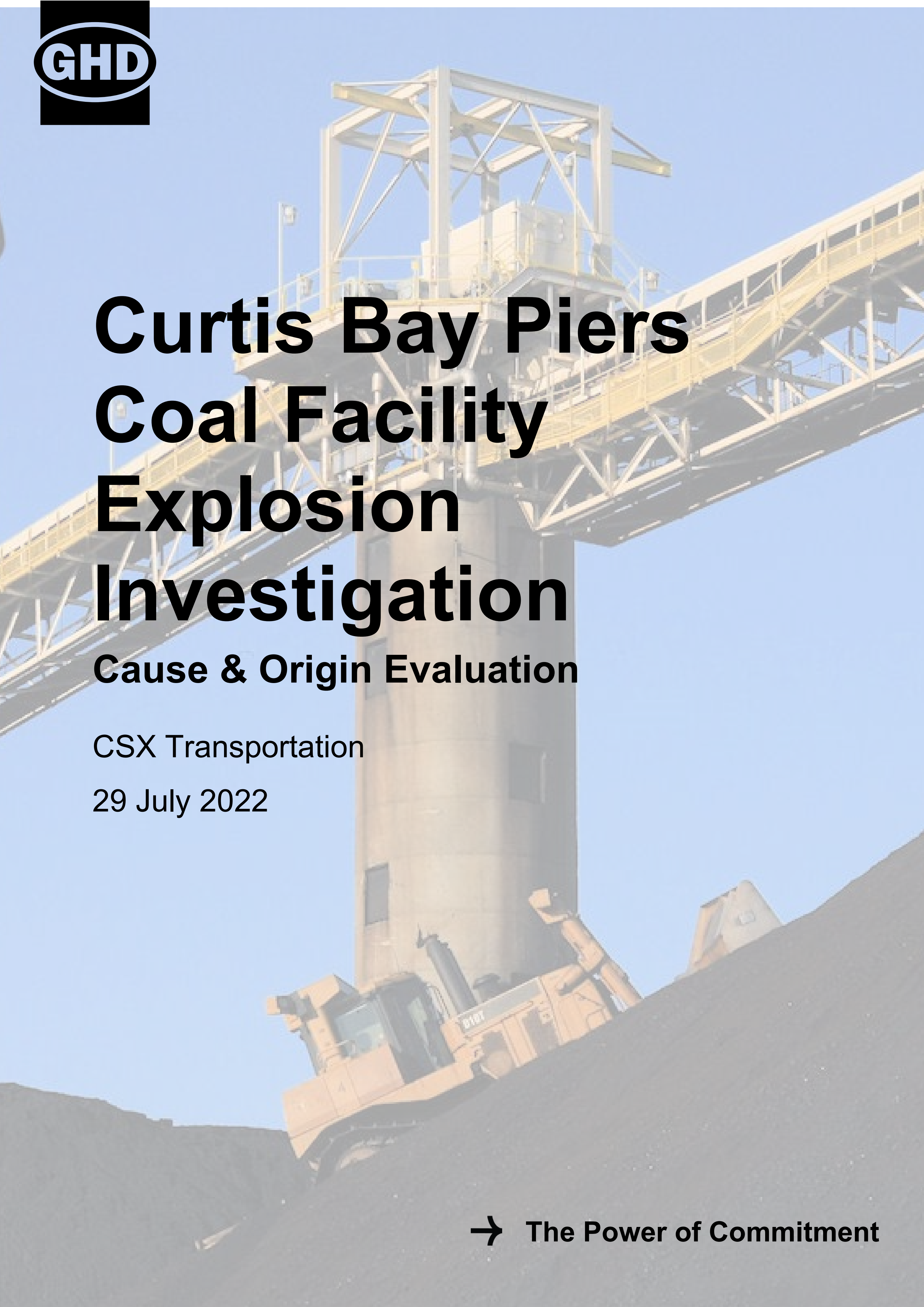

Curtis Bay Piers Coal Facility Explosion Investigation

Cause & Origin Evaluation

CSX Transportation

29 July 2022

→ **The Power of Commitment**

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Executive Summary

On December 30, 2021, at approximately 11:24 AM US Eastern Standard Time, an explosion occurred in the North Reclaim Tunnel of the Curtis Bay Piers (CBP) Coal Facility in Baltimore, Maryland (hereafter, “the facility”). GHD was requested by CSXT to lead an investigation team tasked with determining the cause of the explosion. The investigation team was comprised of personnel with decades of experience in prevention of, responses to, and investigations of fires and explosions across a wide range of industries and scenarios

The North Reclaim Tunnel of the facility is comprised of an approximately 770-foot-long concrete tunnel running from north to south. An approximately 147-foot concrete escape tunnel extends westward from the north end of the North Reclaim Tunnel (hereafter, “North Escape Tunnel”). The North Reclaim Tunnel contained coal feeders, conveyor structure, and associated equipment. The 28 coal feeders were spaced equally from one another throughout the tunnel and were numbered from 4 through 31 from north to south. The North Escape Tunnel was empty with the exception of lighting and a ventilation system designed for air supply to the North Escape Tunnel.

The investigation focused upon visual inspection of the north main and escape tunnels and debris from the explosion, in an effort to identify two primary properties of the explosion: the location of its origin, and the potential initial sources of fuel and ignition. The investigation team preserved evidence such as loose debris and equipment to the extent possible, given constraints of safety and ongoing operational needs. Video footage of the explosion was collected from both on- and off-site sources, and was reviewed in detail as a further aide to understanding the location of the origin of the explosion, and its initial fuel and ignition sources. Employee interviews were conducted to potentially assist with understanding the nature and timing of the event. Samples of the coal being transferred at the time of the event were obtained and analysed for combustible properties. Ongoing monitoring and documentation of operations within the South Reclaim Tunnel have also informed the investigation in regards to potential atmospheric conditions at the time of the event.

Based upon the physical and video evidence of the explosion, the most likely location of origin of the explosion was between feeders 7 and 17 within the North Reclaim Tunnel. The explosion likely was initiated by the ignition of a localized flammable atmosphere comprised of methane released from the coal, and a relatively low concentration of coal dust made airborne by the operating conveyor, which enhanced the flammability of the released methane. This localized atmosphere was made possible by low ventilation rates, which did not allow for adequate dissipation and removal of methane and coal dust. This initial combustion event would have generated a pressure wave travelling both north and south through the North Reclaim Tunnel that increased the quantity and density of airborne coal dust within the tunnel. This coal dust is believed to have fueled further combustion through the tunnel and out of the south surface entrance and North Escape Tunnel of the North Reclaim Tunnel. Combustion and blast pressures increased along the tunnel’s length, resulting in the visible plume that exited the south surface entrance, which damaged the adjacent central coal transfer tower.

Based on the above, the localized congregation of methane and airborne coal dust represents a cause of the December 30, 2021 explosion. The likely cause of the build-up of this flammable atmosphere was insufficient ventilation of the North Reclaim Tunnel, which is therefore also considered a cause. The precise source of the ignition has not been determined but is believed to have been located within the North Reclaim Tunnel between vertical Feeder 7 and 17.

CSXT is continuing its design of a new ventilation system for the North Reclaim Tunnel. Based on early analysis of the explosion, CSXT added monitoring devices and additional ventilation to the South Reclaim Tunnel. Ongoing monitoring of the South Reclaim Tunnel continues to demonstrate the effectiveness of increased ventilation coupled with dust cleanliness protocols to significantly mitigate the possibility of a flammable atmosphere within the tunnel. This information was used in designing the North Reclaim Tunnel to include monitoring devices, higher air flow, additional water sprays, skirting of conveyors, grounding of equipment and installation of electrical fixtures to meet appropriate electrical codes.

This report is subject to, and must be read in conjunction with, the limitations set out in section 1.0 and the assumptions and qualifications contained throughout the Report.

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1. Introduction

This report summarizes the findings of the Curtis Bay Piers Coal Facility Explosion investigation team as of July 25, 2022. These findings are based upon the best judgment and technical knowledge available, at the time of writing.

1.1 Purpose of this report

The purpose of this report is to provide a summary of the findings of the investigation team as of July 25, 2022. Further information may be forthcoming which would add clarity to certain aspects of the investigation; however, the most actionable aspect of the root cause investigation – fuel source and mitigation potential – is complete. This report may also be used to inform best practices for the ongoing safe operations of the CBP Coal Facility, using lessons learned from this incident and associated recommendations for future operations.

1.2 Scope and limitations

This report: has been prepared by GHD for CSX Transportation and may only be used and relied on by CSX Transportation for the purpose agreed between GHD and CSX Transportation as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than CSX Transportation arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

Accessibility of documents

If this report is required to be accessible in any other format, this can be provided by GHD upon request and at an additional cost if necessary.

GHD has prepared this report on the basis of information provided by CSX Transportation and others who provided information to GHD, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.3 Assumptions

GHD assumes that the information provided by CSXT and its employees, for example in relation to employee interviews, is reliable and trustworthy. GHD further assumes that all relevant information available to CSXT management, and of which CSXT management is aware, has been made known and available to GHD during the course of this investigation. GHD assumes that all necessary access to facilities and information has been made known and available during the course of this investigation.

2. Description of Facility

The Curtis Bay Piers Coal Facility is comprised of incoming and outgoing rail service, a railyard, a coal transfer yard, railcar offloading infrastructure, conveyor infrastructure, pier loading facilities, and associated office, maintenance, and operations buildings. The focus of this report will be primarily on the coal transfer and storage yard and conveyor infrastructure.

The coal transfer yard is in the middle of the facility and is comprised of 8 primary stacking tubes (towers) which characterize the appearance of the facility. The transfer yard collects incoming coal into piles created by transferring the coal along conveyors at the tops of the stacking tubes, down through the tubes, and into piles. There are five primary stacking tubes on the north side, and three on the south side of the transfer yard. In between the north and south sides of the transfer yard is a central transfer tower which contains conveyor infrastructure capable of diverting coal a number of different ways. Figure 1 in Appendix A shows an overview of the north coal transfer yard, along with annotated points of interest to the event and the investigation.

The explosion occurred on the north side of the transfer yard, within the North Reclaim Tunnel, which lies directly underneath the yard surface, upon which coal piles are formed. The coal from these piles is transferred to the conveyor system in the tunnel through the use of vibrating feeders mounted to openings in the yard surface. Figure 1 in Appendix B shows the general layout of the North Reclaim Tunnel, with its two parts – the North Reclaim Tunnel and the North Escape Tunnel.

2.1 North Reclaim Tunnel

The North Reclaim Tunnel contains the conveyor structure including the 28 vibratory feeders (commonly labelled VF-4 through VF-31) which are mounted to corresponding openings in the coal transfer yard. Figure 1 in Appendix B shows the general layout of the North Reclaim Tunnel. Discussions regarding the North Reclaim Tunnel operations will be discussed in Section 2.3 below, in context with the South Reclaim Tunnel, whose operations have continued since the event. The North Reclaim Tunnel is approximately 770 feet in length, with a flat section from VF-4 through VF-21, and ramped section gaining in elevation near VF-22.

2.2 North Escape Tunnel

The North Escape Tunnel was expanded in late 2019 / early 2020 to provide a better means of egress from the North Reclaim Tunnel. Appendix C contains the construction plan drawings for the escape tunnel enlargement / replacement.

Prior to installation of the North Escape Tunnel, the only means of egress from the north end of the North Reclaim Tunnel was a 36-inch diameter exhaust tunnel leading westward along the same path as the new North Escape Tunnel. This 36-inch diameter tunnel also served as an exhaust ventilation duct for the entirety of the North Reclaim Tunnel. Air was exhausted through a 42-inch fan mounted to the outlet of the tunnel. The 2019/2020 North Escape Tunnel expansion changed the ventilation system from an exhaust to a supply configuration. The expansion included equipping the tunnel with circular ducts along the ceiling of the tunnel, leading from a ventilation system designed to provide ventilation for occupation of the escape tunnel, at a design flowrate of approximately 4,000 cfm. Figure 2.2.1 shows the conditions of the North Escape Tunnel after the expansion, and prior to the explosion.

Figure 2.2.1. North Escape Tunnel as seen on July 9, 2020.

2.3 South Reclaim Tunnel

The South Reclaim Tunnel is comprised of two parts – a main tunnel containing coal transport infrastructure, and an escape tunnel. The South Reclaim Tunnel and South Escape Tunnel run along the same north-south axis, in contrast to the North Reclaim Tunnel, whose escape tunnel is at an angle slightly more acute than perpendicular. A generic figure depicting the layout of the South Reclaim Tunnel is included in Figure 2 in Appendix B.

The South Reclaim Tunnel provides insight as to the operation of the North Reclaim Tunnel, as it includes similar operating equipment (vibratory feeders – VF-32 through VF-48, conveyor structure, lighting, exhaust conditions, and escape tunnel) and similar operational conditions to its counterpart to the north. Thus, the South Reclaim Tunnel has been used as an effective go-by during loading operations from the south coal transfer yard during 2022 and to inform the investigation team.

Each vibratory feeder is designed to provide up to 900-1,000 tons per hour of coal through the feeder holes in the coal transfer yard, while in reality they generally operate at approximately 500 tons per hour. Any coal accumulating in the walkways on either side of the conveyor is washed periodically to a sump at the south end of the tunnel. A view of washing towards the sump is shown in Figure 2.3 below.

Figure 2.3.1. Washing walkways of South Reclaim Tunnel. View towards north from tail pulley enclosed in yellow grating.

Figure 2.3.2. View from VF-36 along walkway towards the south of the South Reclaim Tunnel

2.4 South Escape Tunnel

A similar expansion of the escape tunnel in the South Reclaim Tunnel was undertaken in early 2021 (similar to what was done in the North Reclaim Tunnel, as described in Section 2.2). A photograph of the South Reclaim Tunnel ventilation system from the smaller 36-inch tunnel / duct is depicted in Figure 2.4.1 below. This would have been a similar arrangement to the previous exhaust fan on the North Escape Tunnel). A similar ventilation system to that of the new North Escape Tunnel was installed during the expansion of the South Escape Tunnel to its current dimensions. Operational tests of the new ventilation system, which was designed to provide fresh air to the escape tunnel only, showed performance consistent with its design flowrate of approximately 4,000 cfm. This would be similar to the flowrate present in the North Reclaim Tunnel, which shared the same cross-sectional dimensions and escape tunnel ventilation specifications.

Figure 2.4.1. South Reclaim Tunnel exhaust as seen on July 9, 2020.

2.5 Railcar Offloading Infrastructure

Railcars entering the facility are decoupled from one another, and enter one of three dumper sheds, where they are turned upside down using a counterweighted platform system. The coal is loaded by means of hoppers and conveyors into the network of conveyors leading to the transfer tower, or directly to the piers for loading onto ships and barges.

GHD has been monitoring air quality in the dumper sheds since the explosion occurred as an additional means of safety precautions. GHD continues to work with CSXT to develop long-term monitoring solutions as warranted.

Figure 2.5.1. Air monitor in top level of railcar dumper shed. The yellow arm in the bottom of the picture is part of the counterweighted platform.

3. Description of Incident

On December 30, 2021, at approximately 11:24 am US Eastern Standard Time, an explosion occurred in the North Reclaim Tunnel at the Curtis Bay Piers Coal Facility ("the facility"). A pressure wave was observed coming from the North Escape Tunnel. Multiple plumes of exhausted coal dust were observed being emitted from the coal transfer yard. A fireball was observed exiting the south portal of the North Reclaim Tunnel.

3.1 Operations at Time of Incident

At the time of the incident, up to 6 vibratory feeders were in operation, moving coal from piles surrounding Tower 1 into the North Reclaim Tunnel. As each vibratory feeder came online, personnel working the piles would ensure the feeders were moving coal and operating correctly. Bulldozers would push coal down through the coal piles into the feeder holes and vibratory feeders. As each vibratory feeder moved coal, crevasses would form in the coal piles where coal was moving to the conveyer system in the tunnel below. The bulldozers on the piles would push the coal towards the feeder holes to ensure a continuous supply of coal was entering the feeder holes.

On the morning of the explosion, employees reported the tunnel had just been cleaned, and there was very little accumulated coal in the walkways. The general consensus was that the tunnel was as clean as it had ever been. As the coal was beginning to move along the conveyor, it was reported to be very wet as well, with more than one employee describing the coal entering the transfer tower as “black rain” due to how wet the coal was. Some lights inside the tunnel were undergoing maintenance, as some of the new LED lights which had recently been installed were not working and were being repaired.

3.2 Employee Operations

Three employees stated they were in the tunnel at approximately 10:00 am starting the feeders and evaluating their operation. These employees were responsible for operating bulldozers on the coal piles surrounding Tower 1; two heavy equipment operators were training a third junior operator to use the bulldozers. The employees were also responsible for going into the North Reclaim Tunnel to apply a jet of water, if necessary, to the vibratory feeders in the event they were not moving coal. At 10:00 am on the day of the event, the three employees had been in the tunnel applying water to VF-6 to get coal moving. The two bulldozer operators had resumed their positions on the pile, and the junior operator had taken a position at the base of the pile to observe their operations when the explosion occurred.

3.3 Feeder Operations

The vertical / vibratory feeders (commonly abbreviated “VF”) had three essential setpoints: manually engaged in the tunnel, activated in the control room, and remotely turned on at the coal pier to control the total flowrate of coal. At the time of the explosion, VF-5 through VF-10 had been activated in the control room and were being turned on at the coal pier as needed. Feeder 10 had some difficulty being engaged, and a fuse and coil had to be replaced in the control room, which was located next to the transfer tower (i.e., not in the tunnel). As noted in Section 3.2, VF-6 needed a water jet applied to get coal moving. The other feeders were noted by facility personnel to have operated normally. All 6 feeders were operating at the time of the explosion.

4. Scope of Investigation

The scope of the investigation was to determine the source of the explosion and to advise CSXT on operational changes which may have been warranted by the findings of the investigation. The investigation team relied on information provided by CSXT and were satisfied that all requests for information were met. The team was limited to some degree by the extent of damage to the tunnel, and by safety and operational considerations. The damage to the tunnel was extensive; thus, the nature and condition of the equipment prior to the explosion was in some cases difficult to deduce. Safety considerations precluded evaluation of certain portions of the tunnel in an undisturbed state; for example, the southern-most portion of the North Reclaim Tunnel was inaccessible due to structural stability concerns and limited means of physical access due to the build-up of debris. Operationally, removal of the debris needed to be conducted as a part of recovery efforts; therefore, some of the debris within the tunnel was only made visible through its forcible removal, which required some destructive actions that may have caused further damage beyond what resulted from the explosion.

The investigation team proceeded to gather and preserve all the evidence possible, despite these constraints. Every effort was made to capture the equipment in its final location, with annotated photographs to describe its condition. This information has been archived and may be produced upon request to CSXT as needed. Investigation of individual pieces of evidence has been undertaken with care and consideration of other potentially interested parties and in some cases has slowed the investigation process. The investigation team has worked with CSXT and other stakeholders to find an appropriate balance to these sometimes conflicting priorities.

4.1 Investigation Project Team

Dyron Hamlin, a GHD Principal chemical engineer and certified industrial hygienist (CIH) with specific experience in response to and investigation of emergency events of this nature, was requested by Mike Austin of CSXT, to lead the investigation team. The investigation team was also comprised of members of EFI Global, SciRisq, and other CSXT personnel. James Wesevich and David Beachy of EFI Global were directly involved with on-site activities, and Andrew Staszak of SciRisq supported the team with Computation Fluid Dynamics (CFD) modelling expertise. Additional personnel were involved in ongoing operations and were engaged for their experience and expertise related to similar circumstances, and their individual expertise has also been relied upon by the primary investigation team. Their contributions are acknowledged and appreciated. CVs for the investigation team are provided in Appendix H.

4.2 Investigation Objectives and Strategy

The investigation team was charged with determining the source of the explosion, and to advise CSXT personnel of any immediate operational changes which should be instituted to ensure employee safety in ongoing operations at the CBP facility as well as other coal transfer facilities. With these objectives, the investigation team set about evaluating the physical evidence available, including:

– Off-site impacts to buildings which would indicate the extent of overpressure effects (broken windows, damage to building structures, etc.)
– Off-site impacts which would indicate material that was released as a result of the explosion and combustion events
– On-site debris field investigation, to inform the possible source of the initiating event, as well as the direction and extent of overpressure
– Tunnel walk-throughs, to evaluate structural damage which might give insight to the source of the explosion as well as the extent of overpressure based on structural damage

In addition to the physical evidence, the investigation team also reviewed objective evidence from video footage collected both on- and off-site. Finally, subjective accounts were obtained through interviews of both off-site and on-site personnel with first-hand observations of the event.

5. Methods of Investigation

The investigation team used a multi-pronged approach to evaluating the effects of the explosion, with a view to determining its origin, and to advise corrective actions to prevent future loss. The primary methods used for investigating the explosion were:

– Visual Investigations of Tunnel
– Collection and Mapping of Debris
– Surveillance Video Reviews
– Modelling of Pressure Wave Propagation
– Evaluation of Coal Samples
– Evaluation of South Tunnel Operations
– Employee Interviews

The following sections will detail the results of each of these methods; further detail is available in the Appendices.

5.1 Visual Investigations of Tunnel

Investigation team personnel conducted dozens of walkthroughs of the tunnel after the incident occurred. The tunnel was deemed structurally sound by an on-site third-party structural engineer prior to entry. Access was limited to the walkway along the western wall of the North Reclaim Tunnel, from the north end of the tunnel to VF-27. Beyond VF-27 towards the south was deemed to be potentially structurally unsound due to the flaring of the ceiling of the tunnel at that location.

Each item of debris in the tunnel was marked and geolocated and is archived in a database which may be made available upon request to CSXT. The items were photographed and numbered according to their position in the

North Reclaim Tunnel. An example presentation is provided in Appendix D, showing the state of the vertical / vibratory feeders and conveyor structure following the explosion.

Of particular note and interest to the investigation team was the apparent direction of flow, as noted on Figure 1 in Appendix B, and elsewhere in Appendix D. Damage to VF-4 and the tail pulley (at the northern end of the tunnel) were also of particular note and are addressed in more detail in Section 5.4. Images of each may be seen in Appendix D. In short, the damage at the north end of the tunnel, by the intersection with the North Escape Tunnel, indicated a secondary explosion or otherwise reflected overpressure which caused more damage relative to the feeders near it, or within the North Escape Tunnel.

5.2 Collection and Mapping of Debris

Debris was released from the tunnel from three primary vectors:

– Released from the North Escape Tunnel, along with the pressure wave, towards the west into the railyard and as into the neighborhood to the west of the facility property
– Released vertically from the open feeder holes in the North Reclaim Tunnel and primarily depositing on the facility property
– Released towards the south from the south portal of the North Reclaim Tunnel, along with the fireball, primarily impacting the central transfer tower.

5.2.1 Off-site Debris and Deposition

GHD conducted a survey of the surrounding neighborhood and found deposition of coal dust (as distinguished from combusted material) in an approximately 12-block area to the west of the facility. The region was consistent with what would be expected to have emanated from the escape tunnel, and possibly from the vertical releases from the open feeder holes advected by winds.

5.2.2 On-site Debris Field

The on-site debris field was located directly west of the North Escape Tunnel portal, and it was comprised of material released primarily from the escape tunnel. This included the ventilation system, escape tunnel lights, electrical and alarm systems associated with the escape tunnel, ducts from the escape tunnel, and the oxygen tank and cart that were located inside the escape tunnel. As noted in Section 5.3 below, the propane tank which was released from the North Escape Tunnel was located on the adjacent property in the direction of the escape tunnel portal, after having come to rest next to the warehouse wall under construction to the west of the facility.

5.2.3 Debris inside North Reclaim Tunnel

Debris inside the North Reclaim Tunnel included:

– All vertical / vibratory feeders, table shaker, and hoppers
– Conveyor structure – belt, frame, and pulleys
– Light fixtures
– Loose electrical conduit and junction boxes
– Two ladders – one fiberglass and one aluminum
– Two gas cylinders which were used in cutting / replacing conveyor infrastructure – one oxygen, one propane. The propane cylinder was found to be slightly leaking and was recovered by CSXT Hazmat personnel on December 31.

To the extent possible, the debris inside the North Reclaim Tunnel was logged and collected for further investigation as needed. As of the time of the preparation of this report, the investigation team has had opportunity to evaluate all of the debris to a satisfactory degree, with the exception of some of the recently-installed LED light fixtures and conduit. All of the debris removed from the tunnel was documented, geolocated, and photographed as conditions allowed.

5.3 Surveillance Video Reviews

Surveillance video was invaluable to the investigation team to validate employee eyewitness accounts, and to explain the timing and speed of the event. Specifically, three primary videos proved most valuable:

- Off-site video from a neighboring auto salvage yard facility, Beltsville Auto Parts
- On-site video facing west, viewing bulldozer activities on the coal pile near Tower / Stacker Tube 1
- On-site video facing south, located along the eastern side of the Towers / Stacker Tubes

The off-site surveillance video showed a number of compelling phenomena. The vestibule of the North Escape Tunnel was blown outwards, and the resulting pressure wave was apparent from the surveillance video. The investigation team was able to slow the video down and analyze the timing of the North Escape Tunnel pressure wave relative to the fireball exiting the south portal of the North Reclaim Tunnel. Given the limitation of a pressure wave propagating through the atmosphere at the speed of sound, the investigation team was able to estimate that the source of the initial ignition would have had to have been somewhere near the midpoint of the south portal of the North Reclaim Tunnel and the west portal of the North Escape Tunnel. The video provided was at a rate of approximately 28 frames per second. On the video, approximately four frames elapse between the appearance of the pressure wave at the portal of the North Escape Tunnel and the fireball appearing at the south portal of the North Reclaim Tunnel. This indicates the time between the appearance of those two effects is approximately 0.1-0.2 seconds. If the pressure source originated from the same location within the tunnel, the distance to either location would be within 100-200 feet of the other, based on the speed of sound of approximately 1125 feet per second. This places the initiating event near the middle of the tunnel, which is consistent with other aspects of the investigation team's evaluation.

A propane cylinder from a cutting torch assembly and its skid were visible being projected from the North Escape Tunnel. The investigation team closely examined the possibility of the involvement of propane from one of the two cylinders in the tunnel as a potential fuel source for the explosion. Upon review of the surveillance video, unignited propane was visibly leaking from the cylinder projected from the escape tunnel upon colliding with the warehouse wall, as depicted on Figure 4 in Appendix B. For this reason and others discussed elsewhere, the propane cylinder was ruled out as a cause of the explosion.

The on-site video facing west showed the bulldozers operating on the coal pile near Tower / Stacker Tube 1. The ventilation system that was mounted to the top of the North Escape Tunnel vestibule was reported by employees to have been projected vertically to nearly the height of the stacking tubes (approximately 150 feet). Debris is visible at the reported location in this on-site video.

The on-site video facing south provided some insight into the fireball which emanated from the south portal of the tunnel. Review of this video was helpful to validate some of the modelling which was conducted, and is discussed in Section 5.4.

These videos have been archived and may be made available upon request to CSXT.

5.4 Modelling of Pressure Wave Propagation

The investigation team used an industry standard computational fluid dynamics (CFD) model called CAMBER to evaluate the pressure propagation throughout the tunnel. CAMBER is a simulation domain that uses **C**artesian **A**daptive **M**eshing for **B**last, **E**xplosion and **R**elease scenarios. It applies hydrocode and CFD techniques to simulate a variety of problems to include simulation of high explosives, and gas-phase/ complex combustion. It uses an object-oriented structure, applying a finite-volume formulation on an automatic mesh refinement (AMR) framework.

The investigation team created CAD drawings of the North Reclaim Tunnel which included features significant to the propagation of a pressure wave and combustion, such as the feeder holes which were open to atmosphere, the presence of vertical feeders and conveyor structure as interfering geometries within the tunnel, and the varying geometries of the North Reclaim Tunnel and North Escape Tunnel. These CAD drawings were imported to CAMBER using a utility that allows for the model to define complex geometries.

The CAMBER model inputs were varied to produce a number of scenarios, which were then compared to observations of damage, debris, and other physical evidence that remained from the explosion. Inputs such as the location of the initiating event, the combustible fuel composition, and the ignition source and timing were varied. Based on the results of the modelling, the investigation team confirmed the likely location of the initiating event as originating between VF-7 and VF-17, with areas closer to VF-17 more likely. The models affirmed the presence of a pressure wave build-up at the western portal of the North Escape Tunnel, as well as a combustion event culminating at the south portal of the North Reclaim Tunnel. They also affirmed the fuel composition as most likely a mixture of methane and entrained coal dust, with secondary and tertiary energetic events / deflagrations at the north end of the North Reclaim Tunnel and the area near VF-21, with a ramp-up in pressure from VF-21 to the south portal.

A full summary of the modelling approach and results is available as Appendix E

5.5 Coal Samples

GHD collected coal samples from the conveyor structure to characterize the possible accumulated dust which may have contributed to a secondary and / or tertiary combustible dust explosion. The samples were sent to EMSL Laboratory in and had them analyzed for combustibility. The results of the analysis were incorporated in the modelling described in Section 5.4 above, and in the modelling results described in further detail in Appendix E. A full copy of the sample results is also included in Appendix F.

5.6 South Tunnel Evaluations

The South Reclaim Tunnel has the same cross-sectional area, a similar ramp-up design towards its exit portal, and nearly identical equipment to that installed in the North Reclaim Tunnel prior to the explosion. As such, it provided a useful go-by for conditions that may have been present in the North Reclaim Tunnel prior to the explosion. The investigation team used observations from the South Reclaim Tunnel in its determination of the cause and origin of the explosion, and to continue to improve operations at the facility.

5.6.1 Monitoring During Operations

Since the restart of the South Reclaim Tunnel operations, GHD has been monitoring the air continuously for both gas and particulate matter concentrations during operations. In addition, GHD has assisted CSXT personnel with monitoring the ventilation conditions within the tunnel. Aside from brief excursions for methane, generally in the range of less than 10% of the lower explosive limit (LEL), levels have been consistently well below lower explosive limits or non-detect for either gases or particulate matter levels similar to background air, and well below any fractional threshold of the LEL that would trigger a temporary cessation of operations.

5.6.1.1 Air Monitoring

Air monitoring has been conducted inside the South Reclaim Tunnel for the purpose of ensuring operational safety and health for workers inside the tunnel. Air monitoring has been conducted using both handheld and telemetry-system air monitoring devices. Honeywell / RAE Systems AreaRAEs have been stationed throughout the South Reclaim Tunnel since operations resumed. These units are equipped with combustible gas sensors capable of detecting methane. Particulate matter monitoring has also been conducted to characterize conditions for the purpose of ensuring operational safety and health for workers inside the tunnel while coal is being transferred.

Figure 5.6.1. Monitor on floor of South Reclaim Tunnel with sample tube leading to higher elevation

Figure 5.6.2. Monitoring high location near top of tunnel using tubing.

5.6.1.2 Ventilation Rate Monitoring

During the restart of the South Reclaim Tunnel, CSXT installed a temporary fan capable of providing up to 100,000 cfm airflow. At normal idle, the fan provides 80,000 cfm airflow, which would yield a theoretical linear flowrate of 500 feet per minute through the South Reclaim Tunnel. The mining industry uses a layering number analysis method to ensure adequate ventilation in underground coal mines. Typical linear velocities that are recommended for places where workers are present, and to prevent methane layering near ceilings or creating pockets in tunnels are reported to be 200-600 feet per minute.[1,2] This is consistent with observations in the South Reclaim Tunnel.

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[1] Vinson, R.P. et al., METHANE ACCUMULATIONS IN COAL MINE ROOF CAVITIES, 1978, USBM Report of Investigations, RI 8267

[2] McPherson, M.J. "Subsurface Ventilation Engineering." Accessed at **https://wipp.energy.gov/Library/Information_Repository_A/Supplemental_Information/2019/References/McPherson.%202009.pdf**.

Figure 5.6.3. Temporary ventilation fan installed at south portal of South Reclaim Tunnel.

5.6.2 Review of Electrical Installations

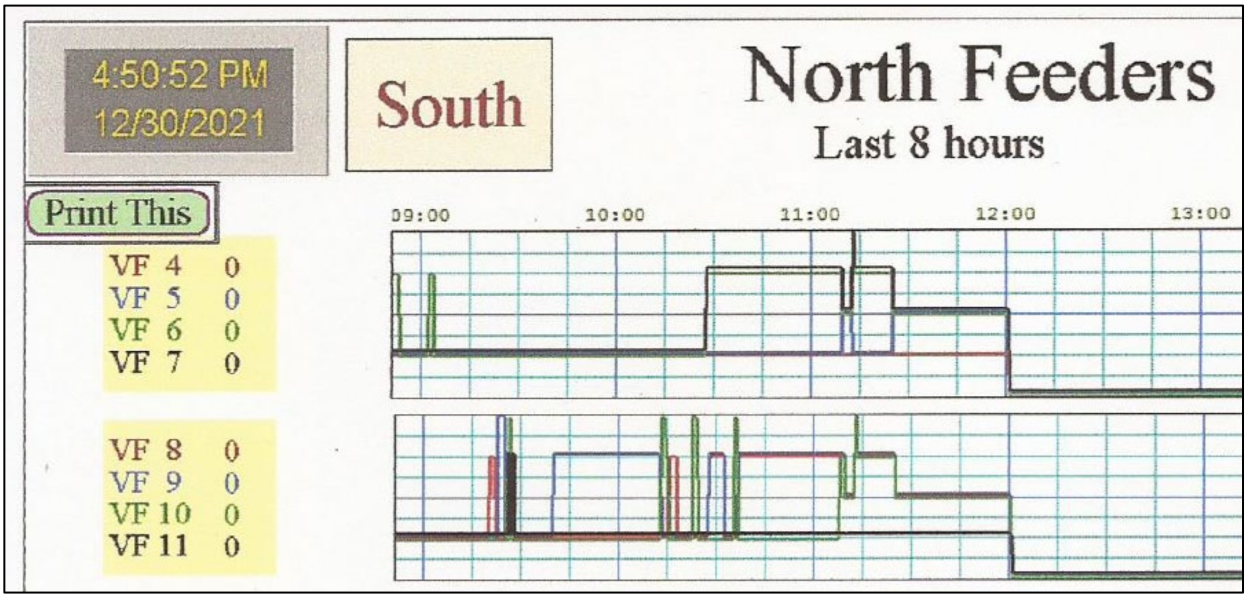
CSXT hired Weiser Engineering, P.C., a third-party electrical engineer licensed in the State of Maryland to evaluate the electrical installations in the South Reclaim Tunnel. Specifically, concerns were raised regarding some of the electrical systems, including the recently installed LED light fixtures. The inspection of the South Reclaim Tunnel revealed a number of installations which did not meet National Electrical Code Article 500 and 501 requirements for Class I, Div II locations. A full copy of the report is provided in Appendix G.

5.7 Employee Interviews

The investigation team interviewed or reviewed interviews of employees present at the facility on the day of the event. These interviews are documented and witness statements were obtained and may be made available for review upon request to CSXT.

Additional detail was provided by Bruno Reyntjens of PCMA Systems, Inc. regarding the control system operation of the feeders during the time of the explosion. He reported that no feeders were being turned off or turned on in the moments before the explosion. A graph of the system is provided in Figure 5.7.1 below, with the intermittent activation of VF-5 through VF-10 visible on the graph.

Figure 5.7.1. Graph of feeder operation leading up to the time of the explosion.



6. Results of Investigation

Based on the above strategy, methodology, and resulting evaluations, the investigation team concluded that the source of the initiating explosion was a combination of methane and coal dust accumulating in the North Reclaim Tunnel between VF-7 and VF-17. Propane was ruled out as a probable fuel due to examination of the regulators and valves recovered from the tanks, which were found to be in the closed position; due to the presence of uncombusted propane leaking from the propane cylinder which struck the warehouse wall; and due to the more probable presence of methane and coal dust. There was also no evidence that certain other structures and equipment damaged during the incident, including the concrete structure of the North Reclaim and North Escape tunnels, the continuous conveyor, and the vertical feeders, would have been causes of the explosion.

The ventilation of the tunnel was inadequate to effectively disperse methane and coal dust produced during the movement of coal in the tunnel, as evidenced by ongoing operations in the South Reclaim Tunnel – namely, when ventilation is not provided in the South Reclaim Tunnel, ongoing monitoring shows that levels of methane can reach up to a maximum of 44% of the LEL for methane, or 2.2% methane by volume. This level was not representative of normal operations; LEL has exceeded 5% on few occasions.

The theory of the explosion is settled on the following facts:

1. Methane from the coal, along with some coal dust, provided the initial fuel

2. Inadequate ventilation allowed the atmosphere to build up flammable levels of this fuel
3. An ignition source for the fuel caused an initiating event between feeders 7 and 17 in the North Reclaim Tunnel
4. This created a lofting event that unexpectedly increased the concentration of coal dust sufficient for combustion in other parts of the tunnel, leading to secondary and tertiary energetic events inside the North Reclaim Tunnel.

6.1 Initial Explosion

The initial explosion likely occurred between VF-7 and VF-17, and most likely was fueled by methane and coal dust. As noted in Appendix E, flammable gases will enhance the combustibility of dust, and dust will enhance the flammability of commingled gases. It is likely that the poorly ventilated tunnel, with an estimated linear air flowrate of approximately 25 feet per minute, allowed this mixture to accumulate. An ignition source within the tunnel caused this mixture to ignite and create a pressure wave that propagated north and south through the tunnel.

6.2 Secondary Energetic Event / Reflection

The pressure wave traveling north in the tunnel encountered the wall at the north end of the tunnel, and was magnified by reflection, as well as the additional confinement at the junction due to tunnel geometry (for example, an approximately 2-foot drop in elevation between the floor of the escape tunnel and the floor of the main tunnel. Pressure built slowly due to the confinement by the vestibule enclosure at the west portal of the escape tunnel until it failed outwards and released the pressure wave, in the absence of combustion. This release is partially evidenced by the presence of coal dust on the north wall of the escape tunnel, and absence of coal dust on the south wall of the escape tunnel, as depicted in Figure 6.2.1.

Figure 6.2.1. View east into escape tunnel portal. North wall (left in picture) is black; south wall is not.

6.3 Tertiary Energetic Event and Deflagration from South Portal

The pressure wave traveling south towards the south portal of the main tunnel built in intensity and picked up additional fuel in the form of dust and additional methane being released by the coal. A tertiary pressure front likely built near VF-21, which was thrust upward and outward through its feeder hole. Figure 6.3.1 shows the surface picture of VF-21, and Figure 6.3.2 shows the feeder from inside the tunnel. This pressure front led to the combustion of a large amount of fuel, and the resulting fireball that exited the south portal.

Figure 6.3.1. Feeder hole for VF-21 from the surface of the coal transfer yard.

Figure 6.3.2. Feeder 21 from beneath the feeder hole, in the North Reclaim Tunnel.

7. Recommendations

To prevent this type of event from occurring, the following recommendations should be considered to minimize the risk of the presence of flammable atmospheres.

The primary means of preventing this type of event is the provision of adequate ventilation, ongoing monitoring to validate continued safe operations, and the installation of electrical systems that meet National Electric Code. Current plans for repair of the North Reclaim Tunnel include:

– 300+ feet per minute airflow (final design to be determined)
– Reduction of feeders from 28 to 15
– New clam shell style feeders instead of vibratory feeders to reduce dust generation and power requirements
– Skirting (sides and top) of conveyor to minimize dust generation, loss, and potential for build up within the tunnel, and to preclude electrical sources in vicinity of conveyor
– Air monitors placed approximately every 80 feet
– Dust suppression at exit side of each feeder using water mist
– Static control through grounding at each end of tunnel
– Electrical system throughout at typically 24 Volts, with higher supply (240 V) reserved only for sump pump
– Electrical system designed to applicable NEC codes for Class I and II Div II specifications up to 15-foot radius outside tunnel; final validation to be conducted by licensed electrical engineer

As noted, GHD has been monitoring the South Reclaim Tunnel continuously since its return to operation. The monitoring includes LEL, VOCs, H_2S, CO, and dust. No levels of any analytes have been a cause for concern during normal operations. CSXT has increased the flow of fresh air within the South tunnel. Monitoring in the South Reclaim Tunnel has confirmed these efforts have proved effective in maintaining safe conditions.

Aside from brief excursions, levels have been consistently well below lower explosive limits for either gases or coal particulate matter, and well below any fractional threshold of the lower explosive limits that would trigger a temporary cessation of operations. Although the facility is not under the Mine Safety and Health Administration jurisdiction, as a general guideline, MSHA regulations dictate that surface installations maintain methane levels below 1.0%, or 20% of the lower explosive limit (LEL) for methane.[3] Operations in the South Reclaim Tunnel have been monitored continuously since resuming operations and have been consistently below 20% of the LEL under normal ventilation conditions. These parameters are being monitored 24/7 by personnel who will make necessary process adjustments, including shutdown of operations, as needed. No shutdown has been necessary.

Similar measures are being implemented in connection with the repair of the North Reclaim Tunnel. Namely, sensors are going to be placed approximately every 80 feet throughout the tunnel. In addition, dust control measures are being implemented, including skirting surrounding the conveyor, and water mist suppression at the exit of each feeder. The feeder systems are also designed to minimize the generation of dust – rather than using a vibratory system, the new feeder systems are clam shell design, meaning they will more directly introduce the coal to the conveyor (lowered a short distance), thereby reducing dust generation.

[3] 30 CFR 77.201

Appendices

Appendix A

Map Overview of Facility

Appendix B

North Tunnel Diagrams

Appendix C

North Escape Tunnel Construction Drawings

Appendix D

Visual Summary of North Reclaim Tunnel

Appendix E

CAMBER Modelling Approach and Results

Appendix F

Coal Dust Sample Results

Appendix G

Weiser Engineering Electrical Inspection

Appendix H

Investigation Team Curriculum Vitae

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