PRELIMINARY ENVIRONMENTAL, HEALTH AND SAFETY RISK ASSESSMENT ON THE INTEGRATION OF A PROCESS UTILIZING LOW-ENERGY SOLVENTS FOR CARBON DIOXIDE CAPTURE ENABLED BY A COMBINATION OF ENZYMES AND VACUUM REGENERATION WITH A SUBCRITICAL PC POWER PLANT

TOPICAL REPORT

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Abstract

The results of the preliminary environmental, health and safety (EH&S) risk assessment for an enzyme-activated potassium carbonate (K_2CO_3) solution post-combustion CO_2 capture (PCC) plant, integrated with a subcritical pulverized coal (PC) power plant, are presented.

The expected emissions during normal steady-state operation have been estimated utilizing models of the PCC plant developed in AspenTech's AspenPlus® software, bench scale test results from the University of Kentucky, and industrial experience of emission results from a slipstream PCC plant utilizing amine based solvents. A review of all potential emission species and their sources was undertaken that identified two credible emission sources, the absorber off-gas that is vented to atmosphere via a stack and the waste removed from the PCC plant in the centrifuge used to reclaim enzyme and solvent. The conditions and compositions of the emissions were calculated and the potential EH&S effects were considered as well as legislative compliance requirements. Potential mitigation methods for emissions during normal operation have been proposed and solutions to mitigate uncontrolled releases of species have been considered.

The potential emissions were found to pose no significant EH&S concerns and were compliant with the Federal legislation reviewed. The limitations in predicting full scale plant performance from bench scale tests have been noted and further work on a larger scale test unit is recommended to reduce the level of uncertainty.

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Abbreviations

ACGIH	– American Conference of Governmental Industrial Hygienists
CA	– Carbonic anhydrase
CAA	– Clean Air Act
CERCLA	– Comprehensive Environmental Response and Liability Act of 1980
CWA	– Clean Water Act
DCC	– Direct Contact Cooler
DOE	– Department of Energy
DB	– Doosan Babcock Limited
EH&S	– Environmental, Health and Safety
EPA	– Environmental Protection Agency
EPCRA	– Emergency Planning and Community Right to Know Act
FGD	– Flue Gas Desulfurization
HSS	– Heat Stable Salts
LEPC	– Local Emergency Planning Committee
mg/kg	– Milligrams per kilogram
mg/m^3	– Milligrams per cubic meter
ml/kg	– Milliliters per kilogram
MSDS	– Material Safety Data Sheet
MWe	– Megawatts electric
NETL	– National Energy Technology Laboratory
NIOSH	– National Institute for Occupational Safety and Health
NFPA	– National Fire Protection Association
NPDES	– National Pollutant Discharge Elimination System
OSHA	– Occupational Safety and Health Act
PC	– Pulverized Coal
PCC	– Post Combustion Carbon Capture
PEL	– Permissible Exposure Limit
PFD	– Process flow diagram
PNNL	– Pacific Northwest National Laboratory
PPM	– Parts Per Million
REL	– Recommended Exposure Limit
RQ	– Reportable Quantity
SARA	– Superfund Amendments and Reauthorization Act
SERC	– State Emergency Response Commission
SCR	– Selective Catalytic Reduction
STP	– Standard Temperature and Pressure
TLV	– Threshold Limit Values
TPQ	– Threshold Planning Quantity
TQ	– Threshold Quantity

TSCA	– Toxic Substances Control Act
TWA	– Time Weighted Average
wt%	– Weight percent

List of Exhibits

Executive Summary

A project team, led by Novozymes North America, Inc. in collaboration with Pacific Northwest National Laboratory, University of Kentucky and Doosan Babcock Limited, was awarded DE-FE0007741 to conduct bench-scale tests of a novel potassium carbonate-based post-combustion capture (PCC) process. Aspects of the process include the application of a carbonic anhydrase enzyme catalyst to promote CO_2 absorption in a low enthalpy potassium carbonate-based solvent and the incorporation of a vacuum stripping process to release CO_2 at a moderate temperature to determine the potential energy benefit of a low temperature regeneration process, which could also reduce thermal degradation of the enzyme.

As part of the project a preliminary environmental, health and safety (EH&S) risk assessment for the proposed enzyme-activated potassium carbonate solution PCC plant, integrated with a subcritical pulverized coal (PC) plant was completed to determine any areas of concern in terms of emissions and legislative compliance.

The expected emissions during normal steady-state operation have been estimated utilizing models of the PCC plant developed in AspenTech's AspenPlus® software, bench scale test results from the University of Kentucky's Center for Applied Energy Research, and industrial experience of emission results from a slipstream PCC plant utilizing amine based solvents. A review of all potential emission species and their sources was undertaken that identified two credible emission sources, the absorber off-gas that is vented to atmosphere via a stack and the waste removed from the PCC plant in the centrifuge used to reclaim enzyme and solvent.

The conditions and compositions of the emissions were calculated and the potential environmental, health and safety effects were considered as well as legislative compliance requirements. Potential mitigation methods for emissions during normal operation have been proposed and solutions to mitigate uncontrolled releases of species have been considered.

The gaseous, liquid and solid emissions were quantified and assessed for PCC plant normal operation and were found to pose no concerns in terms of EH&S effects or legislative compliance that would prevent the proposed process from advancing to a further stage of development and evaluation. However, the limitations of scaling up a process from bench scale data to a representative full scale plant are understood and several areas have been identified for further monitoring and measurement on a larger scale demonstration, utilizing the proposed mitigation and separation methods to confirm expected emissions and reduce uncertainty.

Introduction

1.1 Project Overview

The U.S. Department of Energy's National Energy Technology Laboratory (NETL) issued Funding Opportunity Announcement DE-FOA-000403 – "Bench-Scale and Slipstream Development and Testing of Post Combustion Carbon Dioxide Capture and Separation Technology for Application to Existing Coal-Fired Power Plants" to provide financial support to promising CO_2 capture technologies. Sixteen projects were awarded in August 2011 totaling $41 million. A project team, led by Novozymes North America, Inc. in collaboration with Pacific Northwest National Laboratory, University of Kentucky and Doosan Babcock Limited, was awarded DE-FE0007741 to conduct bench-scale tests and techno-economic assessment of a novel potassium carbonate-based post-combustion capture (PCC) process.

Aspects of the process include the application of a carbonic anhydrase (CA) enzyme catalyst to promote CO_2 absorption in a low enthalpy potassium carbonate-based solvent and the incorporation of a vacuum stripping process to release CO_2 at a moderate temperature to determine the potential energy benefit of a low temperature regeneration process, which could also reduce thermal degradation of the enzyme.

1.2 Report Objectives

The aim of this report is to present a preliminary environmental, health and safety (EH&S) risk assessment of an enzyme-activated potassium carbonate (K_2CO_3) solution PCC plant integrated with a subcritical pulverized-coal (PC) power plant.

Due to the nature of many solvents involved in existing carbon capture processes and their by-products, there is a focus on the assessment of the environmental friendliness and safety of the materials and processes of potential technologies.

This report aims to identify all potential ancillary or incidental air, water and solid emissions from the process with magnitudes of emissions estimated. All potential emissions have been investigated to determine potential EH&S effects and the compliance with the following U.S. Federal EH&S laws:

- Comprehensive Environmental Response and Liability Act of 1980 (CERCLA)[1]
- Toxic Substances Control Act (TSCA)[2]
- Clean Water Act (CWA)[3]
- Clean Air Act (CAA)[4]
- Superfund Amendments and Reauthorization Act (SARA) Title III[5]
- Occupational Safety and Health Act (OSHA)[6]

For any potential hazards, an engineering analysis has been undertaken to identify ways in which they can be eliminated or minimized. Handling, storage, treatment and disposal of PCC plant feedstock and waste have also been considered where applicable.

2 Description of the Proposed PCC Process

The purpose of this section is to provide a sufficiently detailed process description of the proposed PCC technology to allow a good understanding of the main components. Exhibit 1 provides a simplified process flow diagram (PFD) to describe the flue gas and solvent paths. The bulk removal of CO_2 from high volume gases by the use of chemical absorbents is a well established technique as used for the “sweetening” of fuel gas throughout the petrochemical industry. This conventional amine based process has been adapted with the application of 23.5 wt% K_2CO_3 solvent, CA enzyme and vacuum stripping technologies.

The CO_2 is absorbed from the flue gases into an aqueous chemical solvent within the CO_2 absorber column removing 90% of the incoming CO_2 with the remaining off-gas discharged to atmosphere through a stack. The soluble CA enzyme accelerates the inter-conversion between dissolved CO_2 and bicarbonate ions, which is the rate-limiting step for absorption and desorption in solutions that rely on ionic complexation of CO_2. The solvent and CA enzyme catalyst collected at the bottom of the absorber tower, the CO_2-laden solvent, termed ‘rich’ solvent, is then passed to a regeneration section where the CO_2 is removed in a vacuum stripper by the application of energy (heat). The now relatively CO_2-free solvent, termed ‘lean’ solvent, is returned to the absorber column. The application of heat in the stripper reverses the inter-conversion between dissolved CO_2 and bicarbonate ions and releases the CO_2 as gas. The CO_2 gas released from the stripper process is then passed to a compression and dehydration system prior to being dispatched for storage or utilized in enhanced oil recovery.

2.1 Flue Gas Conditioning

Flue gas is created by the subcritical PC process, where coal and primary air are introduced into the boiler through wall-fired burners. Prior to the PCC process, NO_x emissions are controlled through the use of low NO_x burners and over-fired air. The flue gas exits the boiler through a selective catalytic reduction (SCR) unit that further reduces the flue gas NO_x concentration before passing through a pulse jet fabric filter to control particulate emissions. Co-benefit mercury capture results in a 90 percent reduction of mercury emissions. An induced draft fan provides the motive force for the flue gas to pass through a wet limestone forced oxidation flue gas desulfurization (FGD) unit to control SO_2 with a removal efficiency of 98 percent. The wet limestone scrubber calcium sulphate by-product is dewatered before being sold as a plaster constituent. The conditioned flue gas is then passed to the PCC process for further conditioning. There is no requirement for a polishing FGD plant prior to the PCC process, as SO_x does not have a detrimental effect on the enzyme-activated K_2CO_3 solvent performance.

2.1.1 Booster Fan

The PCC system requires a booster fan to overcome the pressure drop of the ducting and all components in the flue gas path (direct contact cooler (DCC) and absorber).

2.1.2 Direct Contact Cooler

Flue gas drawn from the PC plant’s FGD unit is too hot (57°C as per NETL Case 10 PCC plant flue gas inlet temperature) to be passed directly to the PCC plant absorber. In order to achieve optimal CO_2 capture performance, the flue gas temperature entering the CO_2 absorber unit must be reduced to the optimum value of approximately 40°C. Without additional gas cooling, the CO_2 capture efficiency and economic performance may be compromised. The flue gas is passed through the DCC, which is a packed bed column where flue gas is contacted with re-circulating cooling water flowing in a counter-current arrangement. The arrangement also provides additional gas cleaning capabilities by removing undesirable soluble species from the incoming flue gas.

The cooling water is introduced at the top of the single packed-bed through a liquid distributor system. The DCC water system consists of a direct cooling loop with heat exchanger banks used to reject heat to the power plant's cooling water circuit. The potential for acidic build-up in the DCC water loop is controlled by continuously purging and refreshing the loop. The initial fill of the circuit is provided from the process water supply. During operation, the DCC unit will generate excess water from the condensation of flue gas moisture due to the reduction in flue gas temperature. The water level in the sump at the base of the column is maintained by discharging water to the station water treatment plant before being returned to the make-up systems for the CO_2 capture process, therefore contributing towards maintaining the water balance in the PCC plant.

2.2 CO_2 Removal System

2.2.1 CO_2 Absorber Column

The absorber column is designed to remove 90% of the CO_2 from the flue gas by absorption into the CA enzyme-activated K_2CO_3 solvent. In the absorber, lean solvent solution, having been discharged from the regeneration section and reduced to a suitable temperature by cooling, is introduced to the structured packing bed by means of a liquid distribution system, which avoids splashing/droplet formation and ensures the even flow of the solvent onto the packing material. The cooled flue gas from the DCC unit enters the bottom of the absorber column horizontally through a special gas inlet nozzle to minimize liquid entrainment above the liquid sump before flowing upwards through the column packed section.

The solvent solution flows down by gravity over metal structured packing and comes into contact in a counter-current fashion with the flue gas flowing upwards within the column. The column consists of four packed sections in total, consisting of three absorption sections and one wash section. To ensure even distribution throughout the total height of the absorber column, solvent collection and re-distribution between each section of packing material is required. The 'rich' solvent collected at the base of the absorber column is pumped by the rich solvent pump through heat exchangers to the regeneration section in order to facilitate solvent regeneration by the application of heat to remove the captured CO_2.

The remaining flue gas passes upwards through a chimney tray into the water wash section where any potential solvent carryover and any impurities are intercepted and removed from the gas stream before the off-gas leaves the absorber through a stack. A slipstream of water exiting the absorber wash section is discharged to the PC plant water treatment plant, with the remainder recycled to the water wash inlet and mixed with fresh make-up water. Fresh K_2CO_3 solvent, including make-up enzyme, is introduced upstream of the absorber in the CO_2-lean solvent line.

2.2.2 Lean / Rich Heat Exchangers

The rich solvent stream is passed through the lean/rich heat exchangers, where heat is recovered from the hot lean solvent leaving the base of the CO_2 regeneration section. The heat exchangers use hot CO_2-lean solvent solution from the lean solvent header to partially heat the CO_2-rich solvent solution leaving the absorber column before it enters the regeneration section.

2.2.3 CO_2 Regeneration Section

The CO_2 absorption by chemical reaction that occurred in the absorber column is reversed by the application of heat within the vacuum stripping column. A vacuum stripping column is utilized to lower the vaporization temperature and allow a lower reboiler operating temperature as well as prolong enzyme life as the enzyme is susceptible to thermal denaturation. The CO_2-rich solvent from the lean/rich heat exchanger is introduced into the top of the stripper section where it is evenly distributed across the column cross section by means of a liquid distribution system. The column utilizes metal random packing as the contact medium with two packed beds down which the solvent trickles. The packed beds are separated by a liquid collector and redistribution system which is needed to correct the natural tendency of the liquid to become mal-distributed. Hot vapor generated in the stripper reboiler, consisting of predominantly water and released CO_2, flows up the stripper section and exchanges heat with the falling rich solvent liquid thereby stripping (releasing) the CO_2 as gas and simultaneously regenerating the solvent as it flows down the packing.

2.2.4 Solvent Reboiler

The reboiler is used to generate a hot vapor stream from the CO_2-lean solvent that is collected at the bottom of the stripper column. It is a plate-type heat exchanger using low pressure steam extracted from the turbine to indirectly heat the CO_2-lean solvent. The steam condensate generated is returned to the power plant for recovery in the appropriate condensate system.

2.2.5 Solvent and Enzyme Reclaimer

In a conventional amine-based absorption/stripping process, in addition to reacting with CO_2, the solvent reacts with O_2 and acid gases, such as NO_2, SO_2 and SO_3 contained in the flue gas, along with any pipework system corrosion products to produce degradation products such as complex salts. The reactions with acid gases and O_2 form heat-stable salts (HSS) that cannot be thermally regenerated. Thus, an additional FGD polisher is required to mitigate HSS formation.

In the proposed process, the enzyme is not susceptible to degradation by SO_x and NO_x and, therefore, an additional PCC plant FGD polisher is not required upstream of the absorption section. However, the enzyme degrades thermally, loses its catalytic activity and needs to be replenished. The denaturation of the enzyme decreases the solvent effectiveness and increases the energy consumption of the capture process. Therefore, a slipstream of the lean solvent is extracted from the system and passed to a centrifuge separator where the deactivated enzyme is removed as a moist solid sludge along with some of the solvent. The remaining ‘cleaned’ solvent is then recirculated back into the make-up system via a recovered solvent storage tank. It is envisaged that solvent make-up consists of fresh solvent and enzyme combined with recovered solvent. The fresh make-up solvent is required to maintain the solvent balance and ensure a constant solvent effectiveness, i.e. enzyme activity.

The solid waste removed in the reclamation process is a bio-degradable solid waste product that can be used for composting or as a fertilizer.

2.2.6 Compression and Dehydration

Since the stripper in the enzyme-activated K_2CO_3 solution PCC process operates under vacuum conditions, an additional single-stage geared compression system needs to be used to achieve the desired downstream CO_2 pressure target in order to meet the required input operating conditions for the CO_2 compression and dehydration process. In the compression section, the CO_2 is compressed by a six-stage centrifugal compressor with inter-stage cooling. During compression, the CO_2 stream is dehydrated to a dew point of -40°C with triethylene glycol.

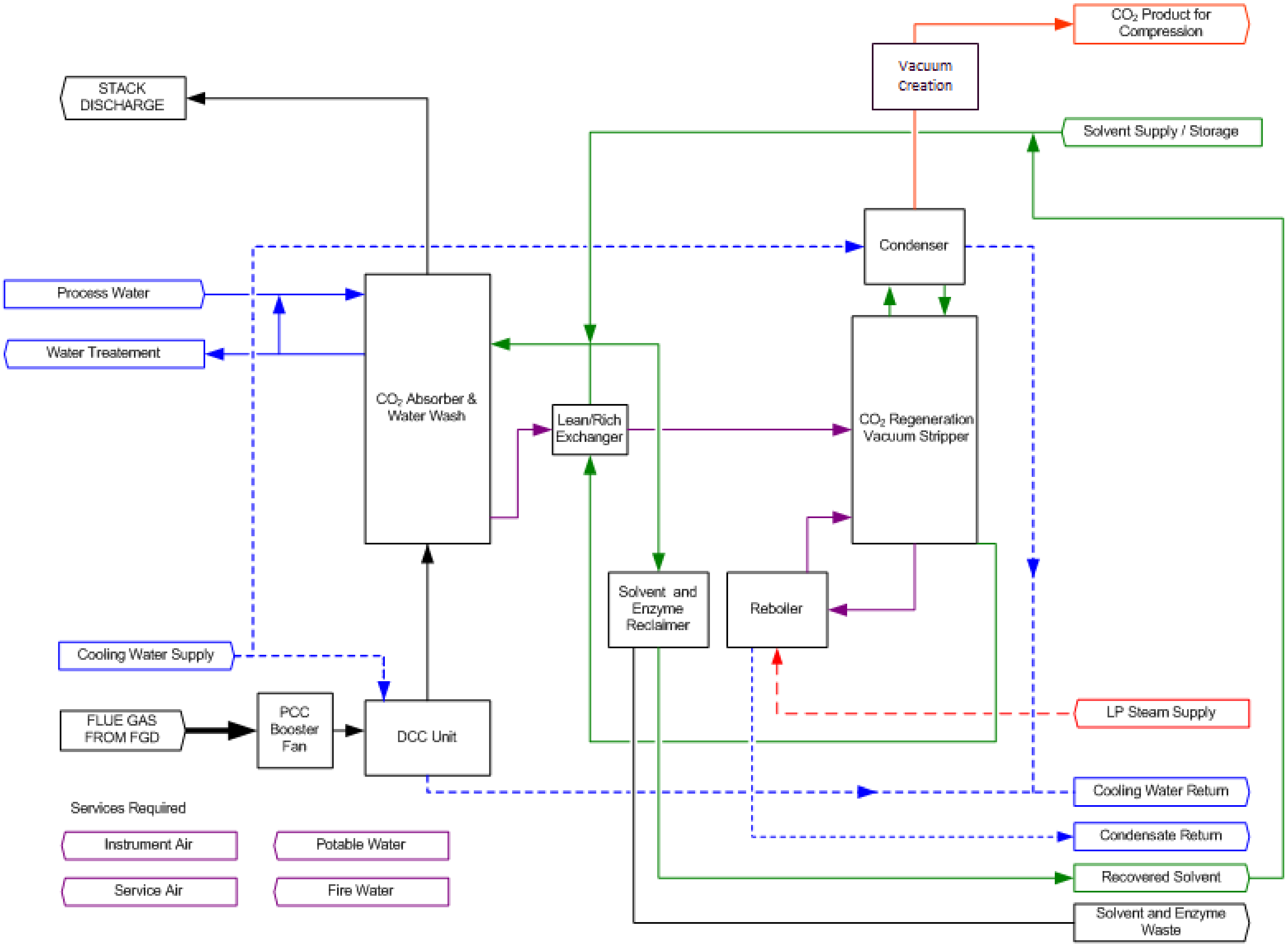


Exhibit 1 Simplified PFD of PCC Plant

3 Potentially Emitted Species

A review of potential species that could be emitted from the PCC process, the sources of the emissions and potential mitigation was undertaken. Areas of the plant where trace amounts of material could be released have been ignored for the purposes of the study. Exhibit 2 gives an overview of the PCC process with potential species emissions, their sources and possible mitigation measures.

Following the identification of potentially emitted species, a literature review was undertaken to identify the EH&S effects of the species. As part of the review, material safety data sheets (MSDSs) were sourced and used to populate Exhibit 3.

Exhibit 3 identifies the potentially emitted species, the sources of emissions, physical states of emissions, the EH&S effects of the species emitted, pertinent properties of the species and the National Fire Protection Association (NFPA) 704 Standard System for the Identification of the Hazards of Materials for Emergency Response categorization[7]. The NFPA 704 Rating acts as a quick visual reference to the potential hazards with a rating of 0 (Least Hazardous) to 4 (Most Hazardous). The Diamond is formed of four colours – red, blue, yellow and white representing flammability, health, reactivity and any special notices, respectively. Special notices are categorised as OX (Oxidiser), W (reacts with water in a dangerous manner) and SA (Asphyxiant).

Exhibit A1 shows the risk assessments carried out for each potential emission species with proposed mitigation measures that have been considered to reduce emission risks.

Notes
[1] As is – no concerns
[2] Very small quantities expected during normal operation – Single Stage Water Wash and demister proposed to ensure no emissions during transient cases
[3] Recycled to maintain PCC plant water balance
[4] Solvent to be recovered following treatment in centrifuge and returned to plant solvent make-up
[5] Enzyme to be separated following treatment in centrifuge; solids exported as biomass product
[6] Water to undergo treatment at PC Plant water treatment facility prior to discharge

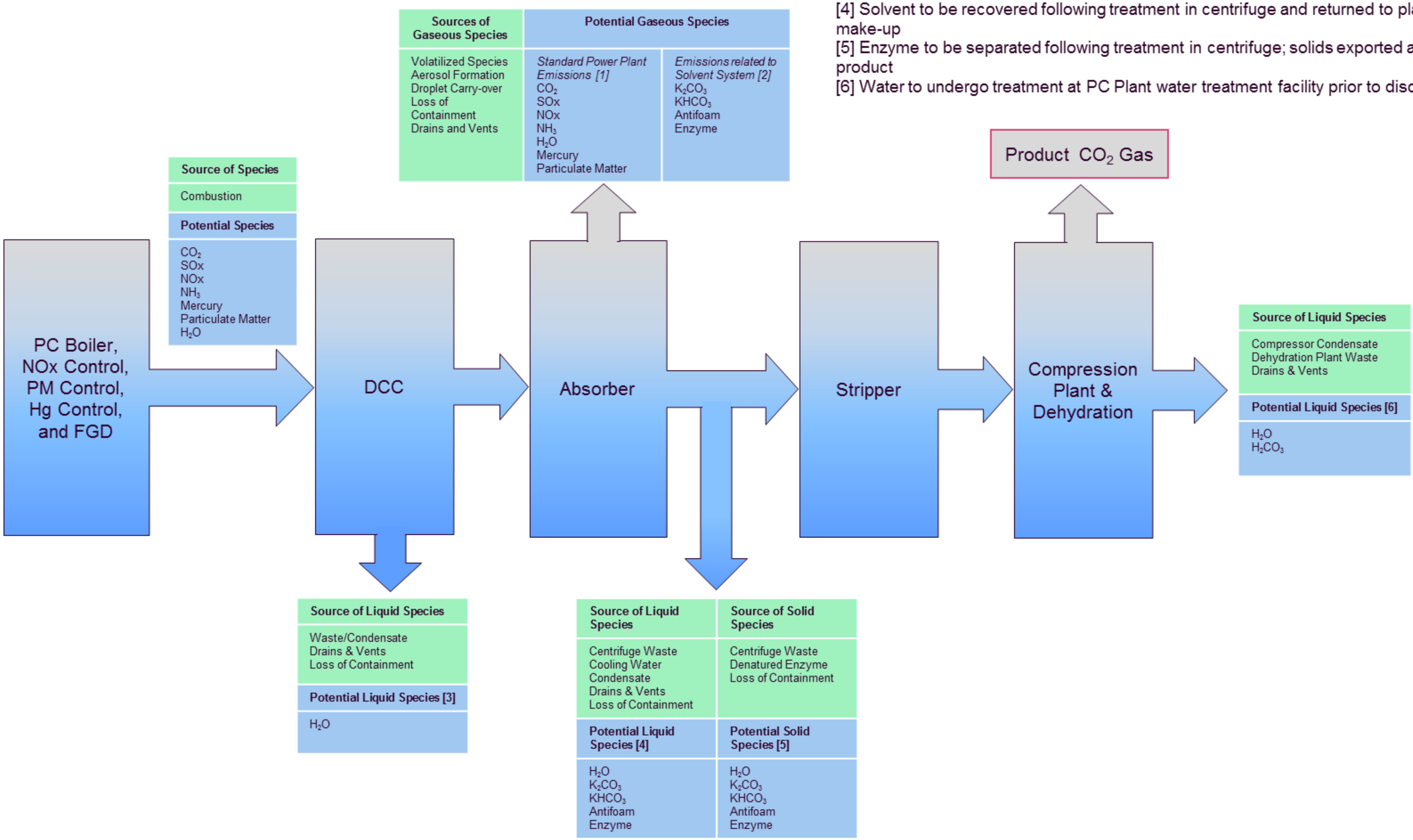
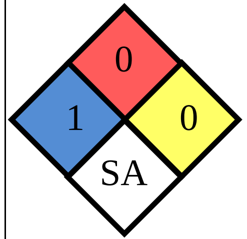
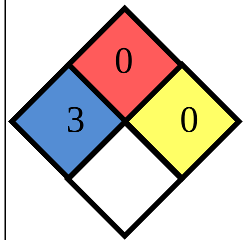
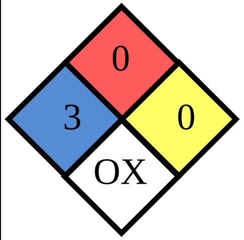
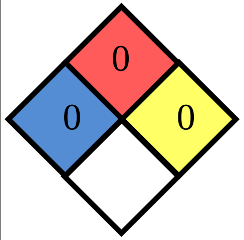
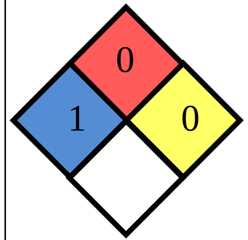


Exhibit 2 Capture Plant Overview with Potential Emissions, Sources and Mitigation

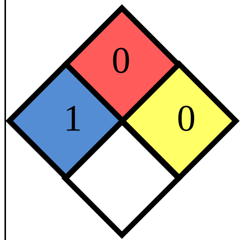
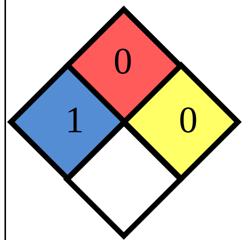
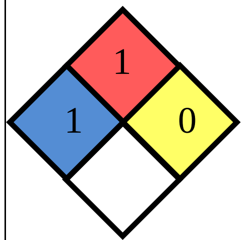
Exhibit 3 Table of Potential Emission Species

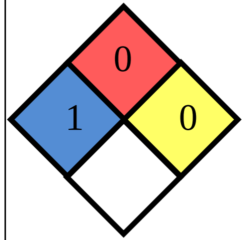
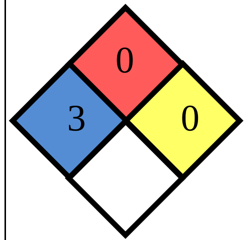
Species	Source of emission	State of species	Toxicological effects	Potential Human Health Effects		Ecotoxicity	Stability and Reactivity	Physical Properties	NFPA Rating
Carbon Dioxide (CO_2)[8]	Normal Stack Product Unplanned Vents Loss of containment	Gas	Lowest Lethal Concentration (LC_{LO}) in humans = 90,000 ppm for 5 minutes	Inhalation	Asphyxiant gas in large concentrations and can cause rapid suffocation.	No known effects. CO_2 does not contain any ozone depleting chemicals.	Chemically stable. Hazardous reactions may occur.	Colorless, odorless gas.	
				Skin/Eye Contact	No harm expected from vapor. Cold gas may cause frostbite.				
				Ingestion	Unlikely route of exposure.				
Oxides of Sulfur (SO_x)[9]	Normal Stack Unplanned Vents Loss of containment	Gas	Median Lethal Concentration (LC_{50}) in rats = 2520 ppm for 1 hour	Inhalation	Life-threatening at high dosage, may result in fluid build-up in lungs and paralysis. Aggravates asthma.	Toxic to fish, algae and detrimental to plant growth.	Stable at standard temperature and pressure (STP).	Colorless, choking gas with irritating odor.	
				Skin/Eye Contact	May irritate eyes and cause inflammation. May burn skin and aggravate existing dermatitis.				
				Ingestion	Unlikely route of exposure. Highly toxic.				

Oxides of Nitrogen (NO_x)[10]	Normal Stack Unplanned Vents Loss of containment	Gas	LC_{50} in rats = 870 ppm for 4 hours	Inhalation	Gas mixture is toxic. Pulmonary damage and breathing difficulty can occur. Permanent lung injury may occur as result of over-exposure.	All release to terrestrial, atmospheric and aquatic environments should be avoided. Undergoes pyrolysis which leads to production of ozone and smog conditions in atmosphere.	Stable at STP. Dissolves in water to form nitric acid (acid rain).	Colorless gas with irritating odor	
				Skin/Eye Contact	May cause burns in presence of moisture. Swelling of eye tissue may occur.				
				Ingestion	Unlikely route of exposure.				
Water (H_2O)[11]	Normal Reclaimer Plant Water treatment Condensate Unplanned Vents Drains Loss of containment	Liquid Gas	Median Lethal Dose (LD_{50}) in rats = 90 ml/kg	Inhalation	Not corrosive, irritating or sensitive to lungs.	Freshwater is now scarce in many regions of the world, the PCC process has a positive water balance allowing for a reduction in plant water consumption.	Stable & non-reactive.	Clear, colorless, odorless liquid.	
				Skin/Eye Contact	No adverse effect.				
				Ingestion	No adverse effect.				

Carbonic Acid (H_2CO_3) [12]	Normal Compressor condensate Unplanned Vents Drains Loss of containment	Liquid	Median Lethal Dose (LD_{50}) in rats = 90 ml/kg	Inhalation	May cause irritation.	May contribute to greenhouse effect if discharged in large quantities. Not listed as a marine pollutant.	Stable under normal conditions of use & storage. Avoid excessive temperatures & exposure to air.	Clear, colorless, odorless liquid.	
				Skin/Eye Contact	May cause slight irritation.				
				Ingestion	May cause irritation.				

Note: Data provided is estimated based on likely dilute nature (similar to simulated Acid Rain)

Potassium Carbonate (K_2CO_3) [13]	Normal Reclaimer Unplanned Stack Vents Drains Loss of containment	Solid Liquid Entrained liquid Aerosol	LD_{50} = 1870 mg/kg, rat	Inhalation	Not expected to be hazardous.	Hazardous to aquatic organisms. Long term degradation products may arise which are less toxic than the compound itself.	Stable under normal conditions of use & storage.	Colorless, odorless liquid.	
				Skin/Eye Contact	Irritation to skin & eyes. May cause permanent eye damage.				
				Ingestion	Large doses may cause gastrointestinal irritation. Excessive ingesting may cause ulcerations and death.				
Potassium Bi-Carbonate ($KHCO_3$) [14]	Normal Reclaimer Unplanned Stack Vents Drains Loss of containment	Solid Liquid Entrained liquid Aerosol	LD_{50} > 2000 mg/kg, rat	Inhalation	May cause respiratory tract irritation.	Generally recognized as safe.	Stable under normal conditions of use & storage.	White granular solid, odorless.	
				Skin/Eye Contact	May cause irritation.				
				Ingestion	May cause irritation of digestive tract.				
Enzyme[15]	Normal Reclaimer Unplanned Stack Vents Drains Loss of containment	Solid Liquid Entrained liquid Aerosol		Inhalation	May cause sensitization and an allergic respiratory reaction.	Bio-degradable.	Stable under normal conditions of use & storage. No possibility of hazardous reactions.	Brown liquid with slight fermentation odor.	
				Skin/Eye Contact	May cause mild irritation.				
				Ingestion	May cause gastrointestinal irritation.				

Antifoam [16]	Normal Reclaimer Unplanned Stack Vents Drains Loss of containment	Liquid Entrained liquid Aerosol Gas	LD_{50} > 5000 mg/kg, rat	Inhalation	No adverse effects from short term exposure. May cause lung damage.	Mineral oil is the main ingredient. Considered to be slightly toxic.	Stable.	Opaque white liquid, mild organic odor.	
				Skin/Eye Contact	Mild irritation.				
				Ingestion	May cause a laxative effect.				
Mercury [17]	Normal Stack Unplanned Vents Drains Loss of containment	Gas	LD_{50} = 25.9 mg/kg, rats	Inhalation	Causes chemical burns to the respiratory tract.	Harmful to aquatic life from very low concentration	Stable under atmospheric conditions. Avoid high temperatures.	Odorless heavy liquid.	
				Skin/Eye Contact	Irritation & possible burns.				
				Ingestion	May cause severe and permanent damage to the digestive tract				

Pulverized Coal Ash[18]	Normal Stack Unplanned Vents Drains Loss of containment	Solid Particles in Gas Stream	No toxicological disease or condition reported to date.	Inhalation	May cause nose, throat or lung irritation.	Has a phototoxic effect but rapidly diminishes with weathering. Alkaline solution formed when released in water. Toxic to aquatic life.	Stable under atmospheric conditions. Inert glassy particulate material.	Fine gray odorless powder.	
				Skin/Eye Contact	Dust in high concentrations may cause eye irritation. Little effect on skin, prolonged contact may cause irritation.				
				Ingestion	No known adverse effects.				

4 Gaseous Emissions

The review shown in Exhibit 2 determined all species that could be expected to be either emitted as a gas or entrained within the gas stream. Expected emissions during normal steady-state operation have been estimated utilizing models of the PCC plant developed in AspenTech's AspenPlus® software, bench scale test results from the University of Kentucky, and industrial experience of emission results from a slipstream PCC plant utilizing amine-based solvents. Emissions during process upset conditions have not been included in the scope of the study although mitigation methods to minimize emissions in transient cases have been considered.

4.1 Species, Sources and Magnitudes of Emissions

Prior to the capture plant, SO_2 emissions are controlled using a wet limestone forced oxidation scrubber that achieves a removal efficiency of 98 percent. The calcium sulphate by-product is dewatered before being sold as a plaster constituent. NO_x emissions are controlled through the use of low NO_x burners and over-fired air. A SCR unit then further reduces the flue gas NO_x concentration. Particulate emissions are controlled using a pulse jet fabric filter, which operates at an efficiency of 99.8 percent. Co-benefit mercury capture results in a 90 percent reduction of mercury emissions.

The PCC plant removes 90 percent of the incoming CO_2 which ultimately becomes the CO_2 product stream leaving the compression plant. The CO_2 product exits the stripper and passes through a water wash stage and then a condenser. The CO_2 product quality is strictly controlled by the process prior to compression and export for enhanced oil recovery or storage, and as a result is not considered a plant emission for the purposes of this study.

There is one location from which gaseous species and liquids entrained in gases can be emitted during normal operation, the off-gas leaving the top of the absorber through the stack. In addition to absorber off-gas stack emissions, unplanned releases can occur from vents or loss of containment.

The potential species leaving the stack as gases are typical PC plant emissions and as such are well understood. Nitrogen, argon, oxygen and moisture have been ignored here as they are abundant in air and pose no EH&S risks at the plant operating conditions. The remaining expected gaseous species emissions are all similar to the levels that would be emitted from an equivalent PC power plant, other than CO_2, which is removed in the PCC plant. The gases are emitted from the absorber off-gas stack at ambient pressure and a temperature of 40°C. The expected magnitudes of the gaseous species emissions leaving the absorber off-gas stack after the PCC process are shown in Exhibit 4, the values are based on the anticipated output from a 685 MWe power plant with an 85% capacity factor that delivers a net output of 550 MWe and 90% CO_2 capture.

	kg/GJ (lb/10^6 Btu)	Tonne/year (Ton/year) 85% CF	kg/MWh (lb/MWh)
SO_2	0.037 (0.085)	1,795 (1,979)	0.353 (0.778)
NO_x	0.03 (0.07)	1,467 (1,617)	0.288 (0.636)
Particulates	0.006 (0.013)	273 (300)	0.054 (0.118)
Hg	4.95E-07 (1.15E-06)	0.024 (0.027)	4.76E-06 (1.05E-05)
CO_2	8.5 (19.7)	414,411 (456,810)	81 (180)
CO_2[1]			101 (223)

[1] CO_2 emissions based on net power instead of gross power

Exhibit 4 Anticipated PCC Plant Gaseous Emissions

Another potential route for emissions leaving the absorber off-gas stack comprises liquid droplets entrained in the off-gas stream. This is caused by the velocity of the flue gas passing up through the absorber and contacting the solvent, which flows down through the absorber over high surface area packing material, generating liquid droplets. Volatilisation of the K_2CO_3 solvent, enzyme or antifoam is not considered to be a credible route for emissions due to the low or non-volatility of the components and the absorber operating conditions.

Uncontrolled releases due to venting or loss of containment cannot be quantified at this stage, but the likelihood of an uncontrolled release event occurring can be reduced by ensuring good engineering practice in the design and implementation of robust operating procedures. All vents and drains would be routed to safe, controlled locations or safe elevations and, as a minimum safety measure, permanent CO_2 monitors would be provided across the PCC and Compression plants.

The only other credible cause for emissions in the off-gas is due to the formation of aerosols from the SCR, FGD or within the PCC plant itself. The potential for aerosol formation and control cannot be estimated at this stage and it is not known whether a simple single-stage water wash and demister would eliminate the emissions during transient cases in their entirety. However, given the benign nature of species utilized in the capture plant and the likely small quantities released during transient operation, the formation of aerosols is not likely to cause EH&S concerns. During normal operation there are not expected to be any liquid species emitted entrained in the off-gas.

The potential for aerosol formation and implementation of more advanced water wash strategies should be investigated further with experimental evidence and measurement from larger-scale demonstrations, particularly with regard to the presence of enzyme in the solvent. Any future study would have to monitor enzyme-containing aerosol emissions in the off-gas to ensure that they do not exceed the generally accepted exposure limit, and demonstrate that the proposed engineering controls to prevent such emissions are adequate. In the case of absorber off-gas stack emissions, which are physically remote from personnel, dispersion modelling would have to be undertaken to ensure any expected releases do not result in personnel exposure levels exceeding the generally accepted limits.

4.2 Management and Mitigation

During normal operation, management and mitigation of gaseous or gas-borne emissions is not considered to be required. Transient conditions occurring in the plant may result in aerosol formation or foaming, which could have the potential to cause emission spikes of entrained components and as a result a number of measures have been considered to ensure that any emissions are minimized. A water wash stage and demister are proposed for the top of the absorber column, an antifoam agent is dosed into the solvent system and the design proposed for the column liquid distribution is such as to minimize droplet formation. With all of these controls in place, it is anticipated that stack emissions as a result of entrained droplets will be minimized. However, further experimental evidence and measurement of emissions on a larger-scale demonstration plant would be required to determine whether a more advanced water wash system is necessary to eliminate emissions due to aerosol formation during upset conditions.

4.3 Handling and Storage

There are no requirements for bulk storage of gaseous substances foreseen as part of the PCC plant and so no specific handling and storage measures are required.

5 Liquid Emissions

The anticipated liquid emissions were determined and quantified utilizing the same methodology as for gaseous emissions described in Section 4.

5.1 Species, Sources and Magnitudes of Emissions

The first potential source of liquid emissions from the PCC plant is when the incoming flue gas from the PC boiler enters the DCC. In the DCC, the temperature of the flue gas is reduced to 40°C, for optimal CO_2 absorption conditions, by directly contacting the flue gas with water. As a result of the cooling, the moisture in the flue gas is condensed and leaves the bottom of the DCC along with the spray water. Most of the water is retained in the DCC spray water loop with a slipstream taken to supplement the absorber water wash. The remainder is sent to supplement the PC boiler water make-up following treatment in the PC plant water demineralization plant, as there is potential for a trace amount of flue gas acidic gases to be present in the condensate. Due to the volume of condensate, despite the potential presence of dissolved acidic gases, the concentrations are expected to be within limits specified for PC boiler water treatment. The models do not predict any acid gas removal and operational experience on a slipstream scale amine-based PCC plant has shown that very little removal of acidic gases takes place. As a result, no water emissions are anticipated from the DCC and the PCC plant is expected to have a net positive water balance, reducing the PC boiler water make-up requirements.

The second source of water produced in the PCC plant is from the water wash stage of the absorber. The water wash is a loop system in which water is cycled to physically remove any droplets entrained in the gas stream exiting the absorber. The water wash loop has a small bleed stream that is replenished with make-up water. The emissions expected here are trace amounts of enzyme, antifoam, K_2CO_3 and potassium bicarbonate ($KHCO_3$) with almost all the remaining waste stream being water. Analysis of the water wash bleed stream needs to be carried out on a larger-scale process demonstration plant to determine the expected levels of emissions. During normal operation, there are unlikely to be any emissions aside from a process water bleed. It is proposed to recycle the waste wash water to the boiler feed water system following demineralization in the PC boiler water treatment plant.

The third source of water produced in the PCC plant is from the compressor inter-stage coolers where condensate is removed from the CO_2 product stream before export. Again, there is potential for the condensate to be slightly acidic due to the presence of H_2CO_3, although again, the model is not able to predict the acidity. As with the DCC condensate, it is proposed to utilize the compressor condensate within the PCC plant for water make-up with excess being sent along with DCC condensate to the PC boiler water treatment plant to undergo demineralization for use as boiler feed water.

The final source of liquid emissions in the PCC plant is from the enzyme and solvent reclaimer. During normal operation of the PCC plant, the enzyme degrades thermally, loses its catalytic activity and needs to be replenished. The loss of enzyme activity decreases the solvent effectiveness and increases the energy consumption of the capture process and causes a build-up of solids that have to be removed. Maintaining balance in the system requires replenishment with fresh enzyme and removal of produced solids. To do this, a slipstream of lean solvent is extracted from the system and passed to a centrifuge separator where the deactivated enzyme is removed as a moist solid sludge along with some K_2CO_3 solution.

Using wet solids removal and solvent flow rate data from the bench-scale unit constructed and operated during this project, lab-scale thermal cycling tests, enzyme thermal degradation rates observed, and model predicted solvent flow rates; the amount of liquid removed during centrifuge separation has been estimated and is displayed in Exhibit 5 (see Section 6). The liquid emissions will consist of water, K_2CO_3 and $KHCO_3$ solution, enzyme in solution and antifoam in suspension, although these cannot be easily quantified as the waste is removed as a wet solid for which there is currently insufficient data to provide accurate quantities of constituent components.

The anticipated emissions are based on a slipstream to be sized for removal of solids at the rate of production and enzyme denaturation after taking typical centrifuge separator solid removal efficiency into account. To eliminate the uncertainty regarding exact quantities and compositions, the application of a centrifuge separator should be tested on a larger-scale demonstration plant with the emissions measured and closely monitored. The emissions will leave the plant at ambient temperature and pressure.

The ultimate fate of the liquid species is dependent on the final destination of the wet solids waste stream. The preferred route is to create an additional product stream from the waste, much like the gypsum product stream from the FGD waste. It is proposed that the liquids, as part of the wet solids, are removed by tanker for composting applications or fertilizer where any potassium content would provide a benefit and the antifoam would have no negative effect. The product potential of any waste stream would have to be evaluated once confirmed compositions and quantities had been determined from a larger-scale process plant employing the proposed separation technology. If the formation of a product stream is not viable, then it is proposed that the wet solids waste be removed from the plant by a specialist contractor for disposal as landfill.

As for gaseous emissions, uncontrolled releases due to venting or loss of containment cannot be quantified at this stage, but the likelihood of an uncontrolled release event occurring can be reduced by ensuring good engineering practice in the design and implementation of robust operating procedures. All vents and drains would be routed to safe, controlled locations or a safe elevation and, as a minimum safety measure, the entire capture plant would be bermed to a level that provides a volume larger than the entire system inventory. In addition, it is proposed to have intermediate storage tanks that are utilized during start-up and shut-down operations, but can also be used to store system inventory in emergencies during normal plant operation. Also, testing to measure the level of environmental toxicity shall be undertaken as a precaution, to establish an appropriate response plan in the event of an accidental release of the enzyme product and the process solvent containing the enzyme due to berm failure.

5.2 Management and Mitigation

During normal operation, management and mitigation of liquid emissions is not considered to be required although the viability of the establishment of a reclaimer waste product stream will have to be analyzed further when more data are gathered with regard to the proposed separation methodology and potential value of the waste product stream.

As an extra layer of protection, a closed-loop cooling water system could be employed to ensure any leakages across heat exchangers are contained within a monitored PCC plant system and therefore no liquid discharges containing solvent and enzyme are made to the PC plant water system.

5.3 Handling and Storage

There are a number of liquids to be handled and stored as part of the PCC process. It is proposed that all solvent and enzyme is off-loaded in a designated area with its own drainage system to minimize any potential for uncontrolled emissions. Solvent, antifoam and enzyme are to be delivered by road tanker and the solvent and enzyme storage vessels will have nozzles to which the tanker can connect before unloading to minimize the chance for any emissions. The main precaution in handling the enzyme in particular is to avoid exposure by inhalation, because like common household allergens, enzymes are proteins that can cause allergic reactions similar to hay fever in some individuals. It is believed that the above precautions should eliminate risk to personnel, but respirators equipped with HEPA or P100 cartridges may be required in the unloading operations of fresh solvent and enzyme.

6 Solid Emissions

The anticipated solid emissions were determined and quantified utilizing the same methodology as for gaseous and liquid emissions described in Sections 4 and 5.

6.1 Species, Sources and Magnitudes of Emissions

There is only one source of solid emissions during normal operation of the PCC plant and that is the waste stream from the solvent and enzyme reclaimer. During normal operation of the PCC plant, the enzyme degrades thermally, loses its catalytic activity and needs to be replenished. The loss of enzyme activity decreases the solvent effectiveness and increases the energy consumption of the capture process, and causes a build-up of solids that have to be removed. To do this, a slipstream of lean solvent is extracted from the system and passed to a centrifuge separator where the deactivated enzyme is removed as a moist solid sludge along with some K_2CO_3 solution.

Using wet solids removal and solvent flow rate data from the bench-scale unit, lab-scale thermal cycling tests, the observed enzyme thermal degradation rates and model-predicted solvent flow rates, the amount of solid removed during centrifuge separation has been estimated and is displayed in Exhibit 5 as follows:

Species	Anticipated Emissions at 85% capacity factor Tonne/year (Ton/year)
Denatured Enzyme	125.7 (138.6)
Enzyme / K_2CO_3 / $KHCO_3$ / Antifoam / H_2O	712.5 (785.4)
Total Wet Solids	838.2 (924.0)

Exhibit 5 Anticipated PCC Plant Wet Solid Emissions

The solid emissions will consist of K_2CO_3 salt, denatured enzyme, enzyme and antifoam although these cannot be easily quantified as the waste is removed as a wet solid for which there is insufficient data to provide exact quantities of constituent components.

The anticipated emissions are based on a slipstream to be sized for removal of solids at the rate of production and enzyme denaturation after taking typical centrifuge separator solid removal efficiency into account. To eliminate the uncertainty regarding exact quantities and compositions, the application of a centrifuge separator should be tested on a larger-scale demonstration plant with the emissions measured and closely monitored. The emissions will leave the plant at ambient temperature and pressure.

The ultimate fate of the solid species is dependent on the final destination of the moist solid sludge waste stream. The preferred route is to create an additional product stream from the waste, much like the gypsum product stream from the FGD waste. It is proposed that the moist solids be removed by road tanker for composting applications or fertilizer where the potassium content would provide a benefit and the antifoam would have no negative effect. The product potential of any waste stream would have to be evaluated once confirmed compositions and quantities had been determined from a larger-scale process demonstration plant employing the proposed separation technology. If the formation of a product stream is not viable then it is proposed that the solid sludge be removed from the plant by a specialist contractor for disposal as landfill. This waste stream would be considered as non-hazardous.

As for gaseous and liquid emissions, uncontrolled releases due to loss of containment cannot be quantified at this stage, but the likelihood of an uncontrolled release event occurring can be reduced by ensuring good engineering practice in the design and implementation of robust operating procedures. All drains would be routed to safe, controlled locations, and as a minimum safety measure the entire capture plant would be bermed to a level that provides a containment volume larger than the entire system inventory. Also, testing to measure the level of environmental toxicity shall be undertaken as a precaution, to establish an appropriate response plan in the event of an accidental release of the enzyme product and the process solvent containing the enzyme due to berm failure.

6.2 Management and Mitigation

During normal operation, management and mitigation of solid emissions is not considered to be required, although the viability of the establishment of a reclaimed waste product stream will have to be analyzed further when more data is gathered with regard to the proposed separation methodology and potential value of the waste product stream.

6.3 Handling and Storage

The reclaimer waste, after undergoing separation by centrifuge, is passed to a reclaimer waste storage tank. It is proposed that the reclaimer waste is loaded in a designated area with its own drainage system to minimize any potential for uncontrolled emissions. Solvent and enzyme are to be removed by road tanker and the reclaimer waste tanks will have nozzles to which the tanker can connect before unloading to minimize the chance for any emissions. Additional nozzles will be provided to allow water wash connections to be made to ensure all waste is removed from the tanks. The main precaution in handling the enzymes in particular is to avoid exposure by inhalation because, like common household allergens, enzymes are proteins that can cause allergic reactions similar to hay fever in some individuals. It is believed that the above precautions should eliminate risk to personnel, but respirators equipped with HEPA or P100 cartridges may be required in the unloading operations for the removal of reclaimer waste.

7 Legislative Compliance

Following the identification of the potential emissions and levels the following U.S. Federal laws were reviewed to ensure compliance:

- Occupational Safety and Health Act (OSHA)
- Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA)
- Superfund Amendments and Reauthorization Act (SARA) Title III
- Clean Water Act (CWA)
- Clean Air Act (CAA)
- Toxic Substances Control Act (TSCA)

7.1 Occupational Health and Safety Act

OSHA, came into effect in 1970 and is in place to ensure safe and healthful working conditions for all employees. A sub-part within the Act is Toxic and Hazardous Substances, including air contaminants in the workplace. Exhibit 6 lists all the identified potential emitted substances from the capture plant with the accompanying permissible exposure limits (PELs) set out by the Act.

The OSHA PELs can be considered outdated and inadequate as the figures have not been updated since 1970 when the Act was created. OSHA therefore recommends that employers consider using alternative occupational limits that may serve to better protect workers. The alternative limits have been taken from two recognized organizations that OSHA recommends. The first organization is the National Institute for Occupational Safety and Health (NIOSH), a U.S. Federal agency responsible for conducting research for the prevention of work-related injuries that has provided recommended exposure limits (RELs), as shown in Exhibit 6. The other recognized organization is the American Conference of Governmental Industrial Hygienists (ACGIH) and they are a scientific association established to advance worker protection by developing guidelines to promote the control of occupational health hazards. The ACGIH guidelines contain threshold limit values (TLVs), which are the air concentration levels of a substance that an employee can be exposed to on a day-to-day basis during their working life, without any adverse effects.

7.2 Comprehensive Environmental Response, Compensation and Liability Act

CERCLA, commonly known as Superfund, authorizes the U.S. Environmental Protection Agency (EPA) to respond to any potential releases of hazardous substances that relate to public health, welfare or the environment. The CERCLA also permits the EPA to force any parties to clean up waste sites or face reimbursement for resultant costs for remediation carried out by the EPA. Various sections of the CERCLA were revised in 1986 by the Superfund Amendments and Reauthorization Act (SARA) which included extending the taxing authority for the Superfund.

7.3 Superfund Amendments and Reauthorization Act (SARA) Title III

The amendment of CERCLA to SARA also created a free-standing law named SARA Title III, also known as the Emergency Planning and Community Right-to-Know Act (EPCRA). This law created an emergency planning structure to allow the public and local governments access to information regarding hazardous chemicals and potential releases within the community. The EPCRA also requires a facility to document, notify and report on the storage, use and releases of hazardous chemicals to federal, state and local governments.

Any facility that has an extremely hazardous substance, as defined by the EPCRA, at or above threshold planning quantity (TPQ) needs to notify, for the purposes of emergency response planning, the State Emergency Response Commission (SERC) and the Local Emergency Planning Committee (LEPC). Any facility producing, using, or storing a hazardous chemical, as defined by the OSHA, that releases a reportable quantity (RQ) of an extremely hazardous substance must immediately notify the LEPC and SERC. The TPQs and RQs for the activated-potassium carbonate PCC process potentially emitted species are listed in Exhibit 6. A release can be defined as any spilling, leakage, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping or disposing into the environment. The RQ of a substance was developed as a quantity that when released, poses potential threat to human health and the environment. The TPQs for emergency planning provisions were designed to help States and local communities focus their planning efforts.

7.4 Clean Water Act

The Clean Water Act (CWA) establishes the basic structure for governing water pollution in the United States. The Act was created in 1972 in order to regulate quality standards for surface waters and allows EPA to implement pollution control programs such as setting wastewater standards for industry. The CWA regulates both direct and indirect discharges and a permit system is set up for states to discharge pollutants, named National Pollutant Discharge Elimination System (NPDES). These permits must be obtained in order to discharge directly into surface waters. The RQs for the CWA are shown in Exhibit 6 and are similar to the EPCRA regulations whereby a release can be defined as any spilling, leakage, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping or disposing into surface waters.

7.5 Clean Air Act

The Clean Air Act (CAA) was established in 1970 in order to regulate air emissions from stationary and mobile sources. The EPA is responsible for enforcing the Act to protect public health and to regulate emissions of hazardous air pollutants; however, individual states are allowed to elect responsibility for compliance with the regulation of the CAA. Exhibit 6 gives the threshold quantities (TQs) of hazardous substances contained in the CAA register, which are the limits of specific toxic chemicals that can be used during the calendar year before additional reporting requirements are imposed.

7.6 Toxic Substances Control Act

The Toxic Substances Control Act (TSCA) of 1976 was introduced to regulate the introduction of new or existing chemicals. The inventory is a list of each chemical substance that is manufactured or processed in the U.S., compiled by the EPA. The Act enforces EPA to have the authority to report, record-keep and test requirements relating to the inventory of chemical substances. Exhibit 6 lists the species potentially emitted from the activated-potassium carbonate PCC process. It can be seen that all the potentially emitted species are listed on the TSCA inventory.

7.7 Legislative Requirements for Potential PCC Plant Emissions

Exhibit 6 tabulates the legislative requirements of all the PCC plant potentially emitted species, the following points should be noted:

- OSHA PELs are 8-hour time weighted averages (TWA) unless denoted with a (C), which is the ceiling limit for the particular substance (the ceiling limit is the concentration of a substance that should not be exceeded at any time).
- PPM is parts of vapor or gas per million parts of contaminated air by volume at $25^{o}C$ and 1 atm.
- mg/m^3 is the milligrams of substance per cubic meter of air at $25^{o}C$ and 1 atm. The value quoted for enzyme is the Derived Minimal Effect Level (for peak exposure) and is an accepted Threshold Limit Value (TLV) for Industrial practice.
- For the SARA Title III: Extremely Hazardous Substances both the RQ and TPQ values quoted are to be measured over a 24 hour period.
- RQs for the CWA: Hazardous Substances are measured over a period of 24 hours.
- The TQ values quoted for the CAA: Regulated substances are measured over a calendar year with the value for mercury being the only exception, which is measured over a 24 hour period.

Potentially Emitted Species	OSHA: PELs for Air Contaminants[19]		Recommended Occupational Limits[20]		SARA Title III: Extremely Hazardous Substances[21]		CWA:Hazardous Substances[22]	CAA: Regulated Substances[23]	TSCA Inventory[24]
			NIOSH RELs	ACGIH® TLVs					
	ppm	mg/m^3	Up to 10-hour TWA	8-hour TWA	RQ, lbs	TPQ, lbs	RQ, lbs	TQ, lbs	Y/N
Carbon Dioxide, CO_2	5000	9000	5000 ppm	5000 ppm	None listed	None listed	None listed	None listed	Y
Sulphur Oxides, SOx	5	13	2 ppm	None listed	500	500	None listed	5000	Y
Nitrogen Oxides, NOx	5 (C)	9 (C)	25 ppm	0.2 ppm	10	100	10	10,000	Y
Mercury	-	0.1 (C)	0.05 mg/m3	0.025 mg/m3	1	-	1	5.1	Y
Pulverised Fuel Ash	-	2.4	None listed	None listed	None listed	None listed	None listed	None listed	Y
Carbonic Acid, H_2CO_3	5000	9000	None listed	None listed	None listed	None listed	None listed	None listed	Y
Water, H_2O	None listed	None listed	None listed	None listed	None listed	None listed	None listed	None listed	Y
Antifoam	-	5	None listed	None listed	None listed	None listed	None listed	None listed	Y
Enzyme	None listed	$6x10^{-5}$	None listed	None listed	None listed	None listed	None listed	None listed	Y
Potassium Carbonate, K_2CO_3	None listed	None listed	None listed	None listed	None listed	None listed	None listed	None listed	Y
Potassium Bicarbonate, $KHCO_3$	-	15	None listed	None listed	None listed	None listed	None listed	None listed	Y

Exhibit 6 Legislative Requirements for Potential PCC Plant Emissions

Most of the species potentially emitted from the proposed PCC plant are well understood, with perhaps only the enzyme being new in the assessment. As Exhibit 3 shows, the potential emissions from the PCC plant do not pose any concerns with regard to EH&S effects. Also the emission levels expected and components required in the process do not pose any concerns with regard to compliance with current Federal legislation covered by this assessment. However, it is recommended that further work is undertaken to remove uncertainty from the predicted emission levels that result from the limitations of scaling-up a process from bench-scale data to a representative full-scale plant. Several areas have been identified for further monitoring and measurement on a larger-scale demonstration plant, utilizing the proposed mitigation and separation methods to confirm expected emissions and reduce uncertainty and ensure legislative compliance.

8 Conclusions and Recommendations

Using information gathered from the bench-scale unit, PCC plant predictive models and industrial operating experience of a slipstream amine-based PCC plant, an estimate of emissions from the activated-potassium carbonate PCC process applied to a 685 MWe PC power plant that delivers a net output of 550 MWe and 90% CO_2 capture was made.

The potential emissions were found to pose no significant EH&S concerns and were compliant with the Federal legislation reviewed.

The limitations of predicting full-scale plant performance from bench-scale tests has been noted and further work on a larger-scale test unit is recommended to reduce the level of uncertainty.

It is recommended that further testing be carried out on a larger-scale PCC test plant utilizing enzyme-activated K_2CO_3 solvent with an arrangement and the separation and mitigation technologies (water wash and centrifuge separator) proposed in this report. During testing, extensive measurements should be taken of waste stream flow rates and compositions to confirm the predicted emission levels and to determine the required engineering controls for handling enzyme at a larger-scale.

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Revision History

Rev	Description	Date	Released by	Approved by
0	Submission to DOE/NETL			

References

[1] Comprehensive Environmental Response and Liability Act of 1980.
[2] Toxic Substances Control Act of 1976.
[3] Clean Water Act (Federal Water Pollution Control Amendments of 1972).
[4] Clean Air Act of 1970.
[5] Superfund Amendments and Reauthorization Act (SARA) Title III.
[6] Occupational Health and Safety Act of 1970.
[7] NFPA 704: Standard System for the Identification of the Hazards of Materials for Emergency Response, 2012.
[8] Example MSDS for CO_2, http://www.tisupply.com/pdf/2013%20updates/Carbon%20Dioxide%20(Compressed).pdf, last accessed 19th November 2014.
[9] Example MSDS for SO_x, http://www.praxair.com/~/media/North%20America/US/Documents/SDS/Sulfur%20Dioxide%20SO2%20Safety%20Data%20Sheet%20SDS%20P4655.ashx, last accessed 19th November 2014.
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[12] Example MSDS for H_2CO_3, http://static.fishersci.com/cmsassets/downloads/segment/ScienceEducation/pdf/Chemicals/MSDS/S25234_CA7700.pdf, last accessed 19th November 2014.
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[15] MSDS for Enzyme supplied by Novozymes.
[16] MSDS for Antifoam (Magrabar PD-218 Antifoam) supplied by Novozymes.
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[19] Occupational Safety and Health Standards, Sub Part Z, Toxic and Hazardous Substances, 1910.1000, Air Contaminants. https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9991, last accessed 5th November 2014. Note that enzymes are not listed in OSHA Subpart Z, therefore, as communicated by Novozymes, the Peak Exposure Limit indicated for enzymes is the generally accepted exposure limit for occupational settings confirmed by official industry representative organizations, including the

International Association for Soaps, Detergents and Maintenance Products (A.I.S.E) and A.C.G.I.H, a member based organization that advances occupational and environmental health: http//www.acgih.org/
[20] Occupational Safety and Health Standards, Permissible Exposure Limits – Annotated Tables. https://www.osha.gov/dsg/annotated-pels/, last accessed 5th November 2014.
[21] Code of Federal Regulations Title 40 Part 355 Appendix A – The List of Extremely Hazardous Substances and their Threshold Planning Quantities, http://www.epa.gov/oem/docs/er/355table01.pdf, last accessed 24th September 2014.
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Appendices

Exhibit A-1 Potentially Emitted Species Risk Assessments

PCC Plant Gaseous Emissions - Enzyme

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability		VM	Min	Maj	F
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Gaseous Emissions - Enzyme										
Air Emissions - Potential release of enzyme in Off Gas	Formation of enzyme Aerosol	Plant operators and persons in the local area	L	VM	L	Install a single stage water wash and demister to reduce possibility of aerosol emission. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of aerosol formation.	VL	VM	L	Very Low Probability of enzyme Aerosol Emission - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of enzyme in Off Gas	Carryover of enzyme in entrained droplets	Plant operators and persons in the local area	L	VM	L	Install a single stage water wash and demister to reducee possibility of droplet carryover. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of droplet carryover.	VL	VM	L	Very Low Probability of enzyme containing entrained droplet carryover - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of enzyme in Off Gas	Volatilized enzyme	Plant operators and persons in the local area	VL	VM	L	Install a single stage water wash and demister to eliminate possibility of volatilized Enzyme emission. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of volatilizing Enzyme.	VL	VM	L	Very Low Probability of enzyme volatilizing - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of enzyme through vents	Enzyme Aerosol, Volatilized enzyme and entrained enzyme released through vents	Plant operators and persons in the local area	L	VM	L	Vents are routed to a safe location for venting/draining to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of enzyme emission.	L	VM	L	
Air Emissions - Potential release of enzyme through loss of containment	Enzyme Aerosol, Volatilized enzyme and entrained enzyme released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Airborne levels of enzyme can be monitored during commissioning and periodically thereafter to confirm proper containment. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of enzyme emission through loss of containment.	VL	VM	L	

PCC Plant Gaseous Emissions - Antifoam

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
H	M	M	H	H
M	L	M	H	H
L	L	L	M	H
VL	L	L	M	M
	VM	Min	Maj	F
	Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Gaseous Emissions - Antifoam										
Air Emissions - Potential release of antifoam in Off Gas	Formation of antifoam aerosol	Plant operators and persons in the local area	L	VM	L	Install a single stage water wash and demister to reduce possibility of aerosol emission. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of aerosol formation.	VL	VM	L	Very Low Probability of antifoam aerosol emission - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of antifoam in Off Gas	Carryover of antifoam in entrained in droplets	Plant operators and persons in the local area	VL	VM	L	Install a single stage water wash and demister to reduce possibility of droplet carryover. Design of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of droplet carryover.	VL	VM	L	Very low probability of antifoam containing entrained droplet carryover - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of antifoam in Off Gas	Volatilized antifoam	Plant operators and persons in the local area	VL	VM	L	Install a single stage water wash and demister to reducee possibility of volatilized antifoam emission. Design of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of volatilizing antifoam.	VL	VM	L	Very low probability of antifoam volatilizing - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of antifoam through vents	Antifoam aerosol, volatilized antifoam and entrained antifoam released through vents	Plant operators and persons in the local area	VL	VM	L	Vents are routed to a safe location for venting/draining to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of antifoam emission.	VL	VM	L	
Air Emissions - Potential release of antifoam through loss of containment	Antifoam aerosol, volatilized antifoam and entrained antifoam released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of antifoam emission through loss of containment.	VL	VM	L	

PCC Plant Gaseous Emissions - NO_x

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Gaseous Emissions - NOx										
Air Emissions - Release of NOx in off gas	Standard expected PC power plant NOx emission	Plant operators and persons in the local area	H	VM	M	NOx reduction technologies installed in PC Boiler - no further remediation required in PCC Plant as emissions levels compliant with legislative requirements.	H	VM	M	Requirements for further NOx reduction if legislative changes are made. Current expected emissions within acceptable levels.
Air Emissions - Potential release of NOx through vents	NOx gases released through vents	Plant operators and persons in the local area	L	VM	L	Vents are routed to a safe location for venting/draining to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize NOx emissions.	L	VM	L	The NOx emissions are considered to be standard power plant emissions and are anticipated to be in very small quantities so cause no major concerns or risks.
Air Emissions - Potential release of NOx through loss of containment	NOx gases released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize NOx emissions.	VL	VM	L	

PCC Plant Gaseous Emissions - SO_x

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Gaseous Emissions - SOx										
Air Emissions - Release of SOx in off gas	Standard expected PC power plant SOx emission	Plant operators and persons in the local area	H	VM	M	SOx reduction technologies installed in PC Boiler - no further remediation required in PCC Plant as emissions levels compliant with legislative requirements.	H	VM	M	Requirements for further SOx reduction if legislative changes are made. Current expected emissions within acceptable levels.
Air Emissions - Potential release of SOx through vents	SOx gases released through vents	Plant operators and persons in the local area	L	VM	L	Vents are routed to a safe location for venting/draining to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize SOx emissions.	L	VM	L	The SOx emissions are considered to be standard power plant emissions and are anticipated to be in very small quantities so cause no major concerns or risks.
Air Emissions - Potential release of SOx through loss of containment	SOx gases released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize SOx emissions.	VL	VM	L	

PCC Plant Gaseous Emissions – Carbon dioxide

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability		VM	Min	Maj	F
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		Consequence			

Probabilities		Consequences	
H - High	- expected to happen frequently	VM - Very Minor - Temporary Discomfort	
L - Low	- might happen but would be an unusual occurrence	Min - Minor Injury	
M - Medium	- expected to happen sometimes	Maj - Major Injury	
VL - Very Low	- probably will never happen	F - Fatality	

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Consequence	Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Consequence	Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Gaseous Emissions - Carbon Dioxide										
Air Emissions - Release of carbon dioxide in Off Gas	Standard expected PC power plant carbon dioxide emission	Plant operators and persons in the local area	H	VM	M	PCC Plant reduces Carbon Dioxide Emissions from power plant flue gas.	H	VM	M	PCC Plant reduces Carbon Dioxide Emissions from power plant flue gas.
Air Emissions - Potential release of Carbon Dioxide through vents	Carbon Dioxide released through vents	Plant operators and persons in the local area	L	VM	L	Vents are routed to a safe location for venting/draining to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of Carbon Dioxide emission.	VL	VM	L	The Carbon Dixoide emissions are considered to be standard power plant emissions and are anticipated to be in very small quantities so cause no major concerns or risks.
Air Emissions - Potential release of Carbon Dioxide through loss of containment	Carbon Dioxide released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Fixed Carbon Dioxide monitors and alarm system to be installed across the PCC and CO_2 Compression plants. All affected personnel to wear personal CO_2 monitors. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of Carbon Dioxide emission through loss of containment.	VL	VM	L	

PCC Plant Gaseous Emissions - Mercury

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Gaseous Emissions - Mercury										
Air emissions - Release of mercury in off gas	Standard expected PC power plant mercury emissions	Plant operators and persons in the local area	H	VM	M	Mercury reduction technologies installed in PC Boiler - no further remediation required in PCC Plant as emissions levels compliant with legislative requirements.	H	VM	M	Requirements for further mercury reduction if legislative changes are made. Current expected emissions within acceptable levels.
Air emissions - Potential release of mercury through vents	Mercury released through vents	Plant operators and persons in the local area	L	VM	L	Vents are routed to a safe location for venting/draining to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of mercury emission.	VL	VM	L	The mercury emissions are considered to be standard power plant emissions and are anticipated to be in very small quantities so have no major concern or risks associated.
Air emissions - Potential release of mercury through loss of containment	Mercury released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize mercury emissions.	VL	VM	L	

PCC Plant Gaseous Emissions – Particulate matter

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
Gaseous Capture Plant Emissions - Particulate Matter										
Air Emissions - Release of particulates in off gas	Standard expected PC power plant particulate matter emissions	Plant operators and persons in the local area	H	VM	M	Particulate matter reduction technologies installed in PC Boiler - no further remediation required in PCC Plant as emissions levels compliant with legislative requirements.	H	VM	M	Requirements for further particulate matter reduction if legislative changes are made. Current expected emissions within acceptable levels.
Air Emissions - Potential release of particulate matter through vents	Particulate matter released through vents	Plant operators and persons in the local area	L	VM	L	Vents are routed to a safe location for venting/draining to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of particulate matter emission.	VL	VM	L	The particulate matter emissions are considered to be standard power plant emissions and are anticipated to be in very small quantities so have no major concern or risks associated.
Air Emissions - Potential release of particulate matter through loss of containment	Particulate matter released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize particulate matter emissions.	VL	VM	L	

PCC Plant Gaseous Emissions – Potassium carbonate

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities		Consequences	
H - High	- expected to happen frequently	VM	- Very Minor - Temporary Discomfort
L - Low	- might happen but would be an unusual occurrence	Min	- Minor Injury
M - Medium	- expected to happen sometimes	Maj	- Major Injury
VL - Very Low	- probably will never happen	F	- Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating			Preventive or Protective Measures considered to be reasonably practicable	Residual Risk			Details of Residual Risk AND Anticipated Measures that could be taken
			Probability	Consequence	Risk		Probability	Consequence	Risk	
PCC Plant Gaseous Emissions - Potassium Carbonate										
Air Emissions - Potential release of potassium carbonate in off gas	Carryover of potassium carbonate in entrained droplets	Plant operators and persons in the local area	L	VM	L	Install a single stage water wash and demister to reduce possibility of droplet carryover. Design of solvent distribution system to minimize droplet formation. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of droplet carryover.	VL	VM	L	Very low probability of potassium carbonate containing droplet carryover - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of potassium carbonate in off gas	Formation of potassium carbonate aerosol	Plant operators and persons in the local area	L	VM	L	Install a single stage water wash and demister to reduce possibility of aerosol emission. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of aerosol formation.	VL	VM	L	Very low probability of potassium carbonate aerosol emission - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of potassium carbonate through vents	Potassium carbonate aerosols and entrained potassium carbonate released through vents	Plant operators and persons in the local area	L	VM	L	Vents are routed to a safe location for venting to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium carbonate emission.	VL	VM	L	
Air Emissions - Potential release of potassium carbonate through loss of containment	Potassium carbonate aerosols and entrained potassium carbonate released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium carbonate emission through loss of containment.	VL	VM	L	

PCC Plant Gaseous Emissions – Potassium bicarbonate

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Gaseous Emissions - Potassium bicarbonate										
Air Emissions - Potential release of potassium bicarbonate in off gas	Carryover of potassium bicarbonate in entrained droplets	Plant operators and persons in the local area	L	VM	L	Install a single stage water wash and demister to reduce possibility of droplet carryover. Design of solvent distribution system to minimize droplet formation. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of droplet carryover.	VL	VM	L	Very low probability of potassium bicarbonate containing droplet carryover further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of potassium bicarbonate in off gas	Formation of potassium bicarbonate aerosol	Plant operators and persons in the local area	L	VM	L	Install a single stage water wash and demister to reduce possibility of aerosol emission. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of aerosol formation.	VL	VM	L	Very low probability of potassium bicarbonate aerosol emission - further measures include increasing the degree of existing water wash or adding a second stage water wash.
Air Emissions - Potential release of potassium bicarbonate through vents	Potassium bicarbonate aerosols and entrained potassium bicarbonate released through vents	Plant operators and persons in the local area	L	VM	L	Vents are routed to a safe location for venting to areas not occupied by personnel. Intermittent venting outdoors would not have a significant effect on ambient air conditions. Design venting velocity is such that it aids vapor dispersion. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium bicarbonate emission.	VL	VM	L	
Air Emissions - Potential release of potassium bicarbonate through loss of containment	Potassium bicarbonate aerosols and entrained potassium bicarbonate released through loss of containment	Plant operators and persons in the local area	VL	VM	L	Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium bicarbonate emission through loss of containment.	VL	VM	L	

PCC Plant Liquid Emissions – Carbonic acid

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities		Consequences	
H - High	- expected to happen frequently	VM - Very Minor - Temporary Discomfort	
L - Low	- might happen but would be an unusual occurrence	Min - Minor Injury	
M - Medium	- expected to happen sometimes	Maj - Major Injury	
VL - Very Low	- probably will never happen	F - Fatality	

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating			Preventive or Protective Measures considered to be reasonably practicable	Residual Risk			Details of Residual Risk AND Anticipated Measures that could be taken
			Probability	Consequence	Risk		Probability	Consequence	Risk	
PCC Plant Liquid Emissions - Carbonic acid										
Liquid Emissions - Potential release of dilute carbonic acid (compressor condensate) into cooling water due to compressor interstage cooler leakage	Compressor condensate contains CO_2 resulting in dilute carbonic acid	Plant operators and persons in the local area	L	VM	L	Any instance of carbonic acid (compressor condensate) will be present in dilute form. Implementation of robust commissioning and operating procedures, plant integrity, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of contamination.	VL	VM	L	Closed and monitored cooling water loop could be considered to ensure any heat exchanger cross leakage is contained within cooling loop prior to appropriate treatment and discharge.
Liquid Emissions - Potential release of dilute carbonic acid through drains (operational)	Dilute carbonic acid released through operational drains	Plant operators and persons in the local area	L	VM	L	Any instance of carbonic acid (compressor condensate) will be present in dilute form. All PCC plant operational drains routed to a controlled, safe location (waste tank) for draining and treatment where necessary. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of dilute carbonic acid emission.	VL	VM	L	
Liquid Emissions - Potential release of dilute carbonic acid through loss of containment	Carbonic acid released through loss of containment in compressor condensate system	Plant operators and persons in the local area	VL	VM	L	Any instance of carbonic acid (compressor condensate) will be present in dilute form. Secondary containment berms in place as a second line of defence for containing any hazardous events. All PCC plant surface drains routed to a controlled, safe location (sump) for additional treatment where necessary. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of carbonic acid emission through loss of containment.	VL	VM	L	

PCC Plant Liquid Emissions – Enzyme

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating			Preventive or Protective Measures considered to be reasonably practicable	Residual Risk			Details of Residual Risk AND Anticipated Measures that could be taken
			Probability	Consequence	Risk		Probability	Consequence	Risk	
PCC Plant Liquid Emissions - Enzyme										
Liquid Emissions - Potential release of enzyme from storage tanks	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of enzyme emission through loss of containment.	VL	VM	L	
Liquid Emissions - Potential release of enzyme from capture plant	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of enzyme emission through loss of containment.	VL	VM	L	
Liquid Emissions - Potential release of enzyme from tank leaks and spillage during road tanker off-loading	Loss of Containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Storage tanks area surface drainage routed to PCC plant sump for treatment where necessary.	VL	VM	L	For handling operations where potential aerosol exposure above the TLV cannot be eliminated, personal respirators equipped with HEPA or P100 cartridges should be implemented.
Liquid Emissions - Potential release of enzyme in cooling water loop due to heat exchanger cross-leakage.	Contaminated cooling water by addition of enzyme	Plant operators and persons in the local area	L	VM	L	Implementation of robust commissioning and operating procedures, plant integrity, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of contamination.	VL	VM	L	Closed and monitored cooling water loop could be considered to ensure any heat exchanger cross leakage is contained within cooling loop prior to appropriate treatment and discharge.
Liquid Emissions - Potential release of Enzyme through drains (operational)	Enzyme released through operational drains	Plant operators and persons in the local area	L	VM	L	All PCC plant operational drains routed to a controlled, safe location (waste tank) for draining and treatment where necessary. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of enzyme emission.	L	VM	L	

PCC Plant Liquid Emissions – Antifoam

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities		Consequences	
H - High	- expected to happen frequently	VM - Very Minor - Temporary Discomfort	
L - Low	- might happen but would be an unusual occurrence	Min - Minor Injury	
M - Medium	- expected to happen sometimes	Maj - Major Injury	
VL - Very Low	- probably will never happen	F - Fatality	

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Liquid Emissions - Antifoam										
Liquid Emissions - Potential release of antifoam from storage tanks	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of antifoam emission through loss of containment.	VL	VM	L	
Liquid Emissions - Potential release of antifoam from capture plant	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of antifoam emission through loss of containment.	VL	VM	L	
Liquid Emissions - Potential release of antifoam from tank leaks and spillage during road tanker off-loading	Loss of Containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Storage tanks area surface drainage routed to PCC plant sump for treatment where necessary.	VL	VM	L	
Liquid Emissions - Potential release of antifoam in cooling water loop due to heat exchanger cross-leakage.	Contaminated cooling water by addition of antifoam	Plant operators and persons in the local area	L	VM	L	Implementation of robust commissioning and operating procedures, plant integrity, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of contamination.	VL	VM	L	Closed and monitored cooling water loop could be considered to ensure any heat exchanger cross leakage is contained within cooling loop prior to appropriate treatment and discharge.
Liquid Emissions - Potential release of antifoam through drains (operational)	Antifoam released through operational drains	Plant operators and persons in the local area	L	VM	L	All PCC plant operational drains routed to a controlled, safe location (waste tank) for draining and treatment where necessary. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of antifoam emission.	L	VM	L	

PCC Plant Liquid Emissions – Potassium carbonate

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
H	M	M	H	H
M	L	M	H	H
L	L	L	M	H
VL	L	L	M	M
	VM	Min	Maj	F
	Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Liquid Emissions - Potassium Carbonate										
Liquid Emissions - Potential release of potassium carbonate from storage tanks	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium carbonate emission through loss of containment.	VL	VM	L	
Liquid Emissions - Potential release of potassium carbonate from capture plant	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium carbonate emission through loss of containment.	VL	VM	L	
Liquid Emissions - Potential release of potassium carbonate from tank leaks and spillage during road tanker off-loading	Loss of Containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Storage tanks area surface drainage routed to PCC plant sump for treatment where necessary.	VL	VM	L	
Liquid Emissions - Potential release of potassium carbonate in cooling water loop due to heat exchanger cross-leakage.	Contaminated cooling water by addition of potassium carbonate	Plant operators and persons in the local area	L	VM	L	Implementation of robust commissioning and operating procedures, plant integrity, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of contamination.	VL	VM	L	Closed and monitored cooling water loop could be considered to ensure any heat exchanger cross leakage is contained within cooling loop prior to appropriate treatment and discharge.
Liquid Emissions - Potential release of potassium carbonate through drains (operational)	potassium carbonate released through operational drains	Plant operators and persons in the local area	L	VM	L	All PCC plant operational drains routed to a controlled, safe location (waste tank) for draining and treatment where necessary. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium carbonate emission.	L	VM	L	

PCC Plant Liquid Emissions – Potassium bicarbonate

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities		Consequences	
H - High	- expected to happen frequently	VM	- Very Minor - Temporary Discomfort
L - Low	- might happen but would be an unusual occurrence	Min	- Minor Injury
M - Medium	- expected to happen sometimes	Maj	- Major Injury
VL - Very Low	- probably will never happen	F	- Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Liquid Emissions - Potassium bicarbonate										
Liquid Emissions - Potential release of potassium bicarbonate from storage tanks	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium bicarbonate emission through loss of containment.	VL	VM	L	
Liquid Emissions - Potential release of potassium bicarbonate from capture plant	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium bicarbonate emission through loss of containment.	VL	VM	L	
Liquid Emissions - Potential release of potassium bicarbonate from tank leaks and spillage during road tanker off-loading	Loss of Containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Storage tanks area surface drainage routed to PCC plant sump for treatment where necessary.	VL	VM	L	
Liquid Emissions - Potential release of potassium bicarbonate in cooling water loop due to heat exchanger cross-leakage.	Contaminated cooling water by addition of potassium bicarbonate	Plant operators and persons in the local area	L	VM	L	Implementation of robust commissioning and operating procedures, plant integrity, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of contamination.	VL	VM	L	Closed and monitored cooling water loop could be considered to ensure any heat exchanger cross leakage is contained within cooling loop prior to appropriate treatment and discharge.
Liquid Emissions - Potential release of potassium bicarbonate through drains (operational)	potassium bicarbonate released through operational drains	Plant operators and persons in the local area	L	VM	L	All PCC plant operational drains routed to a controlled, safe location (waste tank) for draining and treatment where necessary. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium bicarbonate emission.	L	VM	L	

PCC Plant Solid/Liquid (Wet Solids) Emissions – Enzyme

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability		VM	Min	Maj	F
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently L - Low - might happen but would be an unusual occurrence M - Medium - expected to happen sometimes VL - Very Low - probably will never happen	VM - Very Minor - Temporary Discomfort Min - Minor Injury Maj - Major Injury F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Solid / Liquid (Wet Solids) Emissions - Enzyme										
Potential release of enzyme from waste tanks	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Airborne levels of enzyme can be monitored periodically to ensure proper containment. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of enzyme emission through loss of containment.	VL	VM	L	
Potential release of enzyme from tank leaks and spillage during road tanker loading	Loss of Containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Airborne levels of enzyme can be monitored periodically to ensure proper containment. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of enzyme emission through loss of containment.	VL	VM	L	For handling operations where potential aerosol exposure above the TLV cannot be eliminated, personal respirators equipped with HEPA or P100 cartridges should be implemented.
Solid / Liquid Emissions - Potential release of Enzyme in Centrifuge Waste	Ground contamination/exposure to Solid / Liquid Enzyme Centrifuge Waste	Plant operators and persons in the local area	H	VM	M	Expected waste stream from PCC plant. Potentially wet solids waste could be a product used for composting otherwise disposal arranged with a waste management company to be handled off site. Efficient centrifuge system designed and implemented in PCC plant to minimize liquid loss from process. Airborne levels of enzyme can be monitored periodically to ensure proper containment. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of enzyme emission.	H	VM	M	For handling operations where potential aerosol exposure above the TLV cannot be eliminated, personal respirators equipped with HEPA or P100 cartridges should be implemented.

PCC Plant Solid/Liquid (Wet Solids) Emissions – Antifoam

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
H	M	M	H	H
M	L	M	H	H
L	L	L	M	H
VL	L	L	M	M
	VM	Min	Maj	F
	Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Solid / Liquid (Wet Solids) Emissions - Antifoam										
Potential release of antifoam from waste tanks	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of antifoam emission through loss of containment.	VL	VM	L	
Potential release of antifoam from tank leaks and spillage during road tanker loading	Loss of Containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of antifoam emission through loss of containment.	VL	VM	L	
Solid / Liquid Emissions - Potential release of antifoam in centrifuge waste	Ground contamination/exposure to Solid / Liquid antifoam Centrifuge Waste	Plant operators and persons in the local area	H	VM	M	Expected waste stream from PCC plant. Potentially wet solids waste could be a product used for composting otherwise disposal arranged with a waste management company to be handled off site. Efficient centrifuge system designed and implemented in PCC plant to minimize liquid loss from process. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of antifoam emission.	H	VM	M	

PCC Plant Solid/Liquid (Wet Solids) Emissions – Potassium carbonate

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating: Probability	Initial Risk Rating: Consequence	Initial Risk Rating: Risk	Preventive or Protective Measures considered to be reasonably practicable	Residual Risk: Probability	Residual Risk: Consequence	Residual Risk: Risk	Details of Residual Risk AND Anticipated Measures that could be taken
PCC Plant Solid / Liquid (Wet Solids) Emissions - Potassium carbonate										
Potential release of potassium carbonate from waste tanks	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium carbonate emission through loss of containment.	VL	VM	L	
Potential release of potassium carbonate from tank leaks and spillage during road tanker loading	Loss of Containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium carbonate emission through loss of containment.	VL	VM	L	
Solid / Liquid Emissions - Potential release of potassium carbonate in centrifuge waste	Ground contamination/exposure to Solid / Liquid potassium carbonate centrifuge waste	Plant operators and persons in the local area	H	VM	M	Expected waste stream from PCC plant. Potentially wet solids waste could be a product used for composting otherwise disposal arranged with a waste management company to be handled off site. Efficient centrifuge system designed and implemented in PCC plant to minimize liquid loss from process. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium carbonate emission.	H	VM	M	

PCC Plant Solid/Liquid (Wet Solids) Emissions – Potassium bicarbonate

Project Title:	Enzyme-activated PCC	Discipline:	Operation - Enzyme-activated K_2CO_3 PCC Plant Emissions

Probability					
	H	M	M	H	H
	M	L	M	H	H
	L	L	L	M	H
	VL	L	L	M	M
		VM	Min	Maj	F
		Consequence			

Probabilities	Consequences
H - High - expected to happen frequently	VM - Very Minor - Temporary Discomfort
L - Low - might happen but would be an unusual occurrence	Min - Minor Injury
M - Medium - expected to happen sometimes	Maj - Major Injury
VL - Very Low - probably will never happen	F - Fatality

Hazard and Associated Risk	Risk	People at Risk	Initial Risk Rating			Preventive or Protective Measures considered to be reasonably practicable	Residual Risk			Details of Residual Risk AND Anticipated Measures that could be taken
			Probability	Consequence	Risk		Probability	Consequence	Risk	
PCC Plant Solid / Liquid (Wet Solids) Emissions - Potassium bicarbonate										
Potential release of potassium bicarbonate from waste tanks	Loss of containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium bicarbonate emission through loss of containment.	VL	VM	L	
Potential release of potassium bicarbonate from tank leaks and spillage during road tanker loading	Loss of Containment	Plant operators and persons in the local area	L	VM	L	Secondary containment berms in place as a second line of defence for containing any hazardous events. Robust Process and equipment design with fit for purpose materials and design specifications to be used throughout the plant with detailed risk reviews, design reviews and HAZOPs to capture and allow rectification of any plant design deficiencies. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium bicarbonate emission through loss of containment.	VL	VM	L	
Solid / Liquid Emissions - Potential release of potassium bicarbonate in centrifuge waste	Ground contamination/exposure to Solid / Liquid potassium bicarbonate centrifuge waste	Plant operators and persons in the local area	H	VM	M	Expected waste stream from PCC plant. Potentially wet solids waste could be a product used for composting otherwise disposal arranged with a waste management company to be handled off site. Efficient centrifuge system designed and implemented in PCC plant to minimize liquid loss from process. Implementation of robust commissioning and operating procedures, safe systems of work/permit system designed and implemented in consultation with plant owner/operator to minimize chance of potassium bicarbonate emission.	H	VM	M	

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Rethink Tomorrow

February 27, 2013

Andrew P. Jones
Project Manager
Existing Plants Emissions Control
U.S. DOE-NETL
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Re: Letter of Authorization to Use Copyrighted Data in Topical Report for Public Viewing

Dear Mr. Jones,

Novozymes North America, Inc. is the prime contractor under U.S. Department of Energy Award Number DE-FE0007741.

Novozymes hereby authorizes the inclusion of copyrighted material owned by Novozymes in the Topical Report being filed on or around the date of this letter. This authorization is intended to fulfill the authorization requirement for the submission of copyrighted material as set forth in the U.S. Department of Energy Revised Federal Assistance Reporting Checklist.

Novozymes further acknowledges and agrees that the U.S. Government reserves for itself and others acting on its behalf a royalty-free, nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit, and perform this copyrighted material.

Very truly yours,

NOVOZYMES NORTH AMERICA, INC.

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