D12 BEST AVAILABLE TECHNOLOGIES ASSESSMENT FOR TAILINGS

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Dear Drew,

RE: Marathon Palladium Project - Best Available Technologies Assessment for Tailings Management

1.0 INTRODUCTION

The Marathon Palladium Project (the Project) is located approximately 10 km north of the town of Marathon, Ontario and consists of platinum group metals (PGMs) and copper (Cu) deposit that what will be extracted using open pit mining methods. Generation PGM Inc. (GenPGM) retained Knight Piésold Ltd. (KP) to updated the Feasibility Study (FS) design for the Tailings Storage Facility (TSF). The TSF will provide storage for both Non-potentially Acid Generating (non-PAG) tailings and Potentially Acid Generating (PAG) tailings as well as PAG mine rock from the open pit development.

This letter summarizes the high level best available technology assessment completed to identify the preferred tailings management technology for the preferred TSF site. The preferred TSF site was identified in the alternatives assessment completed for the Project (KP, 2012). It is noted that the TSF was referred to as the Process Solids Management Facility in historic documents.

2.0 BEST AVAILABLE TECHNOLOGIES AND PRACTICES

2.1 GENERAL

Best Available Technologies (BATs) and Best Available Practices (BAPs) represent the best available techniques to manage tailings for a specific project. The European Commission (2009) has defined best available techniques as follows:

- Best: Most effective in achieving a high general level of protection of the environment as a whole.
- Available: Developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions taking into consideration costs and advantages.
- Techniques: Includes both the technology used and the way in which the facility is designed built, maintained, operated and closed.

The best overall approach for a project is typically a combination of BATs and BAPs that most effectively reduce the physical, geochemical, ecological, social and economic risks associated with the entire tailings storage life-cycle, from construction through operations and closure. The BATs are not a “one size fits all” solution and are specific to project requirements, climate, geology, geomorphology, downstream sensitivity, tailings characteristics and social considerations. Site selection considerations, technologies and design features that provide for resilient and robust tailings storage throughout the tailings life-cycle are considered when defining the BAT for a project. BATs are applicable at every stage of the tailings life-cycle.

The BAPs for the project are the management and operational procedures that are developed in consideration of engineering and governance practices for the most appropriate BATs. The BAPs should confirm that the tailings facility is designed, constructed, operated, maintained, monitored and closed to achieve the performance objectives. As part of the BAPs, the responsibilities and roles of the involved parties including the owner/operator, regulators, consultants and professional licensing boards are clearly defined and followed.

2.2 TAILINGS MANAGEMENT TECHNOLOGIES

Mine tailings are often characterized by their approximate solids content at delivery to the TSF. Tailings technologies considered in this study include:

- Conventional Slurry Tailings
- Thickened Slurry Tailings
- Paste (ultra-thickened) Tailings
- Filtered Tailings
- Tailings and Waste Rock Co-Disposal

An overview summary of these tailings management technologies is provided in Appendix A.

3.0 SITE CONDITIONS

3.1 TOPOGRAPHY

The Project site is characterized by moderate to steep hilly terrain with ground surface elevations ranging from approximately El. 200 m to greater than El. 400 m. Low lying areas are characterized by abundant water bodies including small to medium sized lakes, streams and wetland areas. There is an overall gradual decrease in elevation on the Project site from north to south and, to a lesser extent, from east to west. Bedrock is very close to, or at surface in most areas and the vegetation is dense. The Project site does provide for significant topographic containment and as result, embankment construction is required for all of the evaluated tailings management technologies.

3.2 HYDROLOGY

Drainage of the Project site is to two main watersheds including the Pic River to the east and Lake Superior to the west. Four Sub-Watersheds (101, 102, 103, and 108) within the Project area drain to the Pic River, which is a large, low to medium gradient river that is approximately 20 to 30 m wide that outlets to Lake Superior. Two Sub-Watersheds (105 and 106) within the Project area drain directly to Lake Superior. The PSMF will be located within Sub-Watersheds 106, 105 and 101. The mine rock storage area (MRSA) will be located within Sub-Watersheds 102, 103, and 108. It is understood that drainage from the Project site towards the Pic River is required to be minimized.

3.3 CLIMATE

The Project is located in the sub-artic region, which is characterized by cold winters, short warm summers and a moderate amount of precipitation. The monthly average temperature ranges from approximately - 13.4°C to 15.1°C based on the data collected at the Marathon airport. The average annual temperature in the Project area is approximately 2°C. Average total annual precipitation is approximately 818 mm consisting of approximately 600 mm in rainfall and about 200 mm of equivalent precipitation from snowfall (Stantec, 2020). Evaporation is in the range of approximately 500 mm per year meaning a net precipitation of about 300 mm. The climatic conditions result in the mine site being in annual water surplus with excess water from the site requiring to be managed. During winter operations the mine site will operate in a water deficit due to meteoric water being retained as snow and ice. As a result, water retention is required to support winter operations.

3.4 BEDROCK GEOLOGY

The Project is located on the eastern margin of the Port Coldwell Alkaline Complex, which is a layered basic igneous intrusion. Mineralization is related to a large magmatic system consisting of three or more cross-cutting gabbro units that comprise the Eastern Gabbro Series of the complex. The geological setting for the project is summarised in the Open Pit slope design report (KP, 2020).

The geology at the Marathon PGM-Cu project is locally characterised by shallow to moderately dipping, sub-parallel lenses that form distinct mineral horizons. Mineralization is most commonly hosted by the Two Duck Lake Gabbro. The PSMF area, west of the ore deposit is generally underlain by coarse grained augite syenite. Several faults crosscut the PSMF area and are defined at surface by the local drainages. Initial subsurface investigation work suggests that some of the faults are healed and not highly permeable. In general, the bedrock at site is highly competent near surface providing for robust embankment foundation conditions and minimal foundation seepage from the TSF.

3.5 SURFICIAL GEOLOGY

The surficial geology at the Project site consists of a range of quaternary soil deposits and exposed bedrock. Surface soils over the majority of the Project area including the proposed TSF footprint generally consist of a thin intermittent layer of glacial drift (sands and gravels). Low lying areas typically have a thin organic layer at surface that is underlain by fine grained soils. Soils along the Pic River flood plain (eastern boundary of the Project site) are comprised of thick deposits of sand, silt and clay (>20 m in some places).

4.0 PROCESS DESCRIPTION

The Project is projected to produce approximately 120 million tonnes of tailings over a 14 year mine life. Ore will be mined using open pit mining methods, crushed, and fed to an onsite Process Plant. The process plant will consist of a 25,200 tonnes per day circuit with the following:

- Primary crushing
- SAG-ball milling and pebble crushing
- Concentrate flotation with regrinding ahead of cleaning
- Concentrate magnetic separation
- Rougher tailings slime separation with regrinding ahead of PGM scavenger flotation
- Concentrate thickening
- Concentrate filtering
- Tailings thickening

The Process Plant products will include a PGM-Cu Concentrate, PGM Scavenger tailings (non-PAG) and 1st Cleaner tailings (PAG). The non-PAG and PAG materials have been defined as Type 1 and Type 2 materials, respectively, for the Project.

All of the site contact water (including supernatant water from the TSF) will be collected and managed in a common Water Management Pond (WMP). Process water will be reclaimed from the WMP to the Process Plant.

5.0 BAT SELECTION BASED ON TAILINGS PROPERTIES

The tailings characteristics are summarized on Table 1 and Figure 1. Grain size analysis completed in 2013 classified the Type 1 and Type 2 tailings as hard rock tailings (HRT) and altered rock tailings (ART), respectively. Recent testing on a combined sample (Type 1 and Type 2) indicates the tailings range from HRT to ART. Tailings characterisation test work is currently in progress for the PGM Scavenger tailings and 1st Cleaner tailings to confirm the material characteristics. As noted above, the Type 1 tailings are non-PAG and Type 2 tailings are PAG.

Table 1 Tailings Characteristics

Parameter	PGM Scavenger Tailings (Type 1)	1st Cleaner Tailings (Type 2)
Percentage of Process Solids Stream by Mass	85 %	15 %
Surry Content by weight	55 %	22 %
Specific Gravity	3.03	3.2
Final Settled Dry Density (tonnes/m^3)	1.6	1.1

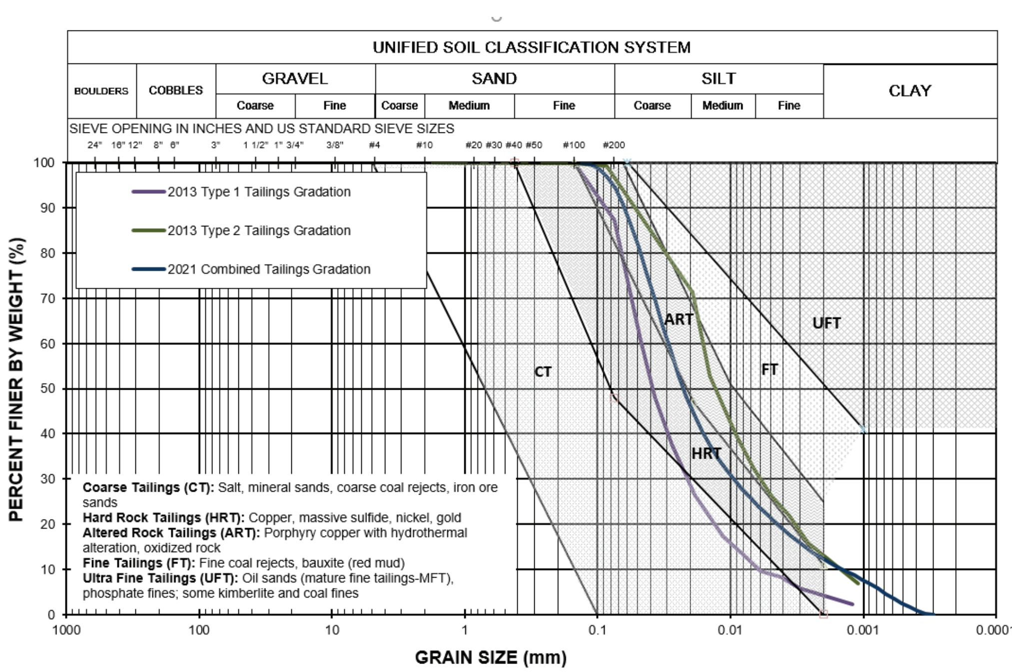

Figure 1 Tailings Particle Size Distribution Classification (ICOLD, 2017)

The physical and geochemical properties of the tailings impact the feasibility of the various tailings management technologies. Finer grained tailings are less viable for filtration than coarser grained tailings. Similarly, tailings that are PAG and may be susceptible to Acid Rock Drainage (ARD) are best suited for conventional or thickened slurry discharge, as the saturated tailings inhibits oxygen ingress and impedes oxidation. Table 2 (ICOLD, 2017) summarizes the feasibility of a particular tailings technology in relation to the physical and geochemical characteristics of the tailings relative to the tailings classification from Figure 1 (ICOLD, 2017).

The Type 1 Tailings are non-PAG and are not susceptible to ARD. The gradation of the Type 1 tailings is within the range of HRT suggesting that the Type 1 tailings would be amenable to conventional and thickened slurry tailings as well as paste and filtered tailings technologies.

The Type 2 tailings are PAG and would be susceptible to ARD if the tailings are not maintained in a saturated state. Due to the gradation of the Type 2 tailings being within range of ART and the potential for ARD, conventional and thickened slurry tailings technology is applicable for the Type 2 tailings.

Table 2 Tailings Technology Applicability (ICOLD, 2017)

Tailings Technology	Feasibility by Tailings Physical Characteristics				
	Coarse Tailings (CT)	Hard Rock Tailings (HRT)	Altered Rock Tailings (ART)	Fine Tailings (FT)	Ultra-Fine Tailings (UFT)
Conventional Slurry Tailings	High	High	High	High	High
Thickened Slurry Tailings	High	High	High	High	Medium
Paste Tailings	High	High	Medium	Low	Low
Filtered Tailings	High	High	Medium	Low	Low

Tailings Technology	Feasibility by Tailings Geochemistry	
	Acid Rock Drainage	Neutral Mine Drainage
Conventional Slurry Tailings	High	High
Thickened Slurry Tailings	Medium to High	High
Paste Tailings	Low to Medium	Medium to High
Filtered Tailings	Low to Medium	Medium to High

6.0 BAT SELECTION BASED ON CLIMATE AND PRODUCTION RATE

Climate and production rate have been shown to have an impact on the feasibility of various tailings management technologies (MEND, 2017). In dry climates where water is at a premium there may be increased benefits to using paste and filtered tailings disposal in order to reduce atmospheric and entrained water losses in the tailings.

Tailings conveyance and disposal in the TSF also needs to be considered during winter operations. Pumping and discharge of conventional or thickened slurry tailings is relatively straight forwarded during freezing conditions. Insulated and/or heat traced pipeline can be utilized to mitigate the potential for frozen pipelines. Hauling or conveying tailings during freezing conditions would require additional mitigation measure to maintain the tailings in a thawed state prior to placement.

Higher production projects (>20,000 tpd) generally utilize conventional or thickened slurry tailings as less sophisticated equipment and operating practices are required. Figure 2 illustrates the tailings technology application for global mining projects based on the daily production rate and mean annual precipitation. The location of the Project is included on Figure 2 for the planned daily production rate of 25,000 tonnes and mean annual precipitation of 300 mm. Base on method precedent, the Project is most similar to existing projects that utilize conventional and thickened slurry tailings for tailing management. The Project is on the outer extent of the range of projects that have been able to utilize filtered tailings for the management of non-PAG tailings. Projects that do utilize filtered tailings either have a lower throughput or are located in drier climates without a winter operating period.

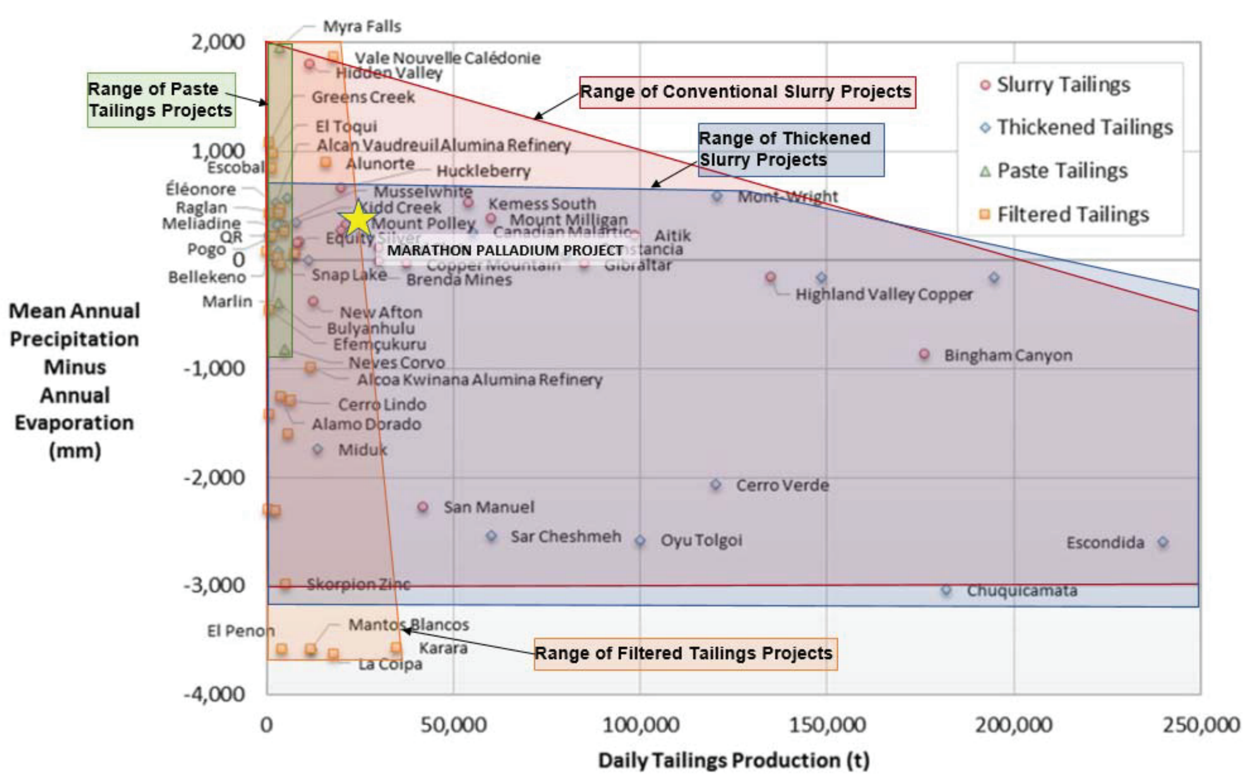

Figure 2 **Method Precedent for Tailings Technology Application (after MEND, 2017)**

7.0 CONCLUSIONS

The preferred BAT for a project is not a "one size fits all" solution and is specific to project requirements. The BAT for tailings management is dependent on the viable alternative technologies the associated management strategies that most effectively reduce the physical, geochemical, ecological, social and economic risks associated with tailings management during all stages of operation and after mine closure.

The following conclusions are provided from this assessment of tailings technologies for the Project.

- **Conventional and Thickened Slurry Tailings:** Conventional and thickened slurry tailings systems provide a high level of operational flexibility to manage both Type 1 and Type 2 tailings. Conventional slurry TSFs include a supernatant pond during operations and the tailings solids are stored at a less dense state as compared to filtered tailings, as a result, the consequence of a hypothetical failure is potentially greater than a filtered tailings stack. In order to reduce the likelihood of a hypothetical failure, the TSF must be designed, constructed, operated, maintained, monitored and closed to achieve the performance objectives.

  Thickening of the Type 1 tailings slurry would reduce the pumping and pipeline requirements between the TSF and Project Plant, reduce the amount of water that is managed in the TSF and increase the settled dry density of the tailings via sub-aerial tailings deposition.

  Thickening of the Type 2 tailings slurry would provide similar benefits to the Type 1 tailings slurry, however, it is noted that due to the smaller volume, the benefits of thickening the Type 2 tailings would be limited.

- **Paste Tailings:** Paste tailings are not considered to be a viable technology for tailings management for the Project. The production of paste would require additional tailings management infrastructure and significant cost increases. A paste TSF would require perimeter embankments and a separate WMP to manage site water similar to a conventional or thickened slurry TSF.

  There is no precedent of the use of paste tailings at a 25,000 tpd operation.

  If the mine plan included for an underground mine, the production of paste for underground mine backfill may be beneficial to store tailings underground.

- **Filtered Tailings:** Filtered tailings are currently not considered to be a viable technology for tailings management for the Project. The Type 2 tailings are required to be stored in a saturated state to reduce the onset of ARD and therefor should not be filtered. Type 1 tailings could potentially be filtered and storage in a stack. A filtered TSF would require rockfill perimeter berms to maintain the stability of the stack, separate storage cells for the storage of higher moisture content tailings produced during operating conditions, and a sperate WMP for site water management similar to a conventional or thickened slurry TSF.

  Production, transport and placement of filtered tailings during winter operating periods would be technically and logistically challenging. There is the potential for significant upset operating conditions and as a separate conventional slurry tailings TSF would need to be considered as a mitigation measure for periods when production and placement of filtered tailings is not feasible.

There is no method precedent for the use of filtered tailings for a project with a similar throughput and located in a similar climate with a winter operating period.

- **Tailings and Mine Rock Co-Disposal:** Tailings and mine rock co-mingling or co-deposition is not considered to be feasible for the Project. The mixing or alternating placement of tailings and mine rock during cold temperatures would be operationally challenging. Co-mingling or co-deposition of tailings and mine rock would not significantly reduce the mine footprint.

  Co-placement of mine rock with the tailings would be feasible if the mine rock is hauled and placed as a separate operating practice within the TSF. The mine rock would then be subsequently inundated with ongoing tailings deposition. Co-placement of Type 2 mine rock with the TSF below the long-term phreatic surface would prevent the onset of ARD conditions from the Type 2 mine rock.

8.0 RECOMMENDATIONS

At this time and based on this assessment, the BAT for tailing management for the Project is conventional and thickened slurry tailings disposal. Conventional and thickened slurry tailings storage provides a robust tailings management strategy to manage Type 1 and Type 2 tailings. Conventional and thickened tailings slurry disposal is recommended as the BAT for tailings management based on the following:

- Sub-aqueous (below water surface) deposition of Type 2 tailings as a conventional tailings slurry to maintain the PAG material in a saturated state.
- Sub-aerial (above water surface) deposition of Type 1 tailings as a thickened tailings slurry to reduce the amount of water that is managed within the TSF and increase the settled dry density of the tailings.
- It is feasible to manage the Type 1 and Type 2 tailings with existing technology.
- The costs associated with the operation of a conventional/thickened slurry TSF are economically viable.
- Operating requirements and logistics for managing the TSF are straightforward and reduce the likelihood of upset operating condition during summer winter operating periods.
- Co-placement of Type 2 mine rock below the long-term phreatic surface within a conventional/thickened slurry TSF would prevent the onset of ARD conditions.

In order to reduce the risk associated with a conventional/thickened slurry TSF appropriate BAPs must be implemented to reduce the likelihood of a hypothetical failure from occurring. The BAPs are required to ensure the TSF is design, constructed, operated, maintained, monitored and close to achieve the performance objectives of the TSF. The BAPs that will be developed for the TSF include:

- Robust TSF designs and thorough supervision and documentation during construction.
- Establishment of an Independent Tailings Review Board (ITRB) to review the TSF design and operation.
- Operations, Maintenance and Surveillance (OMS) Manuals which identify and provide guidance on the operation, maintenance and surveillance of the facilities as will as performance objectives and trigger action response plans (TARPs).
- Emergency Preparedness and Response Plans (EPRPs) which provide guidance on how to respond and document emergency conditions.
- Annual dam safety inspections (DSIs) by the Engineer of Record.
- Independent third-party dam safety reviews (DSRs) every five years.

9.0 CLOSING

Please contact us if you have any questions related to this BAT assessment for tailings management at the Marathon Palladium Project.

Yours truly,
Knight Piésold Ltd.

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Approval that this document adheres to the Knight Piésold Quality System:

Attachments:

Appendix A Tailings Technologies Overview

References:

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APPENDIX A

Tailings Technologies Overview

(Pages A-1 to A-8)

APPENDIX A
TAILINGS TECHNOLOGIES OVERVIEW

1.0 GENERAL

Mine tailings are often characterized by their approximate solids content at delivery to a Tailings Storage Facility (TSF). Tailings can be dewatered with physical characteristics that range along a 'tailings continuum', which qualitatively describes tailings solids content, strength, thickening effort (and/or dewatering), behavior/method of conveyance and segregation potential during placement. The tailings continuum is illustrated on Figure A.1. Certain points along the tailings continuum have been identified as potential 'tailings technologies'. Tailings technologies detailed herein include the following:

- Conventional Slurry tailings
- Thickened Slurry tailings
- Paste (ultra-thickened) Tailings
- Filtered Tailings
- Tailings and Waste Rock Co-Disposal

As the solids content of the tailings increases and the water content decreases, the strength of the tailings increases, and the tailings become less fluid and behave as a soil. The tailings strength is defined as "yield stress" when the mixture is in a slurry or paste-like state and "shear strength" when it is in a solid soil-like state. The yield stress is the minimum shear stress above which flow will start and below which flow will stop. Figure A.2 provides an illustration of the tailings continuum and the yield stress for tailings at various water contents.

Key characteristics for tailings management technologies are summarized on Table A.1 and discussed in the following sections. The typical advantages and disadvantages for each of the tailings management technologies are summarized on Table A.2. Information provided is this section is based on the Mine Environment Neutral Drainage (MEND) Program Study of Tailings Management Technologies (MEND, 2017). The MEND report should be referred to for a more detailed summary of the tailings technologies.

2.0 CONVENTIONAL SLURRY TAILINGS

Conventional slurry tailings are a mixture of water and ground tailings that are generated during ore processing. Conventional slurry tailings typically range from 20 to 50% solids content by weight (defined as weight of solids divided by total weight of slurry) and are characterized by a yield stress less than 40 Pa (MEND, 2017). Conventional slurry tailings are typically transported to the TSF in a slurry pipeline by gravity or using centrifugal pumps. Dams, embankments or surface impoundments are typically required to contain the tailings solids and process water. The containment structures may be constructed of waste rock, locally excavated borrow materials, a portion of the tailings or a combination of these materials and may be lined or unlined depending on construction technique and operating requirements.

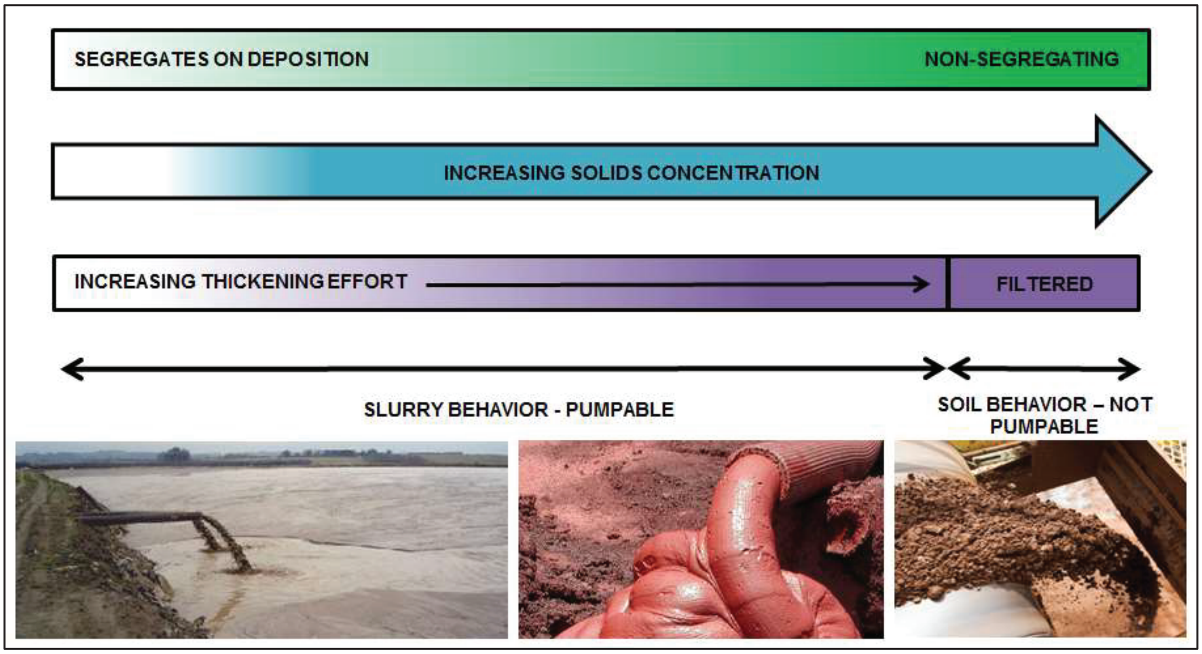

Figure A.1 Tailings Continuum

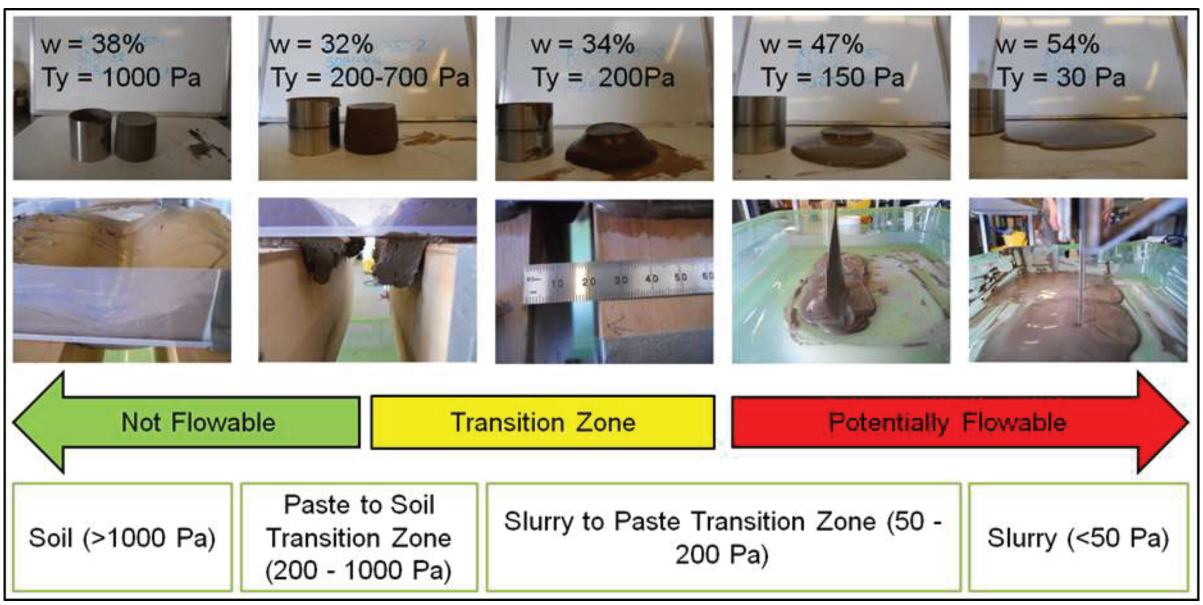

Figure A.2 Tailings Continuum and Yield Stress (Brouwer et al., 2017)

Table A.1 Summary of Tailings Management Technologies

Tailings Technology	Process Equipment	Degree of Saturation During Transport (%)	Solids Content (%)	Yield Stress (Pa)	Transportation Method
Conventional Slurry	None - product of the processing plant with no additional dewatering effort	100	20 - 50	<40	Gravity flow or pumped in slurry pipeline using centrifugal pumps
Thickened Slurry	Flocculants and conventional thickeners or high rate thickeners Flocculants and high compression thickeners or deep cone thickeners for high density thickened slurry	100	40 - 60 65 - 70	<40 40 to 200	Gravity flow or pumped in slurry pipeline using centrifugal pumps
Paste Tailings	Deep cone thickener or a combination of thickening and filtering	100	70-85	±200	Pumped in slurry pipeline using positive displacement pumps
Filtered Tailings	Thickeners and vacuum or pressure filters, centrifuges	<95	>85	>1000	Trucks or conveyors

NOTES:

1. RELEVANT FOR HARD ROCK TAILINGS WITH SG IN RANGE OF 2.6 TO 2.8.
2. TYPICAL RANGE OF VALUES FOR DEGREE OF SATURATION DURING TRANSPORT, SOLIDS CONTENT AND YIELD STRESS.

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TABLE A.2

GENERATION MINING
MARATHON PALLADIUM PROJECT

BEST AVAILABLE TECHNOLOGIES ASSESSMENT FOR TAILINGS MANAGEMENT
SUMMARY OF TAILINGS TECHNOLOGIES ADVANTAGES AND DISADVANTAGES

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Category		Tailings Technologies			
		Conventional Slurry Tailings	Thickened Slurry Tailings	Paste Tailings	Filtered Tailings
Logistics and Infrastructure	Advantages	• Effective for use with various tailings types and production rates • Tried and proven tailings technology • Greater operational flexibility for overall mine water management due to the attenuation capacity within the tailings facility	• Effective with various tailings types and production rates • Tried and proven tailings technology • Greater operational flexibility for overall mine water management due to the attenuation capacity within the tailings facility	• Higher initial settled densities than slurry tailings resulting in lower initial storage volume requirements • Paste tailings may be used as underground backfill where applicable	• Higher placed densities resulting in reduced storage volume requirements as compared to slurry tailings and paste tailings • Potential to store tailings in areas with space limitations
	Disadvantages	• Lower settled densities than filtered tailings resulting in higher storage volume requirements	• Lower settled densities resulting in high storage volume requirements • Optimization of the thickening system to produce a consistent tailings product may take considerable time, the achieved solids content is often lower than the design target • High-density thickeners require operational attention and may be subject to operational upsets due to variation in tailings gradation or operator error	• Less suitable with fine and ultra-fine tailings • Transportation of cement or other amendments will result in increased traffic on local roads • Less suitable for mines with high throughput due to the costs and logistics associated with thickening and transporting the tailings • Positive displacement pumps can be challenging to operate • Paste production requires operational attention and may be subject to operational upsets due to variation in tailings gradation or operator error	• Not suited for fine and ultra-fine tailings • Logistical issues associated with maintaining target moisture content and tailings properties • Increased transportation requirements associated with haulage and/or conveyors as compared to pipelines and pumps • Less suitable for mines with high throughput • Operational flexibility required to manage higher water content tailings during upset operating conditions • More challenging placement conditions at wet, cold and windy sites
Water Management	Advantages	• TSF provides water storage, high level of operational flexible for the management of process water, meteoric water, and excess mine water • Separate process water management facility not required	• TSF provides water storage, high level of operational flexibility for the management of process water, meteoric water and excess mine water • Increased water recovery at Mill reduces the volume of water that is transferred between the TSF and the Mill	• Reduced water storage requirements as compared to slurry tailings • Increased water recovery at the Mill reduces the volume of water that is transferred between the tailings facility and the Mill	• Minimal water storage within the TSF • Reduced potential for groundwater seepage due to unsaturated tailings • Increased water recovery at the Filter Plant • Most beneficial in regions where water is scarce
	Disadvantages	• Lower water recovery at Mill, greater volume of water transferred between the TSF and the Mill • Water management must be balanced to avoid storing too much water in the TSF, while allowing for contingency storage during upset operating conditions	• Separate water management facility may be required if TSF is sized to managed less water	• Separate water management facilities may be required to manage process water and meteoric water	• Separate water management facilities required to manage process water and meteoric water
Capital, Operating, and Closure and Reclamation Costs	Advantages	• Lower tailings processing costs • Lower tailings delivery costs, conventional slurry tailings can be conveyed with low cost centrifugal pumps	• Lower tailings processing costs • Lower tailings delivery costs, thickened slurry tailings can be conveyed with low cost centrifugal pumps	• Potential for lower containment costs due to smaller starter embankments, smaller impoundment footprint, and reduced embankment requirements as compared to slurry tailings	• Lower containment costs due to higher storage efficiency and reduced embankment requirements • Lower closure and reclamation costs as compared to slurry tailings
	Disadvantages	• Potential for higher closure and reclamation costs due to longer tailings consolidation time, water management concerns, larger footprint, and poor trafficability • Higher initial capital costs due to larger starter embankments, facility footprint, and reduced initial storage efficiency	• Potential for higher closure and reclamation costs due to longer tailings consolidation time, water management concerns, larger footprint, and poor trafficability • Higher initial capital costs due to larger starter embankments, impoundment footprint, and reduced initial storage efficiency • Increased tailings processing costs due to energy and equipment required to thicken tailings	• Higher equipment costs to produce and pump tailings • Higher relative tailings processing costs due to energy and additive requirements • Increased tailings delivery costs due to positive displacement pumps being required to transport tailings	• Highest equipment costs to produce and transport filtered tailings • Highest processing costs due to energy intensive tailings filtration • Highest delivery costs to haul or convey tailings to TSF
Physical Stability	Benefits	• May be closed as a dry facility depending on tailings properties and design of the TSF • Tailings below 30 to 60 ft. depth naturally consolidate to similar in-situ density as thickened or paste tailings • Higher settled densities achievable with in situ drainage measures	• Increased initial tailings density as compared to conventional slurry tailings • Potentially non-segregating and may produce a settled tailings deposit with lower hydraulic conductivity • May be more straightforward to cap and close as a dry facility as compared to conventional slurry tailings • Hypothetical failures may have a lower consequence as compared to conventional slurry tailings due to smaller operating pond	• Increased tailings strength and stability as compared to unconsolidated slurry tailings • Potentially non-segregating and may produce a tailings deposit with lower hydraulic conductivity • May be more straightforward to close as a dry facility as compared to slurry tailings • A hypothetical failure may be limited to local slumping and have a lower consequence as compared to slurry tailings due to reduced water storage	• Increased tailings strength and stability as compared to unconsolidated slurry tailings and paste tailings • Higher achievable dry density due to compaction of non-saturated tailings • Tailings will not segregate • Filtered tailings can form a non-flowable mass under optimal operating conditions • Potential for more straightforward closure as a dry facility as compared to slurry tailings • A hypothetical failure may be limited to local slumping and have a lower consequence as compared to unconsolidated settled slurry tailings and paste tailings
	Challenges	• Increased potential for flowable tailings as compared to paste or filtered tailings due to higher water content • Operating pond in TSF increases the potential consequence of a hypothetical failure • Consequence of a hypothetical failure greater than paste tailings and filtered tailings • Requires robust containment dams for storage relative to filtered tailings	• Decreased relative tailings stability due to lower settled density and higher water content as compared to paste tailings or filtered tailings • Difficulty achieving consistent tailings properties which can impact the strength and flowability of the tailings • Increased potential for flowable tailings as compared to paste tailings or filtered tailings due to higher water content	• Difficulty achieving consistent tailings properties which can impact the strength and flowability of the tailings	• Difficulty achieving consistent tailings properties which can impact the strength and flowability of the tailings
Environmental	Benefits	• Suitable for sub-aqueous storage of PAG tailings • Existing precedents for closure • Operating pond provides dust mitigation	• Suitable for sub-aqueous storage of PAG and ARD waste • Existing precedents for closure • Operating pond provides dust mitigation	• Potential for straightforward reclamation and closure planning due to improved trafficability and smaller facility	• Simplified reclamation and closure planning due to good trafficability and smaller facility • Potential for concurrent reclamation and staged capping • More amenable to dry closure and landform development than slurry tailings and paste tailings
	Challenges	• More complex closure planning due to lower trafficability and larger facility as compared to paste tailings and filtered tailings	• More complex closure planning due to lower trafficability and larger facility as compared to paste and filtered tailings • Potential for fugitive dust emissions from exposed tailings surface	• Increased potential for fugitive dust emissions from exposed tailings surface	• Increased potential for fugitive dust emissions from exposed tailings surface • Increased power usage • Difficult to manage metal leaching or PAG tailings using source control measures due to low saturation of materials

I:\1\01\00446\10\A\Correspondence\NB20-00611 - Letter - BAT Summary\[Table A.2 -Tailings Technologies Advant & Disadvant_2021-02-21.xlsm]Table A.2 - General

NOTES:

1. ADVANTAGE AND DISADVANTAGES FOR TAILINGS TECHNOLOGIES BASED ON INFORMATION PROVIDED IN MEND STUDY OF TAILINGS MANAGEMENT TECHNOLOGIES (MEND, 2017).

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Conventional slurry tailings typically segregate upon deposition with the coarsest particles settling near the discharge points and finer particles settling further from the discharge points. The settled tailings tend to form a gently sloping above water beach with slopes ranging from about 0.5 to 1.5%. Finer tailings particles tend to travel further and develop a flatter above the water beach slope. Selective tailings deposition is often used to maintain the supernatant pond away from the embankments to enhance stability and reduce potential seepage from the facility. Tailings may be deposited sub-aerially (above the supernatant pond surface) or sub-aqueously (below the supernatant pond surface). Cyclones may be used to separate the coarse and fine fraction in order to utilize the coarse faction (sand) of the tailings for embankment construction or mine backfill.

Closure of conventional slurry tailings facilities is dependent on the climate, site conditions, facility type, tailings properties and preferred end land use. Closure typically includes removal of the supernatant pond and placement of a soil cover to promote a final vegetated surface. In some cases, an engineered cover may be installed to reduce infiltration of meteoric water into the tailings. Alternatively, closure may include a water cover to prevent acid generation if the TSF contains PAG tailings.

The consequences of a hypothetical dam breach for a conventional slurry TSF during operations can be very high due to flood inundation resulting from the release of the supernatant pond along with remobilized fluid tailings solids. Following closure, the consequences may be significantly reduced through removal of the supernatant pond and after consolidation of the tailings solids.

3.0 THICKENED SLURRY TAILINGS

Slurry tailings can be thickened by removing a portion of the water from the slurry to increase the solids content and the viscosity. Tailing materials are thickened with conventional or high-rate thickeners. Flocculants may be used to aid in settling finer silt and clay sized particles. Thickened tailings slurry typically has a solids content of 40 to 60% by weight. Deep-cone thickeners may be utilized to produce a high-density thickened slurry with a solids content in the range of 60 to 70% by weight. The yield stress of thickened tailings slurry can range from approximately 20 to 200 Pa (MEND, 2017). Surface impoundments are typically required to contain the tailings solids and process water (similar to conventional slurry tailings). Containment structures may be constructed of waste rock, locally excavated borrow materials, a portion of the tailings or a combination of these materials and may be lined or unlined depending on construction technique and operating requirements.

Thickened tailings slurry can generally be conveyed by gravity or by using centrifugal pumps. Positive displacement pumps may be required for high-density thickened slurry tailings with high yield stress. Thickened slurry tailings require less water to be cycled through the tailings distribution and reclaim water systems, require more pumping effort to transport and the tailings tend to segregate less after discharge. The initial settled density and final consolidated density of the tailings is largely unaffected by the solids content of the slurry tailings at discharge. The initial settled density of the thickened tailings may be higher than for a comparable conventional slurry tailings facility but over time thickened tailings and slurry tailings have been shown to achieve similar final densities due to self-weight consolidation. The primary benefit to thickening tailings is a reduction in process water that is temporarily stored and recycled from the TSF.

The consequences of a hypothetical dam breach for a thickened slurry TSF during operations may be lower than a conventional slurry TSF provided that a smaller supernatant pond volume is present on the tailings.

4.0 PASTE TAILINGS

Paste tailings or ultra-thickened tailings are produced using specialized paste or ultra-high-density thickeners, or through a combination of thickening and filtering. The paste point of tailings depends on tailings grain size, mineralogy, specific gravity and other characteristics. Paste tailings typically have a solids content of in the range of about 60 to 75% solids by weight to achieve yield stresses of approximately 200 Pa or greater (MEND, 2017). Additives such as cement may be used to increase the strength of paste tailings for use as underground backfill. Additives may also be used to neutralize acid generation potential in stored tailings.

Paste tailings are typically transported by positive displacement pumps due to the increased viscosity of the tailings. High pressure pipelines comprised of steel or thick wall HDPE are required. The paste tailings pipelines typically discharge from a central location either through risers or from point sources that are raised over the surface of the TSF. Paste tailings generally form a homogenous and non-segregated mass when deposited, with limited volumes of bleed water following deposition. Producing a consistent paste product can be a challenge due to small variations in orebody geology and the percentage of clay sized particles.

Paste tailings disposal facilities typically require the construction of dams or embankments to contain the tailings solids. In many cases, these structures could be lower in height as compared to a slurry tailings impoundment due to the absence of a large supernatant pond.

The initial settled density of the paste tailings may be higher than for a comparable conventional slurry tailings facility but over time paste tailings and slurry tailings have been shown to achieve similar final densities due to self-weight consolidation. In theory, steeper beach slopes of up to 4% may be achieved adjacent to the tailings discharge location with remaining slopes being less than 2% (MEND, 2017). Paste tailings facilities may require smaller embankments than conventional slurry tailings facilities due to reduced water management requirements. However, separate water management ponds are required to manage process water.

Paste tailings facilities need to be designed, operated and closed with the same considerations as conventional slurry tailings facilities. However, paste tailings facilities may be easier and less expensive to reclaim at closure due to better trafficability and reduced capping requirements.

The consequences of a hypothetical dam breach for a paste TSF may be significantly less than a conventional slurry tailings facility due to a much smaller pond volume and the higher yield stress (higher viscosity) for remobilized deposited tailings.

5.0 FILTERED TAILINGS

Filtered tailings are mechanically dewatered to a point at which they no longer behave as a slurry and are more characteristic of a partially saturated soil. Mechanical dewatering is typically achieved through the use of pressure confinement, vacuum filters or centrifuges. Filtered tailings typically have a solids content of 75% by weight or greater for hard rock tailings. The filtered tailings are typically transported by conveyor or hauled by truck to the TSF, where they are placed and compacted as a homogenous, non-segregated and partially saturated mass.

The partially saturated filtered tailings pile must often be stabilized by including outer structural shell/zones to enhance overall perimeter stability. Perimeter berms can be constructed of waste rock or borrow materials to achieve a stable stack. To maintain structural stability, the tailings must be well drained and compacted to minimize the potential for liquefaction due to static and/or seismic loading conditions.

There is the potential for the filtered tailings to creep, slump or liquefy under static and/or seismic loading conditions if high saturation conditions are present and the tailings are loose and contractive. The filtered tailings stack may require isolated cells within the interior of the stack to store contractive tailings solids with high saturation. The isolated storage cells may also be required to store tailings during winter conditions if the tailings cannot be placed and compacted prior to freezing.

Variability in ore, and the resulting tailings, may lead to upset operating conditions in the filter plant. Davies (2011) recommends that a temporary TSF with one to three days capacity be included to store off specification filtered tailings and/or unfiltered tailings to provide operational flexibility. Allowances need to be included to re-slurry the off-spec tailings for reprocessing in the filter plant.

Additional process water tanks or ponds are required at the filter plant to manage the recovered process water. Separate water management ponds are required downstream of the filtered TSF to collect and manage seepage and runoff contact water. The size of the ponds will depend on the site characteristics, TSF design details (i.e. footprint area, constructed diversions, tailings properties, etc.), and climate.

The management of storm events may be challenging as the filtered TSFs need to have significant capacity to temporarily store runoff from storm events. The surface of a filtered tailings facility must be adequately graded to convey precipitation runoff and minimize erosion of the placed tailings. Ditches and sedimentation ponds are required to manage contact water from the facility.

Filtered TSFs are typically constructed, operated and closed similar to a waste rock storage facility or heap leach pad. Filtered tailings stacks may be concurrently reclaimed during construction and are typically more straightforward and less expensive to reclaim at closure due to enhanced trafficability. The consequences of a hypothetical failure of a filtered tailings stack may be significantly less than for a conventional slurry TSF due to the absence of a supernatant pond and the lower mobility (fluidity) of the stored tailings.

6.0 TAILINGS AND WASTE ROCK CO-DISPOSAL

Co-disposal of tailings and waste rock involves managing the materials within the same facility. Co-disposal of tailings and waste rock may include the following:

- Co-mingling: Tailings and waste rock are assumed to be transported and mixed at the storage facility with construction equipment to blend tailings fines into the waste rock voids in order to maximize the in-place waste density.
- Co-placement: Tailings and coarse waste rock are transported to the facility independently and placed within the storage facility. Typical examples include waste rock that is end dumped into a TSF, or the construction of internal berms within a TSF using waste rock to create paddocks for tailings deposition.
- Co-deposition: Waste rock and tailings are placed in individual, alternating layers within the storage facility to create a layered storage facility. This process facilitates ongoing drainage of the tailings solids and allows the tailings to fill some of the waste rock voids. Co-deposition facilities typically require the use of ultra thickened tailings, paste tailings or filtered tailings.

Co-disposal of the tailings and waste rock can achieve a smaller mine waste storage footprint by combining what would otherwise be separate facilities and by increasing the overall density of the mine waste. Waste rock may also be placed or encapsulated within a TSF to reduce oxidation and thus manage PAG waste rock.

Co-mingling of tailings and waste rock can be challenging to achieve on a consistent basis and can be operationally demanding. The appropriate mixture of tailings and waste rock can be critical to maximizing storage efficiency to fill waste rock void spaces and to also maintain rock-to-rock contact in the waste rock to maintain shear strength and stability.

The surface of a facility needs to be adequately graded and ditches and sedimentation ponds may be required to manage contact water from the facility and would be similar to those established for a comparable paste or filtered tailings storage facility. A co-disposal facility is typically constructed, operated and closed in a similar manner to a waste rock storage facility. Co-disposal facilities may be concurrently reclaimed during construction and may be more straightforward and less expensive to reclaim at closure than slurry tailings facilities.

The consequences of a hypothetical failure may be significantly less than other storage facilities if the addition of the waste rock inhibits the potential for the tailings to flow and general slumping would be a more viable failure mechanism.

7.0 REFERENCES

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