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Feasibility of Continuous Particle Monitoring at NSW Coal Fired Power Stations: Guidance Document

Prepared for:
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Attention:
Technical Advice Air Unit

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1 GLOSSARY

g/s: emission rate in grams per second
kg/hr: emission rate in kilogram per hour
Nm^3/hr: flow in normal cubic meter per hour
µg/m^3: concentration in micrograms per cubic meter
mg/m^3: concentration in milligram per cubic meter
mg/dscm: concentration in milligram per dry standard cubic meter 0^{o}C at 101.325 kPa
mg/Nm^3: concentration in milligram per normal standard cubic meter 0^{o}C at 101.325 kPa on a dry volume basis
acm: Actual cubic metre
CEMS: Continuous Emission Monitoring System
CC: Chiappalone Consulting
Extinction (Optical Density): The total loss of light through a flue gas stream over a given path length which may be occurring due to the refraction, reflection, diffraction and internal refraction.
ID: Induced draft fan
NSW EPA: NSW Environment Protection Authority
PM: Particulate Matter/ Particles/ Particulates
PM-CEMS: Particulate Matter Continuous Emission Monitoring System
PS-11: USEPA Performance Specification 11
QAL: Quality Assurance Level
RMS: Root Mean Square
Transmission: Optical transmission is a measure of the proportion of light that is transmitted through a flue gas stream within a duct or stack containing particulates. Light may be attenuated due to refraction, reflection, diffraction and internal refraction.
USEPA: United States Environmental Protection Agency

2 EXECUTIVE SUMMARY

The general feasibility of implementing Particulate Matter Continuous Emission Monitoring Systems (PM-CEMS) at large combustion plants in NSW has been reviewed.

Five NSW coal fired power stations were visited. The site visits informed the type of plant and existing configuration, type of pollution control equipment, monitoring plane detail and typical flue gas parameters. This information has been used to evaluate the general feasibility of PM-CEMS at the power stations and identify any significant limitations.

A review of currently available PM-CEMS technologies is provided with an assessment against key factors and limitations identified for NSW power stations. Table 1 summarises the PM-CEMS technologies and has been provided as a general guide to inform a more detailed site-specific assessment.

Table 1: Application Technology Assessment for Large Combustion Plant

Parameter	Optical Transmission	Optical Light Scatter	Extractive Beta Gauge	Probe Electrification	Optical Scintillation	Harmonic Oscillation
Low particle concentration (< 30 mg/m³)	poor	excellent	excellent	satisfactory	poor	excellent
Dry stack (above dew point)	good	good	good	good	good	good
Humidity (non-condensing) constant	good	good	good	good	good	good
Stack diameter Large (> 3 m)	good	good	poor	poor	good	poor
Particle size (limited variation)	good	good	good	good	good	good
Particle colour (limited variation)	good	good	good	good	good	good
Particle density (limited variation)	good	good	good	good	good	good
Gas velocity varying (>±10m/s)	good	good	poor	very poor	good	poor
Life Cycle Cost	moderate	moderate	high	moderate	moderate	high
Use within Industry	very high	high	none	low	low	none

Note: 1. The criteria around "Use Within Industry" is based upon site observations and experience over the past 20 years at large combustion installations around Australia. It is not a measure of performance or ability to perform within the industry.

Summary of findings and recommendations

Installation and operation of PM-CEMS to measure particulate concentrations was found to be generally feasible for all power stations observed.

Factors identified as requiring focused consideration include: non-ideal monitoring planes, velocity variability and low particulate concentrations <30 mg/Nm^3.

It is recommended that each power station perform an independent site specific review to determine the most appropriate PM-CEMS for their application. The review should, at a minimum, consider the factors discussed in this guidance document including; site installation requirements, stack gas characteristics, particle characteristics and process operating conditions.

3 INTRODUCTION

Chiappalone Consulting has been engaged by the NSW Environment Protection Authority (NSW EPA) to advise on the general feasibility, including options and issues, associated with the adoption of continuous particle monitoring at large coal fired combustion plants operating in NSW.

Continuous Emission Monitoring Systems (CEMS) have been utilised within industry across Australia (and globally) for the past 40 years. During the past 25 years there has been an increasing requirement for the use of CEMS for compliance reporting purposes. Historically, large combustion plants operating in NSW have measured opacity as a surrogate proxy for particulate emissions. With advancements in emission monitoring technologies, improved pollution control equipment and growing community interest in air pollution, there is an increasing need and ability to better characterise emissions on a continuous basis.

The project involved conducting site visits to each of the five coal fired power stations operating in NSW to identify any major constraints, which could impact the feasibility of installing and operating continuous particle monitors. Information gathered from the site visits has been used to develop this guidance document.

It is recognised that the implementation of Particulate Matter (PM) CEMS involves some degree of complexity. The complexity will vary depending on the individual application and emission source configuration. Challenges tend to originate from a lack of knowledge, inappropriate installation locations, variable process conditions, incorrect selection of technology and little or no quality assurance program/procedures.

Installation and operation of PM-CEMS to measure particulate concentrations was found to be generally feasible for all power stations observed.

This document has been developed as a tool to assist operators of large combustion plant to evaluate the selection and implementation of PM-CEMS instrumentation including:

- An overview of CEMS monitoring, certification processes and their suitability for use in Australia is discussed in Section 5.
- The typical flue gas parameters at large combustion plants, including site specific observations, and their influence on PM-CEMS measurement is provided in Section 6.
- An overview of the various analytical technologies currently available for the continuous measurement of PM concentration is provided in Section 7.
- A breakdown of indicative costs for the implementation and ongoing management of PM-CEMS is provided as a guide for budgetary purposes in Section 8.
- A checklist for conducting evaluations for PM-CEMS applicability is included in Section 9.

4 OBSERVED POWER STATION PLANT CONFIGURATIONS

4.1 Description of Source

Table 2 lists the power stations visited.

Table 2: List of NSW Power Generators

Facility Name	Licensee Name	Location	Number of Boilers	Installed Capacity
Bayswater	AGL Macquarie	Muswellbrook	4	2640 MW
Liddell	AGL Macquarie	Singleton	4	2000 MW
Mount Piper	Energy Australia	Lithgow	2	1320 MW
Eraring	Origin Energy Eraring	Lake Macquarie	4	2880 MW
Vales Point	Sunset Power	Wyong	2	1320 MW

Each power station runs bituminous coal fired boilers with sub-critical steam turbine generators. Boiler firing configurations are either tangential or wall fired.

Historically, the power stations have operated as base load facilities, but depending on future demand, future operations could be more responsive to market demands and thus the generating units may operate more dynamically.

4.2 Particulate Control

Each of the five power stations observed use fabric filtration, downstream of the boilers, to reduce particulate emissions. The fabric filtration system is commonly known as a baghouse and contains thousands of fabric filters. As the boiler emissions pass through the baghouse, particles (fly ash) collect on the surface of the bag filters building a dust cake. The built-up cake is removed from the filters periodically by mechanical bag shaking or pulsed air.

The filter media typically used is polyphenylene sulfide (PPS). The typical documented performance of these filters is <10 mg/m^3 of particulate emissions with a capture of efficiency of 99.9 % for >6 µm particle size and >80 % for <2.5 µm when new[1]. Particulate concentrations will increase over time with filter deterioration and are expected to be <30 mg/m^3 prior to bag failure[2].

4.3 Generalised Plant Configuration

The typical configuration of the exhaust side of the boiler is as follows:

- Flue gas is drawn from individual generating units through the baghouse by an Induced Draft (ID) fan.
- The baghouses typically have multiple exit passes (streams) leading to the ID fan.
- The ducting leading to the ID fan are normally horizontal or inclined.
- The ducting leading from the ID fan to the main stack are slightly inclined.
- The ducts are typically square with dimensions of about 6m x 6m
- In some cases, there are inline silencers installed prior to the main exhaust stack to reduce noise.
- Multiple ducts typically merge to be discharged vertically through a main stack, at height.

4.4 Emission Characteristics

The following table lists the range of flue gas characteristics typical of the NSW coal fired power stations. Each of the listed parameters, and their impact on PM-CEMS selection, is discussed in Section 6.

Table 3: Emission Characteristics

Parameter	Unit	Range
Gas temperature	°C	115-150
Gas velocity	m/s	14-20
Gas flow rate	Nm^3/s	240-410
Moisture	% v/v	6.0-11
Moisture Dew Point	-	Above Dew Point
Duct pressure	mmH_2O	-10 - -400
Particulate concentration	mg/Nm^3	5-50
Oxygen	% v/v	6.0-11.0
Nitrogen Oxides as NO_2	mg/Nm^3	400-1500
Sulfur Dioxide	mg/Nm^3	800-1700
Hydrogen Chloride	mg/Nm^3	<50
Sulfur Trioxide + Sulfuric Acid Mist	mg/Nm^3	<100

5 PM-CEMS MONITORING

5.1 What is a PM-CEMS?

A PM-CEMS is a continuous measuring system comprising of a measurement instrument and ancillary equipment that has been designed and configured to monitor particulate emission concentrations from flue gas exhausts or process ducts. The principles for measurement are based upon either direct or indirect measurement technology. The majority of the technologies involve indirect measurements and are designed to measure a characteristic of the particles, such as optical interaction or energy transfer.

Particulate concentration is determined by establishing and maintaining a correlation between the instrument response and manual gravimetric reference method measurements. Correlating the instrument response against a gravimetric reference method allows for continuous measurement of particle emissions as a mass-based concentration (i.e. mg/Nm^3) which can be used to assess compliance with emission limits.

There are a range of PM-CEMS technologies available to the Australian market. The primary technologies used in large combustion plant are listed below. Each technology is discussed in detail in Section 7.

- Optical Transmission/ Extinction (Opacity)
- Optical Light Scattering
- Extractive Beta Gauge
- Probe Electrification
- Optical Scintillation
- Harmonic Oscillation

5.2 International use of PM-CEMS

Continuous monitoring of particulate matter mass concentrations in industrial flue stacks started during the 1960s in Germany and became a German Federal requirement in the mid 1970's. In the United States of America (USA) PM-CEMS was proposed as a regulatory requirement in 1996, as part of the proposed Hazardous Waste Combustion (HWC) Maximum Achievable Control Technology (MACT) emission standard (61 FR 17358).

PM-CEMS are a regulatory requirement in many regions around the world including: the European Union (EU), Japan, United Kingdom (UK), USA, China, South America (including Brazil, Chile and Argentina) and throughout the Asia Pacific Region (including Indonesia, Thailand, Malaysia and Singapore). New Zealand regulations require PM-CEMS only in certain Regions.

5.3 PM-CEMS Validation Requirements

In the USA, Europe and the UK the applicability of PM-CEMS is evaluated against accreditation and certification programs to demonstrate the systems capability to meet minimum measurement criteria as set out in legislation.

In the USA, the US Environmental Protection Agency (USEPA) performance specification standards and associated procedures are used to evaluate the performance of PM-CEMS. In Europe and the UK the main process used to evaluate and verify the performance of a PM-CEMS is EN 14181: *Stationary source emissions - Quality assurance of automated measuring systems* and its associated procedures and methods.

A summary of the different validation approaches is provided in the sub-sections below.

5.3.1 USEPA Performance Specification Standards

In the USA the applicability of a PM-CEMS is determined based on its ability to meet criteria specified in Performance Specification 11[3] (PS-11)—*Specifications and Test Procedures for Particulate Matter Continuous*

Emission Monitoring Systems at Stationary Sources at the time of installation. Chiappalone Consulting first implemented the use of PS-11 within Australia in the year 2000, seeking a robust quality assured procedure for the implementation of PM-CEMS.

The purpose of PS-11 is to establish the initial installation and performance procedures that are required for evaluating the acceptability of a PM-CEMS. The objective of the specification is to determine the performance of the PM-CEMS and establish its correlation to manual reference gravimetric method measurements in units of mass concentration such as milligrams per actual cubic meter (mg/acm).

PS-11 details all the activities required to establish the applicability of a PM-CEMS at the time of installation. The key activities include, but are not limited to:

- Selecting the appropriate instrument technology
- Locating a representative monitoring plane
- Performing an initial correlation test
- Performing 7 day zero/span drift tests
- Handling and quality assuring data
- Performing statistical calculations
- Referencing associated standards

The ongoing quality assurance requirements for a PM-CEMS are then determined in accordance with Procedure 2–*Quality Assurance Requirements for Particulate Matter Continuous Emission Monitoring Systems at Stationary Sources*[4]. Procedure 2 requires the implementation of a Quality Assurance Plan (QAP) to detail the management process of the PM-CEMS. It outlines all the key quality control activities which should be addressed such as maintenance, performance testing requirements and the associated standards to be met. Procedure 2 is an integral part of the PM-CEMS program as it ensures ongoing performance once PS-11 is completed. Figure 1 summarises the PS-11 and Procedure 2 process.

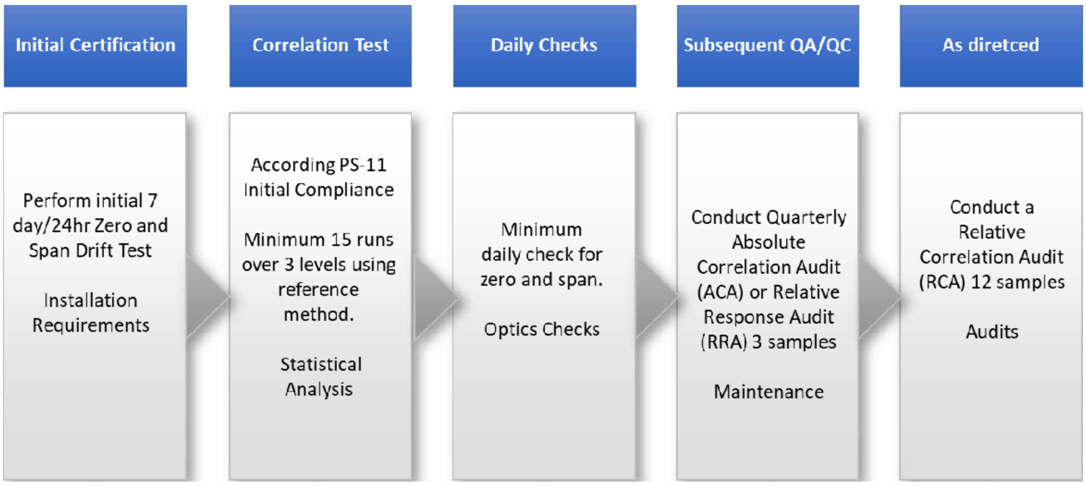

Figure 1 – High Level Overview of USEPA PS-11 and Procedure 2 Process.

5.3.2 European Standards

In Europe and the UK, CEMS are also referred to as Automated Measuring Systems (AMS). According to EU and UK legislation, only automated measuring systems successfully certified in accordance with European Standard EN 15267[5],[6],[7] may be used for emission monitoring of air pollutants in the regulated sector. EN 15267 sets out the procedures to be used for quality assurance testing and provides a mechanism for demonstrating an AMS is fit for purpose prior to installation.

EN 14181[8] specifies procedures for establishing quality assurance levels (QAL) for automated measuring systems installed on industrial plants for the determination of the flue gas components and other flue gas parameters. EN 14181 is for use after the AMS has been accepted according to the procedures specified in EN 15267 (QAL1). EN 14181 specifies:

- A procedure (QAL2) to calibrate the AMS and determine the variability of the measured values obtained by it, so as to demonstrate the suitability of the AMS for its application, following its installation
- A procedure (QAL3) to maintain and demonstrate the required quality of the measurement results during the normal operation of an AMS, by checking that the zero and span characteristics are consistent with those determined during QAL1
- A procedure for the annual surveillance tests (AST) of the AMS in order to evaluate (i) that it functions correctly, and its performance remains valid and (ii) that its calibration function and variability remain as previously determined.

EN 14181 is restricted to quality assurance (QA) of the AMS and does not include the QA of the data collection and recording system of the plant.

Figure 2 summarises a high-level overview of the EN 14181 QAL process.

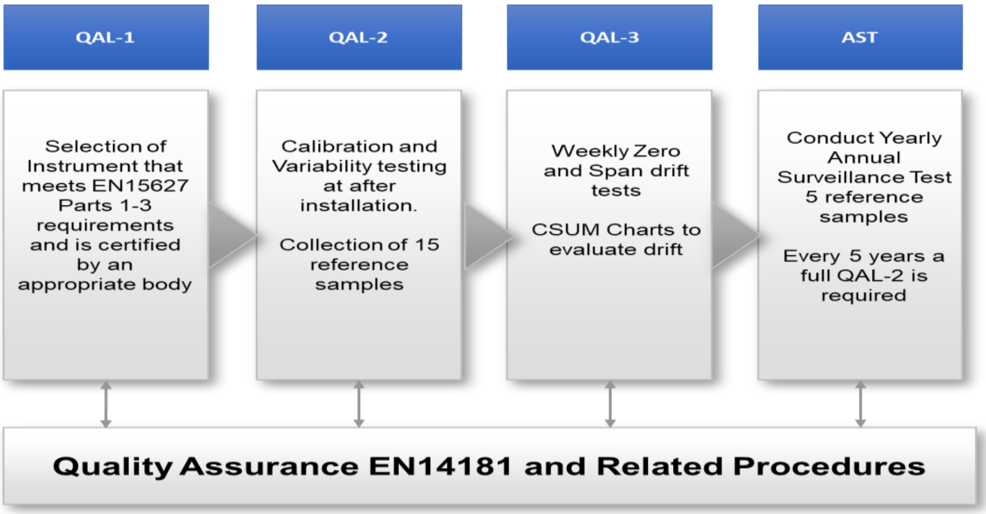

Figure 2 – High Level Overview of EN14181 Process

5.3.3 Standards Applicability for Australia

The European QAL1 certification program provides a valuable level of assurance that an instrument has been demonstrated to be suitable for the intended use.

The majority of PM-CEMS suppliers and manufacturers from Europe and the UK have products that meet QAL1 requirements which can be purchased for compliance monitoring purposes. Certificates should be made available by the manufacturer or supplier which detail the equipment model and intended application. An important check for large combustion facilities is to evaluate the certified range, as it should be between 2.5-3 times the licence limit[3,4,5,6,18]. Appropriate ranges should be selected otherwise there is an increase of uncertainty when the range becomes too large in comparison to the emission limit.

QAL-1 certification is specific to the measurement system that has undergone the laboratory and field performance trials. Parts that make up the certified measuring system are stated within the QAL certificate and or MCERTS Certificate. PM-CEMS manufacturers build various models of measurement systems, with different capabilities, some of which are not for compliance monitoring purposes and therefore do not have the QAL1 certification. As such, prior to purchase, the model of the PM-CEMS should be checked to ensure it has a QAL1 certificate.

The use of USEPA Performance Specification PS-11 has been implemented across a wide range of industries including coal fired power stations throughout Australia and the World.

Based on industry experience and observations made at large combustion plants throughout NSW, Australia and globally, the adoption of USEPA Performance Specification 11 is considered a suitable choice of verification standard in NSW as it offers a comprehensive framework for the installation, commissioning and ongoing quality control for the operation of a PM-CEMS. Additionally, the methodology is consistent with the current NSW regulatory framework and policies including the Approved Methods for the Sampling and Analysis of Air Pollutants in NSW (Approved Methods)[9]. The Approved Methods predominately references USEPA sampling methodologies for stationary source emission testing.

6 FACTORS TO CONSIDER WHEN IMPLEMENTING PM-CEMS

There are a number of factors that influence the acceptability and performance of a PM-CEMS. The PM-CEMS selected for the application must be able to operate and be correlated within the stack conditions. Therefore, prior to selecting a PM-CEMS, it should be determined whether site specific conditions could potentially undermine the integrity of the measurement system and monitoring data.

The following sub-sections provide a general overview of the typical flue gas parameters at large combustion plants and their influence on PM-CEMS measurement. Each parameter is then further evaluated based on the site observations made at each of the observed facilities.

Site specific reviews should be performed to determine the most appropriate PM-CEMS for the application. The review should, at a minimum, consider the factors discussed in the following section, including but not limited to:

- Flue gas velocity
- Flue gas temperature and pressure
- Pollutant gases
- Moisture
- Monitoring plane
- Stratification
- Particulate characteristics
- Particulate loading

6.1 Flue Gas Velocity

Flue gas velocity is a measure of the speed flue gas is travelling through a duct or exhaust stack. Velocity is most often expressed in meters per second (m/s). The gas velocity calculation is a function of several variables including the differential pressure of the flue gas, the flue gas temperature, and the absolute flue gas pressure. Velocity is used to calculate the volumetric flow rate of the flue gas.

Flue gas velocity is important to know as it directly relates to particle velocity and rate of emissions. A highly variable velocity or a velocity outside of an optimal operating range of the measurement instrument can impact on the performance of certain PM-CEMS technologies. For example, velocity changes can affect the response and associated correlation of some probe electrification systems.

Variable velocities also make it difficult for extractive PM-CEMS to achieve and maintain isokinetic sampling conditions. Isokinetic sampling occurs when the velocity of the sample being extracted from the stack equals that of the velocity of the flue gas flow. Oversampling or under-sampling occurs when the sample velocity is greater than or less than the local gas flow, respectively. For an extractive PM-CEMS to achieve isokinetic sample extraction, the stack gas flow velocity must be continuously measured and transmitted to the PM-CEMS.

Flue gas velocity can be determined using a variety of measurement devices such as ultrasonic meters, thermal dispersion meters, cross correlation meters, and pitot tubes. The most common way to evaluate flue gas velocity is by measuring the differential pressure across the duct or stack using a pitot tube. Measurement procedures are provided in USEPA Method 2[10]—*Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube).* Historic stack test data may be available which can provide an indication of the typical velocity ranges for existing facilities.

The velocity should be assessed under the expected range of standard operating conditions of the plant. The measured range and deviation of flue gas velocity should be compared to PM-CEMS manufacture specifications to determine instrument suitability.

6.1.1 *Continuous Velocity Measurement*

Continuous velocity measuring instruments are used in PM-CEMS monitoring programs for two main reasons:

1. The volumetric flow rate is used in order to calculate the mass emission rate of particulates.
2. For applications where the PM-CEMS are located on multiple ducts leading to a single emission point, which is common for large combustion plants, installing a flow monitor with each PM-CEMS will enable the determination of the correct average particulate concentration at the main exhaust stack by pro-rata the volume flow of each duct as a portion of the total flow.

The location of the flow monitor should be at a position that is in close proximity to the PM-CEMS but does not interfere with the measurement. Checks for non-cyclonic or non-swirling flow conditions shall be made to ensure the suitability of the sampling site. Calibration of the flow measuring device should be undertaken either before or after installation. Refer to USEPA Performance Specification 6[11] (PS-6) —*Specifications and Test Procedures for Continuous Emission Rate Monitoring Systems in Stationary Sources*.

6.1.2 *NSW Plant Observations Relating to Flue Gas Velocity*

The typical range of flue gas velocities observed at each of the NSW power stations was 14 to 20 m/s. Based on this range there will be an optimal PM-CEMS solution. However, if plant operations become more responsive to markets demands, process conditions (unit load) may fluctuate more frequently or rapidly, resulting in more variable flue gas velocities.

Certain PM-CEMS technology rely on consistent velocity, such as extractive or electrified probe technology, and will be affected by frequent process variations. For example, the sampling rates of extractive systems may become non-isokinetic causing a bias in the measured data. To overcome this issue, the sampling rate will need to be constantly adjusted to maintain an isokinetic sampling rate. However, there are often limitations in the range of adjustments available. This is a high maintenance issue requiring significant operator time or capital investment.

For probe electrification technology, the instrument correlation may be affected by a change in velocity. It may be possible to perform multiple correlations to account for the variation. However, this would add significant cost to the management of the PM-CEMS.

Optical based technologies are not influenced by changes in velocity and are considered a suitable alternative to extractive and probe electrification systems.

6.2 *Temperature and Pressure*

Flue gas temperature and pressure are important factors to consider when selecting a PM-CEMS. Under extreme circumstances they can affect the operation, performance and correlation of PM-CEMS. This is normally experienced in conditions such as a temperature >400^{o}C and static pressure outside the range of -50 to +20 hPa.

The other consideration for PM-CEMS is the environmental temperatures and exposure to the elements. Direct sunlight and extreme temperatures can cause instrument malfunctions and increase the service frequency. Consideration towards having robust weather protection should be factored when reviewing the application.

It is important that a PM-CEMS is constructed from materials appropriate for the expected temperature ranges of the given application. To ensure the suitability of a PM-CEMS, it is not only important to understand the expected range of flue gas temperatures (maximum and minimum), but also the variation and expected frequency and duration of extreme temperature events.

For example, the temperature of the flue gas is expected to be at ambient conditions during a plant shutdown. However, as combustion takes place the temperature rises rapidly. Rapid heating and cooling can cause stress on a PM-CEMS through expansion and contraction of equipment parts and joints causing cracks and leaks. Leaking equipment may lead to equipment blockages, fouling of equipment and sample dilution through the introduction of ingress air. Extreme temperatures may result in permanent deformation of equipment.

When the flue gas temperature drops below the acid dew point (e.g. sulfur dioxide condensing to sulfuric acid), low temperature corrosion may occur (see further detail regarding acid formation provided in Section 6.3 below).

Flue gas temperature is typically measured using a temperature sensor such as a thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gauge capable of measuring temperatures to within 1.5 percent of the minimum absolute stack temperature. A common type of thermocouple material for flue gas measurements is the K-type, however there are a number of other types available. Thermocouple manufacturers usually specify the accuracy, and temperature range of temperature for the given application.

Temperature and pressure should be measured in accordance with USEPA Method 2 - *Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube).*

6.2.1 NSW Plant Observations Relating to Flue Gas Temperature and Pressure

The observed flue gas temperature at each of the large combustion plants ranged between 115-150 ^{O}C. The pressure typical of the flue gas at the observed plants ranged from -10 to -400 millimeters of water (mmH_2O) or -98 to -3920 pascals (pa).

The temperature and pressure ranges are considered to be within the normal range for all PM-CEMS technology. As such, the selection of the PM-CEMS are unlikely to be influenced by these conditions.

It was observed at each of the facilities, that water spray systems and dilution air ports are used to decrease the temperature of the flue gas, prior to the baghouse, to protect the filter fabric from excessive temperatures. As such, it is unlikely that temperature extremes will be present downstream of the baghouses, where a PM-CEMS would most likely be installed. However, data was not available on the frequency and duration of extreme temperature events.

It is therefore recommended that the full range of temperature and pressure conditions likely to occur at the facility be fully assessed and used to inform appropriate PM-CEMS selection. Flue gas conditions found to be outside the normal operating range for PM-CEMS equipment would require careful selection and possible customisation.

6.3 Pollutant Gases

Pollutant gases in the flue gas are typically generated from the combustion process and are dependent on fuel quality and composition. The types of pollutant gases that are considered are nitrogen oxides, sulfur oxides and acid gases (including hydrogen chloride, chlorine and fluorine). Other inert gases generally have little influence on the instrument performance.

Though the presence of pollutant gases may not have an immediate influence on the PM-CEMS technologies, they may have long-term effects such as increased maintenance due to low temperature corrosion. Low temperature corrosion is caused when the flue gas temperature drops below the acid dew point temperature. The acid dew point of a flue gas is the temperature, at a given pressure, at which any gaseous acid in the flue gas will start to condense into liquid acid. Low temperature corrosion can affect the metal and rubber components of a PM-CEMS. Condensable acid gas aerosols (droplets) may also interfere with a PM-CEMS measurement.

There are many factors that affect the acid dew-point temperature of the flue gas, such as fly ash and sulfur content (sulfur dioxide and sulfuric acid mist), water vapor content and flue gas pressure. There are various methods for calculating acid dew point. However, there is no unified and standard method for the calculation of acid dew-point temperature at present[12]. Historic measurement data could be used to inform potential for acid mist in the ducts and for calculating the acid dew point. It is recommended that the acid due point be determined in consultation with an engineer with the adequate knowledge and experience.

Measurement probes are also available for the determination of acid dew point. However, it is recommended the monitoring equipment be operated by a technician with the relevant skills and experience.

Pollutant gases can be measured using the methods listed in the Approved Methods, including;

Table 4: NSW EPA Approved Methods

Method Number	Method Name
TM-3	Sulfuric acid mist (H_2SO_4) or sulfur trioxide (SO_3)
TM-4	Sulfur dioxide
TM-7	Chlorine
TM-8	Hydrogen chloride
TM-9	Fluorine

6.3.1 NSW Plant Observations Relevant to Pollutant Gases

Based on the typical gas composition data provided for each of the NSW coal fired power stations, it is unlikely pollutant gases will adversely impact the ability to install and verify a PM-CEMS. However, the sampling ports at certain facilities appeared to be affected by corrosion indicating the likelihood of acid gases causing low temperature corrosion at the monitoring planes of some facilities.

It is therefore recommended that the likelihood of weak acid formation, present at the monitoring location of each facility, be assessed and used to inform appropriate PM-CEMS selection. All relevant flue gas composition data should be provided to equipment suppliers to ensure the technology and materials are suitable for the application. Additional precautionary measures such as the development of robust maintenance procedures may need to be considered to minimise the effects of corrosion.

Where there is a possibility of high concentrations of corrosive gases its recommended to avoid PM-CEMS that use in-situ probes either for extraction or impact measurements.

6.4 Moisture

Moisture is present in the flue gas as a product of combustion process and is typically measured as a percent on a volume basis (% v/v). The moisture content of the flue gas is dependent on:

1. moisture content in fuel
2. water (H_20) formed by the combustion of hydrogen in the fuel
3. moisture in air required for the combustion of fuel.

A saturated flue gas is where there is free moisture and or liquid droplets in the gas stream at the measurement plane under normal operating conditions. This has a direct influence on certain PM-CEMS as an interferent. All in-situ optical and electrified probe technologies respond to liquid droplets in the sample gas stream and are considered inappropriate for saturated or nearly saturated applications. The reason is that water droplets act and are detected as particulate material biasing the data in a positive manner. The influence of saturated gases cannot be dealt with through the correlation process.

The method for evaluating a saturated gas is to measure the moisture concentration of the flue gas using NSW EPA TM-22—*Moisture content in stack gases.* By knowing the stack temperature and pressure the dew point can be determined and compared to the stack conditions. If the conditions are below the moisture dew point, then appropriate PM-CEMS selection is required.

An extractive PM-CEMS which dilutes and heats the sample for analysis should be considered appropriate for these conditions. Either extractive beta gauge or optical light scattering technologies are available.

6.4.1 NSW Plant Observations Relevant to Saturated Flue Gas

The typical moisture content measured at the observed facilities ranged between 6 % and 11 %. Based on the moisture content range and the typical flue gas temperatures (115-150 ^{O}C) at the facilities observed, it is unlikely that free moisture would be present at the monitoring planes.

It is recommended the moisture content of the flue gas at the monitoring plane be evaluated to determine the likely range and to confirm free moisture is not present. All moisture data should be provided to equipment suppliers to inform appropriate selection of PM-CEMS technology.

6.5 Monitoring Plane

The monitoring plane is the location on the stack or duct where flue gas measurements are undertaken. For the purposes of this guidance document, the monitoring plane is considered to be the location a PM-CEMS is installed.

A monitoring plane should be selected that minimises problems due to: flow disturbances, cyclonic flow, and varying PM stratification. The PM-CEMS must be installed at an accessible location downstream of all pollution control equipment that is most representative of PM emissions. Wherever possible, a location should be chosen where the PM is not significantly stratified across the monitoring plane and where a correlation can be achieved against a manual refence method. Guidance on the selection of monitoring planes for PM-CEMS installation is provided in USEPA PS-11.

In NSW the monitoring plane is selected in accordance with NSW EPA TM-1, *Selection of sampling positions.* TM-1 references two methods, AS4323.1[13] or USEPA Method 1[14]. An ideal monitoring plane location, as per USEPA Method 1, is eight stack diameters downstream and two stack diameters upstream of flow disturbances. When the monitoring plane does not meet this criterion then it is said to be non-ideal.

A non-ideal monitoring plane may still be used, if it can be demonstrated, to the satisfaction of the EPA, that an adequately representative measurement can be achieved.

Additional considerations regarding the location of a PM-CEMS include:

- It is always accessible for service and maintenance
- It is installed downstream of particulate control devices
- Ambient light is not present – such as away from the stack exit and places where light leaks into the stack – to ensure the monitor does not respond to ambient or background light

The primary method for evaluating the suitability of a monitoring location prior to installing a PM-CEMS is to conduct a stratification test as outlined in Section 6.6.1. Following installation, if a PM-CEMS meets the performance criteria of PS-11 then the monitoring plane is said to be suitable.

If the mean particle size (D_{50}) is equivalent to PM 1.0 µm then the particles are said to behave more like a gas[15] and tend to be less influenced by stratification. As such, the monitoring plane should be acceptable. Though an in-stack particle size distribution analysis would need to be conducted to confirm the condition.

6.5.1 NSW Plant Observations Relevant to Monitoring Plane

The following items were identified across the individual power stations during the site visits as factors affecting the selection of the monitoring planes:

- Very short straight section duct lengths – Non-ideal locations
- Horizontal ducts
- Inclined ducts
- Close to bends
- Close to ID fans
- Very large ducts – 6m x 6m dimensions
- Potential for stratification

Other factors limiting monitoring location include:

- The provision of adequate access to service and maintain the PM-CEMS
- The ability to collect reference method samples at the monitoring plane location

6.6 Stratification

Stratification of a gas stream in a duct is a condition in which one or more characteristics of the gas stream differ significantly over the cross-section of the duct or stack. Stratification can be problematic for PM-CEMS when establishing the initial correlation and meeting the correlation criteria of PS-11.

The primary factors responsible for particle stratification are the size, mass density, and velocity of the particles, the duct configuration and the degree of mixing in the gas stream. Particle shape also affects stratification, but in most cases, to a much lesser degree than do the other factors listed above. Stratification of PM usually results from a combination of these factors, so it can be misleading to discuss these factors independently of one another.

Stratification of particles is generally more severe than gaseous pollutant stratification because of the inertial forces that act on PM but do not affect gases. For a specific gas stream velocity, the magnitude of the inertial forces is largely a function of particle size and mass density. Stratification is more likely to occur in gas streams with particles that are larger than 1.0 µm, and the likelihood for stratification increases with increasing particle size and density. Any factor that affects particle size can also affect the severity of PM stratification.

Though stratification may occur in vertical ducts or stacks, it would be more likely to occur in ducts or stacks in a non-vertical position, such as an incline or horizontal orientation. In these cases, the particles will stratify due to gravity based on particle mass and velocity affects. If the velocity is high, then it is likely that the particles will carry sufficient momentum and not to fall out of the gas path.

Stratification is more likely to occur immediately downstream of a disturbance in a duct. Specifically, stratification can be present in the following locations:

- Immediately downstream of a bend
- Downstream of any obstruction that results in changes in the velocity of the exhaust stream
- Downstream of a junction in the duct where an additional exhaust or air stream is introduced to the duct
- Along any nonvertical section of duct where the exhaust gas velocity is relatively low
- Along long sections of nonvertical ducts.

Where the monitoring location is not ideal or does not meet the alternative criteria then a stratification test should be conducted to evaluate the location. The stratification tests should include particulate, diluents and flowrate.

6.6.1 Stratification Evaluation Procedure

Determining the presence of particle stratification in a duct can be carried out by following the same general steps specified for gaseous pollutants[16]. It is recommended to use USEPA Performance Specification 2[17] (PS-2): *Specifications and Test Procedures for SO_2 and NOx Continuous Emission Monitoring Systems in Stationary Sources* as it includes procedures for evaluating gaseous pollutant stratification.

The basic procedure for evaluating stratification is to sample over the cross-section of the duct and compare the concentrations at each sampling point to the average concentration for the cross-section. For rectangular ducts, a minimum of nine sampling points is recommended, with each point located at the centroid of similarly shaped, equal area divisions of the duct cross-section. Isokinetic sampling should be used at all sampling points during a stratification test.

Stratification should be evaluated in accordance with a robust test plan outlining how the testing will be performed. A stratification test plan should, at a minimum, consider:

- The minimum sampling time at each point (typically between 15 and 60 minutes)
- Number of sampling points and traverses. For very large ducts a cross section of traverse points maybe selected to determine the stratification level
- Particulate concentrations
- Potential for temporal variations in PM concentrations over the duration of the stratification test. Stable conditions are required during the sample collection period to ensure stratification is measured rather than process/pollution control variability
- How the data will be interpreted and evaluated

The level of stratification can be determined by calculating the percent stratification value at each sampling point and comparing it to a standard[16]. However, as noted above, the presence of stratification does not necessarily have an adverse effect on the correlation.

An alternative stratification procedure may be adopted where two reference method sampling trains are used for the analysis[16].

6.7 Particulate Characteristics

The particle characteristics are influenced by numerous factors including fuel type and composition, process conditions and performance of the pollution control equipment. Particulate characteristics such as particle size, composition, colour and shape have an influence on optical and electrified probe PM-CEMS. With optical instruments, the change in particle characteristics changes the interaction with the light and subsequent instrument response.

Optical technologies account for particle size, colour and shape through the correlation of the PM-CEMS within the application. If the characteristics are variable, then it may require multiple correlations or alternative PM-CEMS technology.

With electrified probe devices particle size, charge, composition and mass are also accounted for through the correlation of the PM-CEMS within the application. If the characteristics are variable, then it may require multiple correlations or alternative PM-CEMS technology.

Since beta (β) gauge type instruments are much less sensitive to changes in particle characteristics when compared with optical and electrified probe-based instruments, they are more appropriate for sample gas streams that are likely to have highly variable particle size distributions associated with the operation such as electrostatic precipitators and or changing fuels.

Particle characteristics may be evaluated by using various techniques including: 1) scanning electron microscopy (SEM) where size, shape and colour can be observed or 2) in-stack sizing techniques such as cascade impactors with subsequent chemical analysis. This will provide some information about the particle characteristics, though what is important is to understand is the variability of these characteristics as it is the variability that will alter the correlation of the PM-CEMS rather than the actual characteristics.

6.7.1 NSW Plant Observations Relating to Particulate Characteristics

Limited information was available regarding the site-specific particle characteristics at the observed plants. However, morphological analysis shows that the particle emissions from pulverised coal-fired plant is composed of regular, spherical particles. Particulate emissions from coal-fired power stations with high efficiency bag filter houses result in concentration lower than 30 mg/Nm^3.

The mean particulate size distribution (D_{50}) from a fabric filter baghouse in good working order should be PM 2.5µm or less[1]. If there is bag deterioration or failure over time then the distribution may change and D50 is likely to be much greater than 2.5 µm. Furthermore, the particle characteristics such as colour and shape may also change. In this case it is possible that an initial PM-CEMS correlation will not hold.

There are three strategies to manage this scenario, which are as follows:

1. If the source generates 24 consecutive hourly average PM CEMS responses that are greater than 125 percent of the highest PM CEMS response used to establish the original correlation curve, then additional correlation testing (minimum of three tests) is required to update the curve. This will account for any new changes with particle characteristics. As per the guidance in USEPA Procedure – 2[3].
2. If the particulate concentration elevates quickly then it is possible that there is a bag failure. This can be investigated, and filters changed or capped to return the emissions back to typical levels.
3. Perform the initial correlation curve with a broken or deteriorated bag creating elevated levels to include a larger range of particle sizes.

Alternatively, extractive beta gauge technology is not affected by changing particle size and characteristics as it measures particle mass directly.

6.8 Particulate Loading

Where baghouse pollution control equipment is installed, the concentration for particulates is typically expected to be low (<30 mg/Nm^3)[18] when the pollution control equipment is working optimally. When particulate concentrations are low, the sensitivity of a PM-CEMS instrument needs to be carefully considered.

With optical methods, transmission technology is less sensitive than light scatter and achieving correlations at low concentrations has been found to be difficult. In comparison light scatter instruments have a higher precision and accuracy for particulate concentrations at <10 mg/Nm^3. This technique has been successfully demonstrated across Australia on large combustion plant including coal fired power stations with fabric filter baghouse control technology installed.

Extractive beta gauge instruments are designed to measure very low concentrations; however, the technique is based on an integrated run time approach and therefore does not report particulates continuously. Typically, sample run times are an average of 30-minute time periods.

Electrified induction probe devices are said to be sensitive at low concentrations but the ability of the instrument to measure low concentrations with accuracy and precision is dependent on how it is initially set-up and the associated application.

Particulate loading can be determined using a manual gravimetric reference method test as described in Section 6.8.1.

6.8.1 Reference Method Sampling

The manual reference method testing (particulate matter stack test) must be performed in accordance with NSW EPA Test Method 15 (TM-15). It is highly recommended that paired sampling trains are used for the manual reference method testing, particularly for low concentration sources. The manual reference method testing should be conducted over a suitable particulate concentration range that corresponds to the full range of normal process and control device operating conditions.

Reference method testing should be conducted at a location considered representative (or able to provide data that can be corrected to be representative) of the total particle emissions as determined by the manual reference method.

As the manual reference method testing for correlation test is not being undertaken for compliance purposes, the reference method test runs can be less than the typical minimum test run duration required by TM-15.

Further guidance on performing the reference method sampling is provided in PS-11 and reference methods listed under TM-15 in the Approved Methods.

Reference method test results must be corrected to a reference oxygen (O_2) or carbon dioxide (CO_2) condition. Typically, at large coal fired combustion plant, corrections to 7% O_2 or 12% CO_2 are used. Where particulate matter is continuously measured, O_2 and or CO_2 should also be continuously monitored using a diluent CEMS system or similar and appropriate performance testing undertaken.

6.8.2 Diluent CEMS

Diluent CEMS are monitoring systems designed to measure CO_2 and or O_2 concentrations in the duct or flue gas on a continuous basis.

Diluent CEMS are important to PM-CEMS monitoring programs as particulate concentration data generated from these instruments are required to be normalised either to an O_2 or CO_2 standard. This is to take account for any dilution associated with process control such as fresh air intake for bag house temperatures management.

O_2 and CO_2 dilution CEMS should be sampled at a location point in close proximity to the PM-CEMS but avoiding any interference. The specification for evaluating acceptability of O_2 and CO_2 CEMS is USEPA Performance Specification 3[19] (PS-3) —*Specifications and Test Procedures for O_2 and CO_2 Continuous Emission Monitoring Systems in Stationary Sources*.

6.8.3 NSW Plant Observations Relevant to Particulate Loading

The five NSW power stations all use fabric filters to control particulate emissions and as such it is expected the typical particle loading will be low. From the data provided, particle emission concentrations typically range between 5 and 50 mg/m^3.

The selection of a PM-CEMS for low particle concentration applications need to be carefully considered. Less sensitive instruments may struggle to meet PS-11 or equivalent correlation requirements Typically, less-sensitive instruments have poor precision at lower concentrations which can result in a poor correlation factor being determined.

PM-CEMS that are more sensitive at the lower range, such as optical scatter, extractive beta gauge and some probe electrification devices, are typically considered more appropriate for low particle concentration sources.

6.9 Feasibility of Installing PM-CEMS at Large Combustion Plant in NSW

Based on the observed combustion plants, the installation and operation of PM-CEMS appeared to be generally feasible in all instances. It is recommended that each facility perform their own independent application review, taking into account the site installation requirements, stack gas characteristics, particle characteristics and process operating conditions.

It is recommended that PS-11 be used to establish the initial installation and performance procedures for evaluating the acceptability of installed PM-CEMS at large combustion plant in NSW. The ongoing performance of installed PM-CEMS should be evaluated using quality assurance procedures developed in accordance with USEPA Procedure 2.

Where a PM-CEMS is installed, flue gas velocity should be continuously measured to ensure accurate determination of flue gas flow rate. It is recommended flue gas velocity monitors be installed, operated and maintained in accordance with PS-6.

If PM-CEMS data is required to be reported at a standard O_2 or CO_2 reference condition, it is recommended that an O_2 and or CO_2 measurement system be installed to measure these parameters on a continuous basis. PS-2 should be used for evaluating the acceptability of installed O_2 and CO_2 CEMS.

7 MEASUREMENT TECHNOLOGY

This section presents a summary of the common PM-CEMS technologies available and adopted by large combustion plant facilities.

A comment on whether each measurement principle is suitable for the proposed application of large combustion facilities is made based on the general industry observations. Due to the range of potential technology variations, the descriptions provided are generalised for informational purposes.

7.1 Optical Light Scattering

A light scatter instrument measures the amount of light scattered by reflection or refraction in a particular direction (forward, side, or backward) and outputs a signal proportional to the amount of particulate matter in the stream.

Back scatter, as shown Figure 3, devices are particularly suitable for in-situ applications in small ducts, where low levels of dust are present. The low angle of back scatter measurement increases the effective penetration of the measurement volume into the stack but makes the instrument less sensitive to fine particles.

There are three types of forward scatter devices currently available : (i) the extractive type, (ii) probe configuration and (iii) cross duct configuration.

Extractive devices draw a flue gas sample from the stack via a sampling nozzle and then presents it to a forward scattering photometer. The sensor measures the amount of light scattered from particles in the stack illuminated by a modulated red laser. The advantage of this system is the ability to heat the sampling system, which is important where there are significant amounts of moisture in the flue gas.

Probe forward scatter instruments have a measurement volume at the tip of a probe and measures the light scattered at a forward angle to the incident beam (typically coming from a laser diode). This instrument can provide high accuracy measurement in a variety of low and high particle concentration applications.

The cross duct forward scatter instrument has a transmitter and a receiver opposite each other on the stack. A diode laser projects a beam of light into the stack: part of the beam is attenuated, and some is scattered by the particulate. The receiver has a large lens behind which are two photo-detectors, the nearer lens detects a transmission signal and the further, the scattered component.

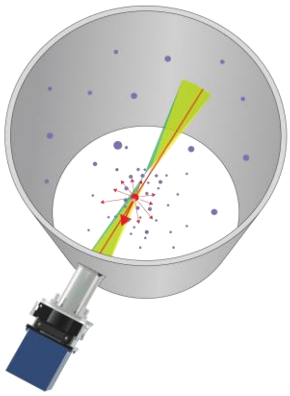

Figure 3 – Example of Optical Light Scatter Technology – Back Scatter[20]

7.2 Extractive Beta Gauge

The Beta Gauge measuring system extracts particulate laden gas isokinetically from the duct via a small nozzle. Particulates are collected on a filter tape and then presented to a β-gauge to measure the mass. The beta gauge works by measuring beta counts before and after collecting PM on the filter media. The attenuation of intensity in beta rays is proportional to the amount of material present.

Extractive Beta Gauge or β-gauge samplers are the only systems which continuously measure the mass concentration of particulate by extraction. The two main components of a beta attenuation measuring system are the beta source, generally Carbon-14, and the detector. Many different types of detectors can quantify beta particle counts, but the ones most widely used are the Geiger Mueller counter or a photodiode detector. An example of a Beta Gauge sampling system is shown in Figure 4.

A key advantage of β-gauge samplers is that they are not affected by chemical composition, size or colour changes in the particles, and the use of a heated probe obviates water effects. However, they do not provide short term dynamic monitoring of particulates and a single point measurement may not always be representative. The heated isokinetic sampling train may also be prone to maintenance problems.

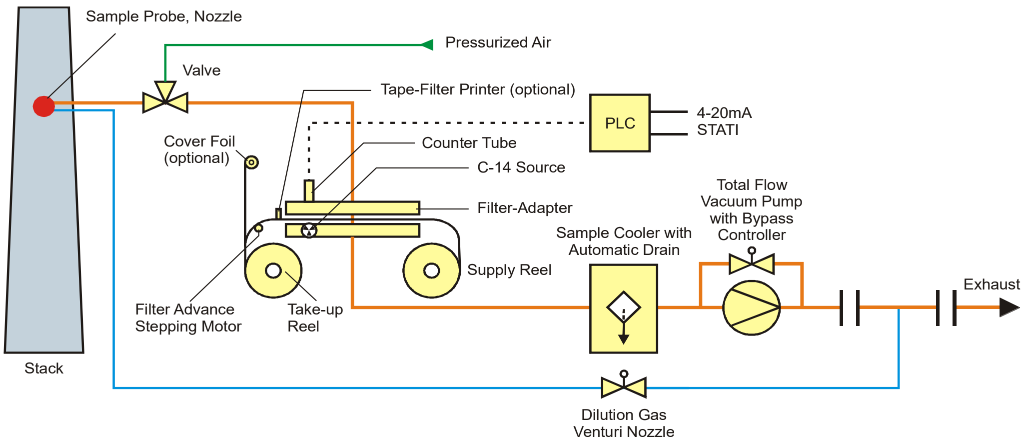

Figure 4 – Example of β-Gauge Attenuation Technology[20]

7.3 Probe Electrification

Probe electrification technologies can be broadly separated into two types, Triboelectric and Electrodynamic instruments.

7.3.1 Triboelectric Instruments

Triboelectric devices detect three separate effects when particulate strikes or passes close to a conductor placed in a particle laden gas stream:

(i) when a particle strikes the conductor, a charge transfer takes place between particle and conductor

(ii) as the particle strikes the conductor it rubs on the surface and causes a frictional charge

(iii) as charged particles pass close to the conductor, they induce a charge of equal and opposite magnitude in the conductor.

The amount of charge generated by the first two effects depends on the velocity of the particle, its mass and the charge history of the particle, while the third effect is an inductive charge.

Triboelectric monitors are very sensitive to low levels of particulate concentration. They work best where the particulate material is non-conductive.

Since the response of the probe is sensitive to gas velocity, these systems are most suited to situations where the gas flow is constant. Probe electrification does not work well in wet gas streams with water droplets or when the particles are subject to a varying electrical charge.

Shown below in Figure 5 is a simplified example of a Triboelectric probe setup.

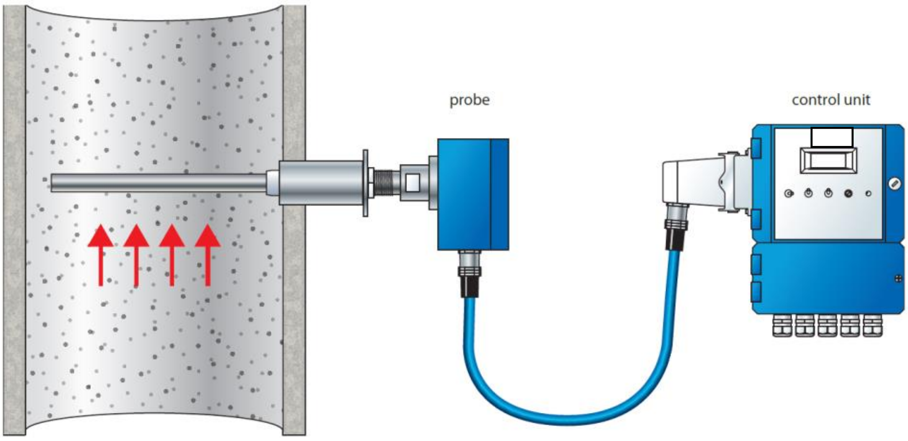

Figure 5 – Example of Triboelectric Technology[20]

7.3.2 Electrodynamic Instruments

Like triboelectric devices, the sensor measures the current created by particles passing and colliding with a grounded sensor rod inserted into the duct or stack. However, unique to ElectroDynamic™ instruments, the sensor electronics filter out the dc current created by particle collisions on the rod and measures an RMS signal within an optimised frequency bandwidth which results from the particles passing and colliding with the rod. This signal, being independent of the rod surface condition, has a stable and repeatable relationship to dust concentration in many types of industrial applications. In applications where the particle charge, particle size and particle distribution remain constant the resulting Alternating Current (AC) is proportional to particle concentration.

The instrument response of these probes is said to be less sensitive to the effects of changing velocity in the range of 8-20m/s[21].

An example of electrodynamic induction probe technology is provided in Figure 6.

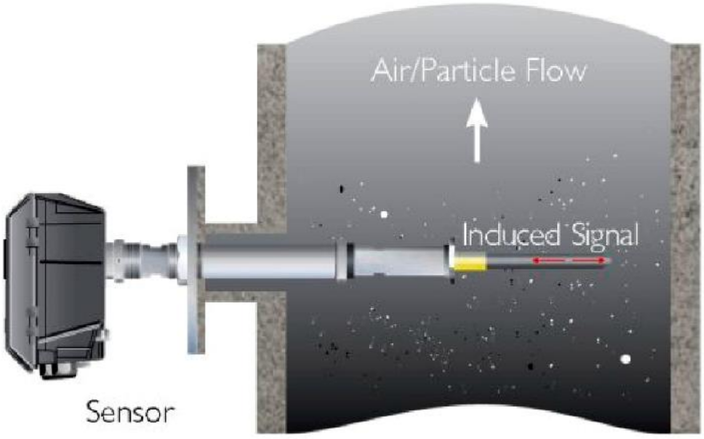

Figure 6 – Example of Electrostatic Induction Probe Technology[18]

7.4 Optical Transmission - Extinction

Optical transmission (opacity) meters measure the decrease in light intensity due to absorption and scattering as the beam crosses the stack according to Beers-Lambert's Law. The basic operational principle of these instruments is that a collimated beam of visible light is directed through a gas stream toward receiving optics. The receiving optics measure the decrease in light intensity, and the instrument electronics convert the signal to an instrument output. These instruments measure particle density in transmission, opacity, Ringelmann units or optical density (extinction) and/or mass concentration of particulate in mg/Nm^3 with a correlation.

The intensity of the light at the detector, I, is compared with the reference light intensity, Io, to give the transmittance T, as shown in Equation (2):

$$T = \frac{I}{Io} \quad (2)$$

Transmittance can be converted to opacity Op (Equation (3)) or optical density D (Equation (4)):

$$Opacity = 1 - T \quad (3)$$

$$Optical\ Density\ (Extinction) = \log_{10}(\frac{1}{T}) \quad (4)$$

The loss of light intensity can be correlated to particulate mass concentration measured by manual gravimetric sampling.

There are two formats for opacity devices. Single path monitors simply project a beam across a duct to a receiver. Dual beam devices have a reflector mirror on the opposite side of the stack from the light source and the beam is projected between two transceivers. This enables each transceiver to compensate for gradual window contamination by using clean mirrors inserted periodically into the beam path. In this way, any errors caused by misalignment of the sensors may be compensated for.

An opacity meter used as PM-CEMS should use a red or near infrared light source, and not the white light source used on traditional opacity monitors since the extinction-to-mass concentration for a given aerosol type is dependent on particle size within the visible light spectrum but nearly independent of particle size at the infrared wavelength. Some manufacturers have started using a green LED to monitor both opacity and PM concentration simultaneously.

Opacity measurements are dependent on particle size, composition, shape, colour and refractive index. These properties may change with fuel type and thus calibration is necessary with variation of process conditions. The measurement sensitivity of opacity meters is not fine enough to detect small changes in PM concentration. Opacity systems require a high level of maintenance to prevent dust contamination on the lens which can reduce their performance.

Shown in Figure 7 below is an example of a dual pass transmissometer.

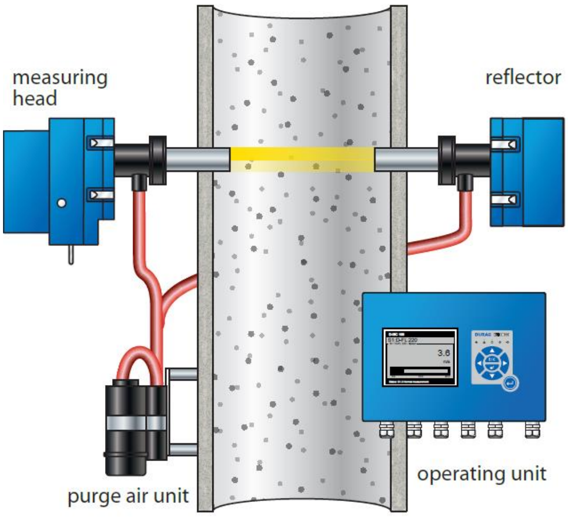

Figure 7 – Example of Tramission Technology[20]

7.5 Optical Scintillation

Optical scintillation, like light extinction, utilises a light source and a remote receiver that measures the amount of received light. The difference is that the scintillation monitor uses a wide beam of light, no focusing lenses, and the receiver measures the modulation of the light frequency due to the movement of particles through the light beam and not the extinction of light. The principles at work here are that the particles in a gas stream will momentarily interrupt the light beam and cause a variation in the amplitude of the light received (scintillation). The greater the particle concentration in the gas stream the greater the variation in the amplitude of the light signal received. The scintillation monitor must be calibrated to manual gravimetric measurements at the specific source on which it is installed.

This method offers a significant advantage over traditional opacity methods, as the ratio metric measurement is unaffected by lens contamination allowing the instrument to operate with significant lens contamination. Since both the reduction in light intensity and the variation in intensity caused by lens contamination are affected by the same proportion, it results in no net effect.

Optical scintillation is not considered suitable for applications where short-term process changes cause a large variation in the particle size distribution.

7.6 Harmonic Oscillation

Harmonic oscillation instruments measure the mass of particles continuously collected on a filter mounted on the tip of a glass element which oscillates in an applied electric field.

Sampled air passes from the sampling inlet, through a hollow tapered tube. The wide end of the tube is fixed, while the narrow end oscillates in response to an applied electric field. A filter is attached to the narrow end of the tube and an electronic sensor measures the vibration of the tube. As the mass increases in the tube and on the filter the frequency of oscillation is also altered. The mass collected on the filter can be determined by comparing the baseline frequency to the frequency at any time.

Once the filter becomes saturated, the instrument must be taken offline for filter replacement, which requires significant maintenance requirements and instrument downtime.

7.7 Comparison of PM-CEMS Technologies

As there are several different types of technologies available for continuous particulate concentration measurements, it is important to compare and evaluate the optimal technology for individual applications. Table 5 details various characteristics for general applications.

Table 5: PM-CEMS Technology Comparison

Criteria	**PM-CEMS Principle of Operation**					
	Optical Transmission	Optical Light Scattering	Extractive Beta Gauge	Probe Electrification	Optical Scintillation	Harmonic Oscillation
Method of Measurement	Amount of light attenuated by particles	Amount of light scattered by particles	Amount of beta rays attenuated by particles	Electrical current generated by particle friction, charge or impact	Variations in amplitude of light due to particles	Change in oscillation due to mass collected on filter
Installation Configuration	In-Situ[1]	In-Situ[1]	Extractive	In-Situ[1]	In-Situ[1]	Extractive
Continuous or Batch	Continuous	Continuous	Batch	Continuous	Continuous	Batch
Extent of Use on Large Combustion Plant	Wide Spread Use	Wide Spread Use	Rare	Used mainly for fabric filter bag leak detection	Limited	Rare
History of Use	Long History	Long History	Long History, though stopping production	Long History as bag filter detectors	Short History	Short History
Particle Characteristics	Highly Dependent	Highly Dependent	Less Dependent	Highly Dependent	Highly Dependent	Not Dependent
Interferences	Water Droplets	Water Droplets	None	Electrical Fields and Water Droplets	Water Droplets	None
Other Comments	May not be appropriate for wet scrubber controlled sources and difficult to correlate low concentrations	May not be appropriate for wet scrubber controlled sources		Not appropriate for ESP controlled sources and difficult to correlate	May not be appropriate for wet scrubber controlled sources	Current design for short term use only (3 days)
Documented Problems in Meeting Correlation Criteria for Performance Specification 11	Yes, for low concentration applications <30mg/Nm^3	No	No	Yes, for low concentration applications <30mg/Nm^3	No	No

[1] In-Situ measurement systems are described in Section 7.9

7.8 *Application Technology Guide*

Table 6 details information relating to the effectiveness of various technologies for the use within the NSW coal fired power industry using fabric filter baghouses as the pollution control technology. The application assumes that the pollution control equipment is working in a controlled manner. The application also assumes industry will be operating with variable loads.

Table 6: Application Technology Assessment for the NSW Coal Fired Power Industry

Parameter	Optical Transmission	Optical Light Scatter	Extractive Beta Gauge	Probe Electrification	Optical Scintillation	Harmonic Oscillation
Low particle concentration (< 30 mg/m³)	poor	excellent	excellent	satisfactory	poor	excellent
Dry stack (above dew point)	good	good	good	good	good	good
Humidity (non-condensing) constant	good	good	good	good	good	good
Stack diameter Large (> 3 m)	good	good	poor	poor	good	poor
Particle size (limited variation)	good	good	good	good	good	good
Particle colour (limited variation)	good	good	good	good	good	good
Particle density (limited variation)	good	good	good	good	good	good
Gas velocity varying (>±10m/s)	good	good	poor	very poor	good	poor
Life Cycle Cost	moderate	moderate	high	moderate	moderate	high
Use within Industry	very high	high	none	low	low	low

Note: 1. The criteria around "Use Within Industry" is based upon site observations and experience over the past 20 years at large combustion installations around Australia. It is not a measure of performance or ability to perform within the industry.

7.9 *In-situ Measurement*

In-situ systems monitor the flue gas at a stationary point within the stack without extraction. In-situ monitors can be classified into two basic categories, point and path. Point monitors measure at a single point in the stack. Path monitors measure from one side of the stack or duct to the other.

There are several options within the two measurement categories, and each has advantages and disadvantages. Different types of measurement errors and biases can occur, such as those associated with flue gas stratification as discussed in Section 6.6. Errors of measurement specific to the different types of in-situ monitoring systems should be discussed with the equipment supplier to ensure it is appropriate for the application.

An overview of the two in-situ measurement categories is provided below.

7.9.1 Point In-Situ PM-CEMS

A point PM-CEMS takes a sample representative of a single point within the cross-sectional area of the monitoring plane. The measurement point should ideally be located:

- No less than 1.0 metre from the stack wall, or centrally located over the centroidal area of the stack or duct cross section
- When measuring across a horizontal duct the instrument should be installed between a third to half distance of the duct height from the base of the duct.

Variations on these requirements is permissible provided the performance specifications are satisfied for the PM-CEMS in question. Therefore, so long as the PM-CEMS meets the requirements of PS-11 for the correlation coefficient, confidence interval half range, and tolerance interval half range then the location and PM-CEMS can be used for measurement. Figures 8 and 9 provide a visual representation of a measurement point locations for circular and rectangular or square stacks.

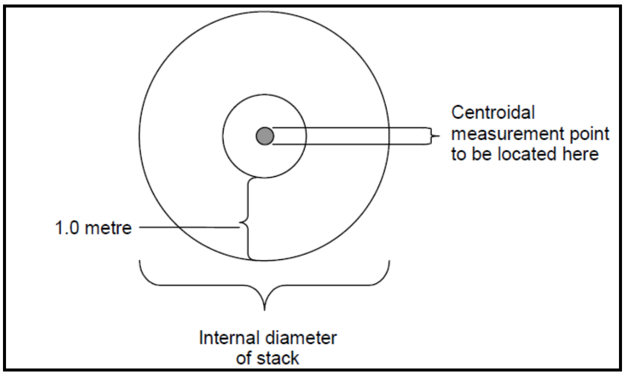

Figure 8 – Point In-Situ Measurement Point Location – Circular Stacks

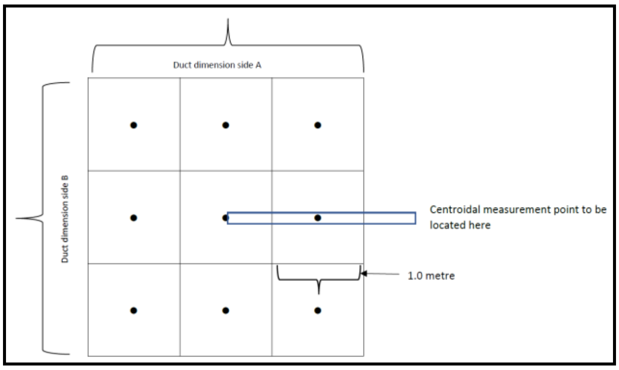

Figure 9 – Point In-Situ Measurement Point Location – Rectangular/Square Stacks

7.9.2 Path In-Situ PM-CEMS

A path in-situ PM-CEMS takes a representative sample of monitoring plane across the duct or stack diameter. The coverage of the path is associated with the beam dimensions. Path monitors can be of either single-pass or double-pass design. Where the PM-CEMS instrumentation uses a path located measurement principle, the path should ideally be located:

- To exclude the area bounded by a line 1.0 metre from the stack or duct wall; or
- Have at least 70 per cent of the path within the inner 50 per cent of the stack or duct cross sectional area; or
- Be centrally located over the centroidal area

Figures 10 and 11 provides a visual representation of the measurement path for path in-situ PM-CEMS.

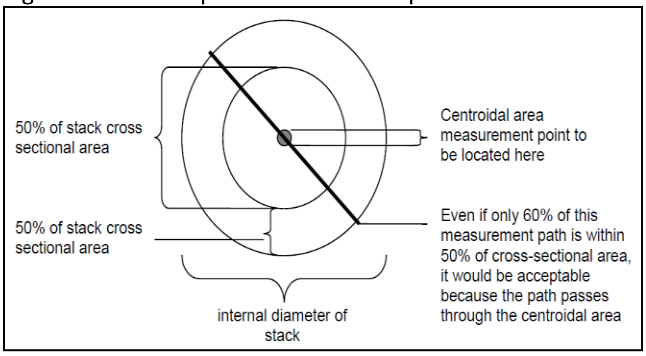

Figure 10 – Path In-Situ PM-CEMS - Circular Stacks

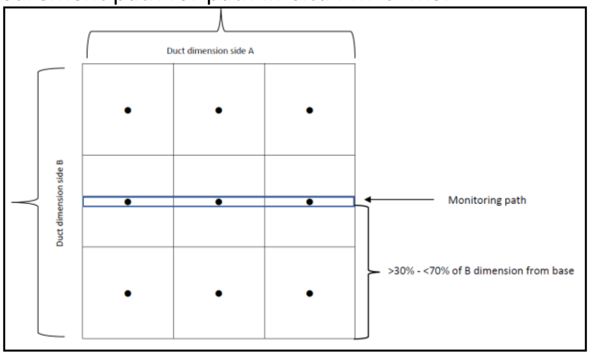

Figure 11 – Path In-Situ PM-CEMS – Square Stacks

8 PROJECT COSTS

The following is a breakdown of costs which could be realised during a PM-CEMS implementation program. These figures are only indicative and should be used as an initial guide only.

8.1 PM-CEMS Costs

Table 7 breaks down the indicative costs for the implementation of a single PM-CEMS in a duct or stack. It does not take into account the possibility of locating the PM-CEMS in a remote location. It assumes the adoption of current available sample ports, signal cables, power cables and access infrastructure. The costs do not take into account the purchase of multiple units and the associated savings of running multiple PM-CEMS program and costs associated with the installation and operation of diluent and flowrate CEMS.

Table 7: PM-CEMS Initial and Ongoing Cost Breakdown

Cost Item	Optical Transmission	Optical Light Scatter	Extractive Beta Gauge[6]	Probe Electrification	Optical Scintillation	Harmonic Oscillation
Planning, Design and Selection[1]	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000
Stratification Testing[2]	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000
Purchase of PM-CEMS	$32,000	$35,000	$150,000	$20,000	$25,000	$90,000
Commissioning[3]	$6,000	$6,000	$12,000	$4,000	$6,000	$12,000
Performance Testing QA/QC Reporting	$18,000	$18,000	$18,000	$18,000	$18,000	$18,000
QA Plan Development – Procedure 2[4]	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000
Initial Cost Upon Installation	$89,000	$92,000	$219,000	$81,000	$80,000	$159,000
Yearly Maintenance	$10,000	$8,000	$30,000	$8,000	$14,000	$30,000
Yearly RRA	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Quarterly ACA	$3,000	$3,000	$15,000	$3,000	$3,000	$15,000
Annual Audit and Update[5]	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000
Ongoing Yearly Cost	$24,000	$22,000	$56,000	$22,000	$28,000	$56,000

1. Optional Cost – Includes Planning, Design and Selection: determined based on the time associated with organisation, design and selection of an applicable PM-CEMS.
2. Stratification test only to be undertaken, if required. To be performed on each type of stack.
3. Commissioning: physical installation of the PM-CEMS and initial start up and checks as per manufacturers requirements.
4. QA Plan Development – Procedure 2: The development of a Quality Assurance Plan that covers the important aspects of the implementation, verification and ongoing operation of PM-CEMS.
5. Optional - Annual Audit and Update: associated with conducting an annual review/audit of the PM-CEMS program and allow for appropriate updates and improvements.
6. Extractive light scatter technology will have similar costs to the beta attenuation technology

9 CHECKLIST

Table 8 serves as a general checklist for conducting site specific evaluations for PM-CEMS applicability for the NSW coal fired power industry. This checklist is provided as a guide only and is intended to be supplementary to USEPA Performance Specification 11.

Table 8: PM-CEMS Evaluation Check List

Item	Description	Check
1	**Evaluate process and stack conditions for the application**	☐
1.1	Assess stack gas velocity over the expected range of standard operating conditions of the plant. Velocity should be determined in accordance with NSW EPA TM-2 or CEM-6. Historic test data may be referenced.	☐
1.2	Assess the typical temperature and pressure ranges of the stack gas. Determine if the temperature is above or below the moisture dew point. Temperature should be determined in accordance with NSW EPA TM-2. Historic test data may be referenced.	☐
1.3	Assess the presence of pollutant gases in the stack gas and determine the acid dew point. Empirical analysis may be used to identify likely pollutant gases, which can be confirmed by conducting reference method tests in accordance with NSW EPA Approved Methods Sampling. Significant changes in fuel type or quality may require further assessment. Historic test data may be referenced.	☐
1.4	Assess the moisture content of the stack gas over the typical operating range of the plant. Moisture should be determined in accordance with NSW EPA TM-22. Historic test data may be referenced.	☐
1.5	Assess the particle characteristics of the stack gas. Characteristics such as size, shape, colour, mass and composition should be assessed if possible. Historic test data may be referenced.	☐
1.6	Assess the typical particulate matter concentration range over the likely range of operating conditions. Particulate matter concentrations should be determined in accordance with NSW EPA TM-15. Historic test data may be referenced.	☐
2	**Evaluate installation locations for PM-CEMS and select most appropriate location**	☐
2.1	Assess the monitoring plane using the guidance provided in NSW EPA TM-1. For non-ideal monitoring planes, a stratification test should be conducted to identify the most representative sampling position within the gas stream.	☐
2.2	Ensure monitoring plane is; • Downstream of all pollution control devices	☐
2.3	• As far practicable from all flow disturbances (bends, changes in diameter, fans etc)	☐
2.4	• At a location that has minimal gas and particle stratification	☐
2.5	• Accessible for servicing and maintenance	☐
2.6	• Adequately protected from extreme weather and contamination	☐
3	**Selection of suitable PM-CEMS for the application**	☐
3.1	Collate the information gathered from steps 1 and 2, above	☐

Item	Description	Check
3.2	Approach reputable service providers to discuss the range of PM-CEMS options available	☐
3.3	Evaluate the range of potential options based on application, concentration range, reliability and life cycle cost	☐
3.4	It is recommended that the instrument have certification such as QAL-1	☐
4	**Develop a PM-CEMS verification monitoring plan in-line with PS-11**	☐
5	**Installation and commissioning of PM-CEMS**	☐
5.1	Refer to manufacturer for installation and commissioning requirements. Installation requirements will vary with instrument type and site specific conditions. Ensure signals and appropriate corrections are considered.	☐
5.2	Before conducting the initial correlation test, a 7-day zero/span drift test is successfully completed as required in PS-11	☐
6	**Undertake performance specification testing for PM-CEMS in accordance with the verification monitoring plan and PS-11**	☐
7	**Evaluate data and perform statistical analysis including derivation and selection of correlation equation in accordance with PS-11**	☐
8	**Develop a Quality Assurance Plan for ongoing PM-CEMS management in accordance with USEPA Procedure 2**	☐

10 REFERENCES

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[3] USEPA 40 CFR 60, Appendix B, Performance Specification 11—Specifications and Test Procedures for Particulate Matter Continuous Emission Monitoring Systems in Stationary Sources

[4] USEPA 40 CFR 60, Appendix F, Procedure 2 Quality Assurance Requirements for Particulate Matter Continuous Emission Monitoring Systems Used at Stationary Sources

[5] EN 15267-1:2009 Air quality. Certification of automated measuring systems. General principles

[6] EN 15267-2:2009 Initial assessment of the AMS manufacturer´s quality management system and post certification surveillance of the manufacturing process

[7] EN 15267-3:2007 Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources

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[10] USEPA 40 CFR 60, Appendix A, Method 2—Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)

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[15] U.S. Environmental Protection Agency. 1997. Handbook: Continuous Emission Monitoring Systems for Non-criteria Pollutants. EPA/625/R-97/001. U.S. Environmental Protection Agency, Office of Research and Development.

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[17] USEPA 40 CFR 60, Appendix B, Performance Specification 2 - Specifications and Test Procedures for SO2, and NOX, Continuous Emission Monitoring Systems in Stationary Sources

[18] Comparative Analysis of Monitoring Devices for Particulate Content in Exhaust Gases Sustainability 2014, 6, 4287-4307; doi:10.3390/su6074287

[19] USEPA 40 CFR 60, Appendix B, Performance Specification 3—Specifications and Test Procedures for O2 and CO2 Continuous Emission Monitoring Systems in Stationary Sources

[20] Figures 3, 4, 5 and 7 are courtesy of DURAG GmbH

[21] PCME – Electrodynamic Technology for Particulate Monitoring by William Averdieck http://groupinstrumentation.com.au/news--resources/dust-monitoring-resources.aspx