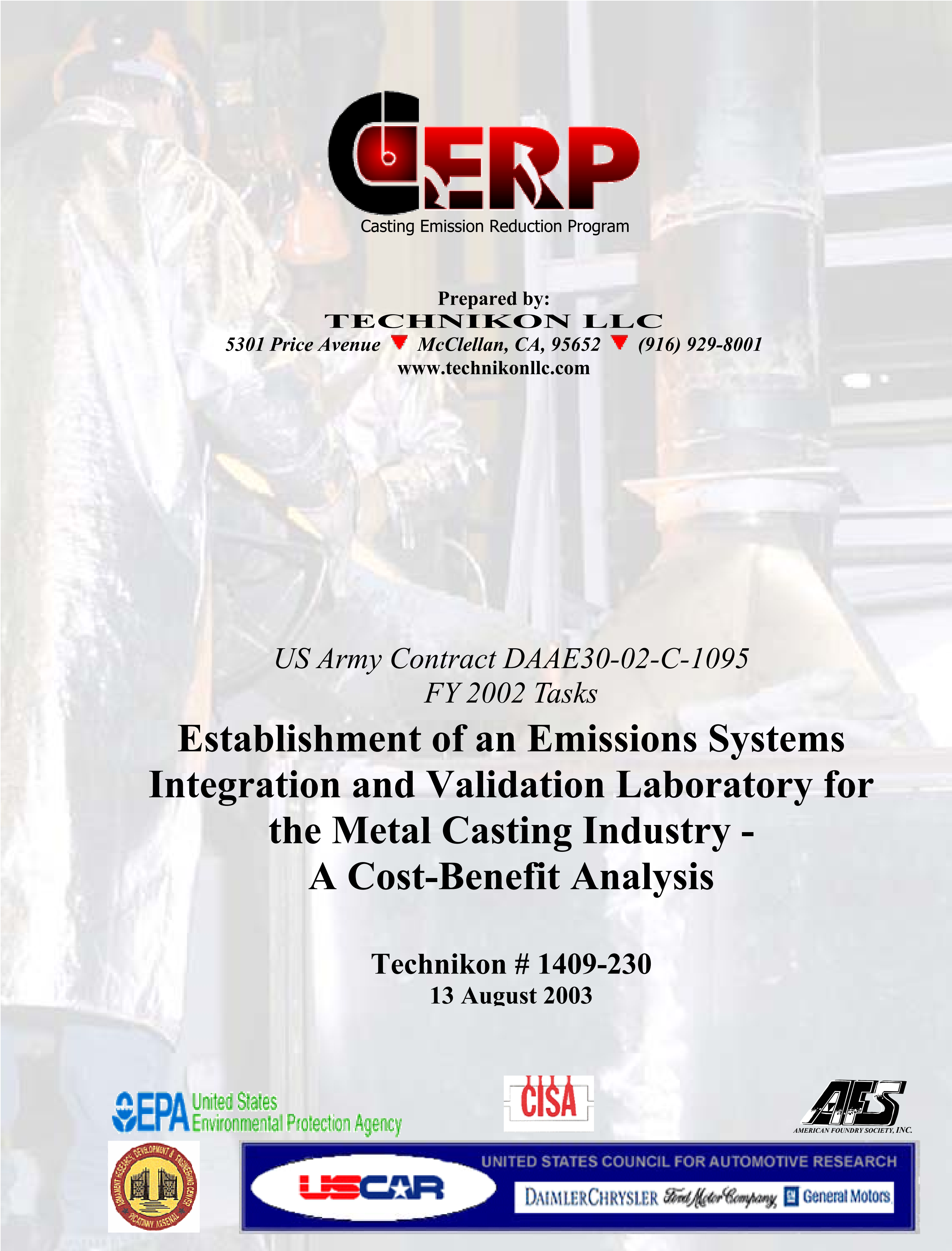
Establishment of a Systems Integration and Validation Laboratory Test Site – A Cost/Benefit Analysis

Technikon Test Plan # 1409-230

WBS # 2.3.0

13 August 2003

THIS PAGE INTENTIONALLY LEFT BLANK



CERP

Casting Emission Reduction Program

Prepared by:

TECHNIKON LLC

5301 Price Avenue ▼ McClellan, CA, 95652 ▼ (916) 929-8001

www.technikonllc.com

US Army Contract DAAE30-02-C-1095

FY 2002 Tasks

Establishment of an Emissions Systems Integration and Validation Laboratory for the Metal Casting Industry - A Cost-Benefit Analysis

Technikon # 1409-230

13 August 2003

EPA United States Environmental Protection Agency

CISA

AFS AMERICAN FOUNDRY SOCIETY, INC.

ARMAMENT RESEARCH, DEVELOPMENT & ENGINEERING CENTER PICATINNY ARSENAL

UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

USCAR

DAIMLERCHRYSLER Ford Motor Company GM General Motors

THIS PAGE INTENTIONALLY LEFT BLANK

Establishment of an Emissions Monitoring Systems Integration and Validation Laboratory for the Metal Casting Industry – A Cost-Benefit Analysis

Technikon # 1409-230

This report has been reviewed for completeness and accuracy and approved for release by the following:

VP Technology and Business Development:	*//Original Signed//* Dennis Schuetzle, Ph.D.	*8/13/03* Date
VP Measurement Technologies:	*//Original Signed//* Clifford Glowacki, CIH	*8/13/03* Date
President:	*//Original Signed//* William Walden	*8/13/03* Date

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

Listing of Tables

Listing of Figures

Appendices

THIS PAGE INTENTIONALLY LEFT BLANK

1.0 Executive Summary

The proposed EPA MACT standards for the metal casting industry will be finalized and promulgated during the September 2003 time frame with an implementation period through 2007. Although there are nearly 2500 U.S. casting plants, not all of these plants will be required to meet the MACT standards. It is estimated that approximately 200 plants will need to meet these standards through fiscal year 2007. Our study concludes that the estimated cost for emissions monitoring, record keeping and reporting will average $71.9 million/year for the industry using current (1st) generation continuous emissions monitoring systems (CEMS) and EPA batch techniques during the first four years of implementation. The conservative cost-benefit analyses presented in this report were based upon anticipated final EPA requirements - if EPA changes their anticipated requirements subsequent to the publication of this report, then an addendum will be published to reflect those changes.

In addition to this significant financial burden, there are insufficient core measurement competencies in the U.S. to adequately support the metal casting industry. No organization has yet been established that has the systems capability for the integration, validation and certification of new measurement technologies. In addition, emerging measurement technologies developed for other industries, such as transportation, have not been adequately validated for metal casting plants. Because of the complex chemical and physical nature of metal casting emissions, instrument developers, manufacturers and integrators have a limited capability to validate their emerging measurement technologies.

This report provides an assessment of the potential benefits to be accrued by the establishment of a Systems Integration and Validation Laboratory (SIVL) for support of the U.S. metal casting industry. A SIVL would provide the industry with a central facility for the development, validation and implementation of low-cost, reliable emissions measurement technologies. In addition, it could take the lead in the development and validation of low-cost and reliable CEMS that are likely to represent the next generation of lower-cost, more reliable emissions monitoring technologies. The cost analysis provided in this paper forecasts that through the establishment of a SIVL, and the successful development of inexpensive and reliable 2nd generation CEMS systems, the industry could save up to $21.3 million/year during 2004-2006 and up to $36.9 million/year for 2007 and beyond if 3rd generation CEMS systems can be successfully validated and implemented.

The Casting Emission Reduction Program (CERP) is supported and managed by the U.S. Army's Industrial Ecology Center in Picatinny, New Jersey. The Technikon Environmental Development Center in McClellan Park, CA operates the CERP program. This Center offers an ideal location for the establishment of a SIVL, since Technikon already has a state-of-the-art capability for the generation, measurement and reporting of metal casting emissions. The technologies developed and validated as a result of these efforts will also have direct applicability to other industries such as refineries and emerging industries such as co-generation and integrated gas combined cycle (IGCC) power plants. In addition to helping reduce costs and optimize manufacturing processes; the SIVL Center could provide additional industry benefits by serving as a training site for manufacturing plant personnel, academic organizations and regulatory agencies.

THIS PAGE INTENTIONALLY LEFT BLANK

2.0 Introduction

2.1 Regulations

U.S. foundry operations face many environmental and global competitive challenges. The passage of the US 1990 Clean Air Act Amendments promulgated the Air Toxic Regulations that included the Maximum Achievable Control Technologies (MACT) requirements. These MACT regulations will require foundries to meet the hazardous air pollutant (HAP) emission levels, equal to the average of the best 12% of the industry.

The final version of the iron and steel foundry MACT will be promulgated during the 3rd quarter of 2003. The EPA MACT standards will require that metal casting plants begin monitoring their source emissions beginning in 2004-2005 with a phase-in of emission control systems during 2006-2007.

It is not EPA's intent to require foundries to go through a new source review (NSR) as a result of the changes that may have to be made to comply with the MACT standards. After MACT is implemented, EPA will analyze the "Residual Risk" associated with MACT compliance and determine the need to further regulate the industry.

Prior to the final MACT deadline, applicability determinations will have to be made on sources potentially affected by the regulation. It will be important that HAP emission factors are available to assess if each foundry is subject to the requirements of "case-by case" MACT. Once the HAP emissions data has been calculated, the necessary foundry process and material changes, and control technologies can be implemented to reduce HAPs to acceptable levels.

2.2 Casting Emission Reduction Program (CERP)

The Casting Emission Reduction Program (CERP) was initiated on October 4, 1993 at McClellan Air Force base. President Clinton visited McClellan for the associated media events and commented, "I see some of the work being done here at McClellan to develop "dual-use" technologies. That means the people here have decided that change will be our friend and not our enemy" (Sacramento Bee Newspaper, 10/4/1993).

CERP was the first major research and development partnership established between the automotive industry and a Department of Defense facility. The primary objective of this project was to develop new metal casting manufacturing processes that have no adverse effect on the environment while producing high quality, competitive products for the United States (Schuetzle, 1993). Since that time, CERP has served as a "blue-print" for the establishment of "dual-use" efforts at other U.S military bases.

A Cooperative Research and Development Agreement (CRADA) for CERP was formally established in 1994 between the U.S., by the U.S. Department of Defense (DOD) through the Sacramento Air Force Logistics Center (USAF, 1994), and the U.S. Council for Automotive Research (USCAR). Other significant collaborative partners have included the U.S. Environmental Protection Agency, the California EPA, the American Foundry Society and the Casting Industry Suppliers Association.

Since 1994, the CERP has been primarily funded and administered by the U.S. Department of Defense (DOD) with some financial support from USCAR. During 2000, the administration of this program was transferred from the Air Force Logistics Center to the U.S. Army's Industrial Ecology Center (CERP, August 2000). The Technikon Environmental Development Center in McClellan Park, CA operates the CERP program.

A key CERP objective has been to develop and validate monitoring techniques for hazardous air pollutants (Cole, Schuetzle, Rogers, Bindbeutel et. al. -1996a, 1996b). This includes the development and validation of continuous monitoring techniques that have been traditionally used to measure emissions and to evaluate new technologies that have the potential of significantly reducing the cost of emissions monitoring, record keeping and reporting. Since that time, a state-of-the-art capability has been developed for the generation, measurement and reporting of metal casting emissions (see www.technikonllc.com for details).

2.3 Preparing for MACT and Beyond

Individual metal casting plants affected by the MACT will be required to monitor casting process emissions to insure compliance with these standards. Preparing for the MACT regulations presents numerous challenges to the metal casting industry. In addition to increased costs, these challenges include: identification, installation, and validation of new monitoring equipment; and the hiring and/or training of operating personnel.

If the usual pattern of regulation follows, more stringent regulations lie ahead. Newer measurement and monitoring technologies will be needed. At issue is how to most efficiently and effectively bring these new and emerging emissions measurement technologies to the metal castings industry. This report describes the results of a study undertaken by Technikon to assess the cost/benefits for a national systems integration and validation laboratory (SIVL) to serve the metal casting industry.

3.0 Objectives and Approach

The objective of this study was to evaluate the costs vs. benefits for establishing a systems integration and validation laboratory (SIVL) for the casting industry that would, 1) provide the industry with low cost and accurate emissions monitoring techniques as necessary to effectively meet current and future emissions standards and, 2) establish a centralized capability for the development, systems integration, validation and certification of emissions measurement techniques. We assessed the following in our study:

- The anticipated requirements for MACT source emissions monitoring and reporting through 2007 (Chapter 4).
- The status of currently available monitoring and reporting capabilities (Chapter 4).
- The potential benefits of continuous emissions monitoring systems (CEMS) technology vs. batch sampling and analysis techniques (Chapter 5).
- The need for a SIVL and conceptual design (Chapter 6)
- A technical assessment for the potential of successfully developing, validating and implementing CEMS for the metal casting industry (Chapter 6).
- The estimated costs to the industry for emissions monitoring and reporting using currently available techniques, 1) without the support of a SIVL capability, 2) the cost of establishing a SIVL at Technikon and, 3) the estimated costs with a SIVL capability (Chapter 7).
- The cost-savings and other benefits that could be realized by the establishment of the SIVL capability (Chapter 7).

THIS PAGE INTENTIONALLY LEFT BLANK

4.0 Status of MACT Emissions Monitoring and Currently Available Technologies

4.1 MACT Background and Status

The Clean Air Act Amendments (CAAA) legislation was passed in 1990. These amendments to the original Clean Air Act of 1970 classified a manufacturing facility as a major or minor source of airborne emissions. Major sources are those that emit more than 10 tons per year of any individual hazardous air pollutant (HAP) or more that 25 tons per year of total HAPs. Title III of the amendments provided a list of 189 individual compounds and families of compounds that were defined as HAPs. The amendments also instructed the US EPA to enact regulations to control all major sources in the United States. In response to the amendments, the US EPA developed the concept of maximum achievable control technology (MACT). Sources were grouped and target dates for promulgation of each group's MACT established. The metal casting industry was placed in the last group to have their MACT promulgated with an original schedule date in 2000. Delays caused by litigation have resulted in a slippage of 3 years. It is expected that the MACT for the casting industry will be promulgated in late August or early September 2003 as shown in the timeline below. Industry groups estimate that approximately 200 foundries will be affected by the MACT requirements (J. Stone, 2003).

1990	**1991**	**2000**	**2002**	**2003**
CAAA Passed	Iron and Steel Foundry MACT Development Begins	MACT Originally Due	Draft MACT Published	MACT Promulgated (Expected Sept.'03)

4.2 Current Status and Issues

Emissions monitoring consists of two processes, emissions sampling and sample analyses. Metal casting plants have available a number of US EPA approved analytical techniques for both sampling and analysis. However, not all of these methods have been validated for MACT emissions monitoring in a metal casting environment. These techniques are summarized in Table 1.

Most casting plants do not have the trained personnel and analytical capabilities to evaluate instrumentation (hardware and software) as well as to carry out monitoring and reporting as required to meet the MACT standards. Consequently, these plants will need to hire environmental testing companies to monitor their stacks to insure compliance with MACT standards. Very few of these environmental testing companies have had experience with monitoring emissions from metal casting operations.

Table 1 US EPA Approved Sampling and Analytical Methods

Measurement Parameter	Test Method
Port location	USEPA Method 1
Number of traverse points	USEPA Method 1
Gas velocity and temperature	USEPA Method 2
Gas density and molecular weight	USEPA Method 3
Gas moisture	USEPA Method 4
HAPs	USEPA Method 18
VOCs	USEPA Method 25A
Particulates	USEPA Method 5
Carbon Monoxide	USEPA Method 10

The complexity of the sampling process is illustrated in Figure 1, which shows USEPA Method 5 that was established for the batch sampling of particulate matter (PM) emissions from stationary sources. Particulate matter is withdrawn iso-kinetically from the source and collected on a glass fiber filter maintained at a temperature of 120 ± 14°C (248 ± 25°F), or at other temperatures as specified by an applicable subpart of the standards or approved by the EPA for a particular application. The gas stream subsequently passes through a series of two water impingers and two dry impingers. The volatile organic compounds in each impinger are determined by chemical analysis and the PM mass is determined from the summation of the particle mass collected on the filter and the mass of condensate after the removal of un-combined water. These batch collection and analyses techniques require multiple steps and are labor intensive.

In contrast, the procedure developed for the determination of PM emissions from mobile sources employs a dilution tube to dilute tailpipe emissions with ambient air maintained at a constant humidity and temperature. The use of a dilution tube simulates the natural process of particulate formation in the atmosphere. The emissions are sampled iso-kinetically from this dilution tube at a constant temperature of 37^{o}C and collected on filter media. The PM mass is then determined directly from the mass of particles collected on the filter.

A major problem with the EPA Method 5 protocol is that this sampling technique does not simulate conditions experienced by stack emissions as they mix with the atmosphere. As a result, traditional hot filter/impinger methods suffer from significant artifacts that result in high PM masses. These artifacts often dominate PM2.5 results measured using these methods. Dilution sampling is widely accepted in the scientific literature as the valid source emissions measurement method for characterizing PM emissions for source apportionment and source-receptor studies. Improved source sampling and characterization methodologies are one of the top ten national priorities identified by the National Research Council Subcommittee on Research Priorities for Airborne Particulate Matter. As a result, ASTM has established a project to develop and validate these dilution sampling methods for stationary sources (ASTM, 2003).

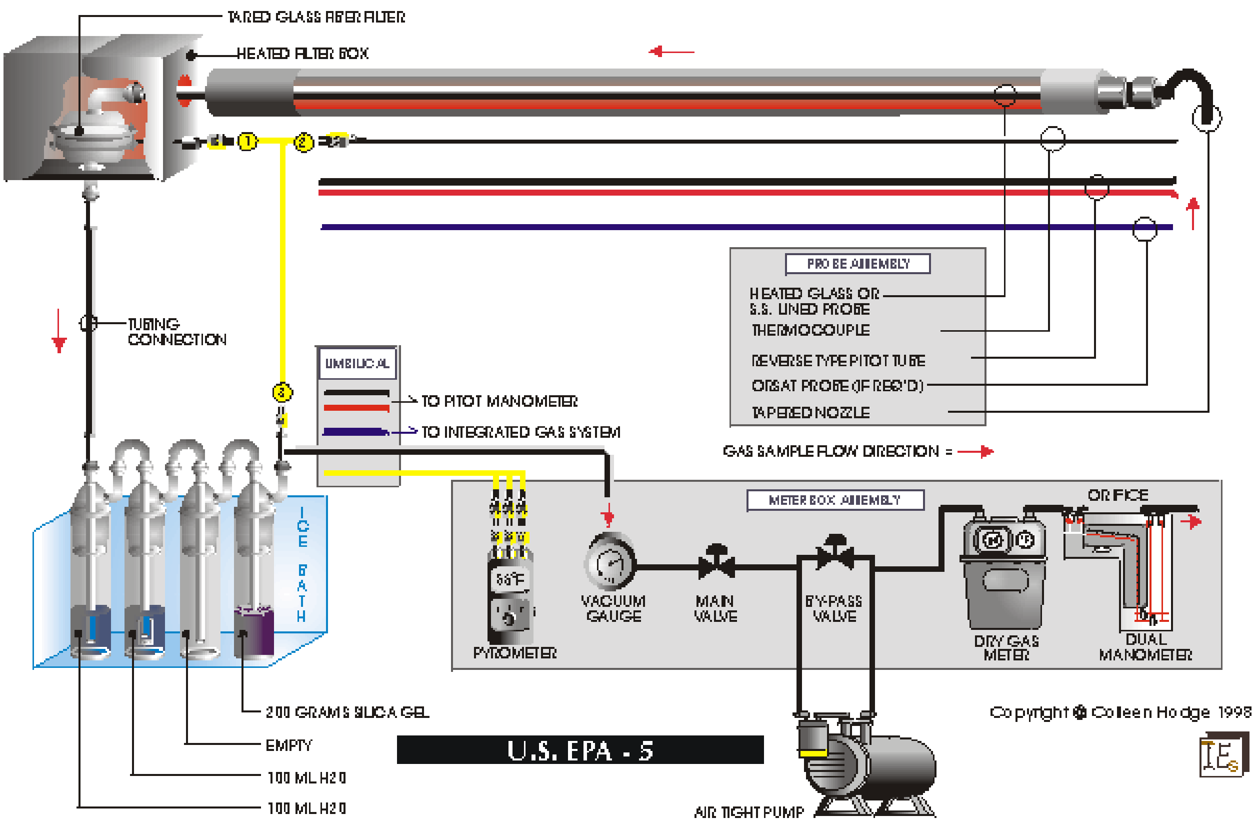
While little has been done in recent years to advance methodologies in the metal casting industry for sampling, a great deal of work has been carried out during the past 20 years to develop and validate continuous emissions monitoring systems (CEMS) for particulates from vehicles. These studies have included comprehensive comparisons of various CEMS instruments with the dilution tube/filter sampling technique. Very little validation work has been undertaken to compare CEMS instruments with EPA batch sampling and analysis protocols for metal casting emissions. As an example, we have chosen in this study to compare what is known about comparisons for particulate matter CEMS instruments with the EPA Method 5 protocol typically used for metal casting emissions. For this analysis, we critically reviewed what has been learned from the CEMS studies of particulates from vehicle emission sources.

4.3 Future Emissions Monitoring Requirements

In addition to the monitoring of CO, particulates and VOCs, it is possible that casting plants may be required to monitor other emissions in the future. These emissions include SO_2, NO_2, triethylamine, aldehydes and non-methane hydrocarbons (NMHC). In addition, foundries may have to prove whether or not that they are a major source of HAPs. Other possible species that may have to be monitored in the future include formaldehyde and benzene. There is a possibility that EPA will move away from a PM limit to an emission limit specific for selective metallic HAPs. However, there is very little background information on the emission of lead from metal casting plant melting operations.

EPA's Office of Air Quality Planning and Standards (OAQPS) is considering particulate matter (PM) continuous emission monitoring systems (PM-CEMS) for use in all future standards (***US EPA – Sept. 25, 2000***). Also, individual States are considering PM-CEMS for State Implementation Plans (SIP) and Economic Incentive Program (EIP) monitoring, and industries may use PM-CEMS for Title V monitoring. Therefore, EPA has an ongoing program of providing grants for the development and evaluation of PM-CEMS technologies.

Figure 1 US EPA Method 5 for Particulates



4.4 Technikon Analytical Methodologies – A Resource

One significant resource available to affected metal casting operations is the CERP analytical methodologies. Technikon, operator of the CERP, has evaluated and validated EPA methodologies for the sampling and analysis of metal casting emissions since the inception of that effort in 1994 (Figures 2 and 3) (Technikon - 2003). Technology transfer from CERP to individual casting operations is on going.

Figure 2 Sampling of Emissions at the Technikon Environmental Development Center

Figure 3 Laboratory Analyses of Emission Samples at the Technikon Environmental Development Center

THIS PAGE INTENTIONALLY LEFT BLANK

5.0 Continuous Emissions Monitoring (CEM)

5.1 Introduction

Over the past 30 years, the trend has been for EPA to initially require batch sampling and analysis techniques with a trend toward continuous emissions monitoring systems (CEMS). As a result, CEMS is currently the primary methodology used for monitoring emissions from motor vehicles, power plants, painting operations, chemical plants, petroleum refineries and other sources of emissions from major manufacturing processes (California Air Resources Board: March 21, 2001). Although each of the above industries initially resisted this move to CEMS, they have learned that there are many advantages of CEMS over batch sampling and analysis techniques. These advantages are likely to include:

- A reduction in the cost of monitoring and reporting emissions over the long term
- On-line process information that can provide the plant with valuable information for optimizing manufacturing systems and assessing the operational efficiency of emissions control equipment.
- On-line process control data for optimizing manufacturing and other stationary production processes thus reducing costs from outages, reduced energy consumption, and decreased materials use.
- A decrease in community complaints related to odor, particulates and other pollutants by local residents. In the past, such community complaints have been responsible for a number of plant closures in the U.S.
- Reduced episodes of non-compliance that may result in fines and/or plant shutdowns.
- Inaccurate emissions measurements that can result in fines
- Government incentives for plants that have installed CEMS at an early point in the regulatory phase.

5.2 Current (1st Generation) Continuous Emissions Monitoring Systems (CEMS)

Several instruments were developed during the 1970's for the continuous monitoring of emissions from mobile and stationary sources. The primary CEMS methods used currently for stack emissions include:

- Total Hydrocarbons – Flame Ionization Detection (FID)
- Total Nitrogen Oxides – Chemi-Luminesant Detection
- Total Sulfur Oxides – Solid State Sulfur Detector
- Carbon Monoxide – Non-Dispersive Infrared Detector

- Particulate Matter – Opacity-Based Detection System

Although FID analyzers have been used since the 1970's for the CEM of total hydrocarbons (THC) from stationary sources for nearly 30 years, the integration of these instruments into CEMS is expensive and their maintenance is high. The FID-THC instruments require hydrogen as an operational fuel and the FID burner often extinguishes under adverse environmental conditions. A number of particulate matter CEMS have been developed but none of these systems have been validated for the CEM of metal casting emissions.

5.3 Future (2nd Generation) Technologies - Spectroscopic Instruments

Infrared spectroscopy has high potential as a low-cost CEMS for several key gas-phase emission components in stationary source emissions from foundries, power plants, boilers, stationary generators and other stationary sources. Such systems tend to be low-cost, robust and don't require gases (e.g. hydrogen) for operation.

Horiba has developed low-cost, lightweight, portable IR based instruments for vehicle emissions measurements that could have application to the CEMS of metal casting emissions. These instruments potentially have the sensitivity, high-end range, accuracy and reproducibility (with some modification (such as increasing the IR cell path length), to serve as a low-cost CEMS system for meeting MACT monitoring requirements. Technikon has carried out some limited testing of these instruments for the CEM of casting plant emissions. Preliminary results indicate that these instruments have the potential of serving as a 2nd generation, low-cost CEMS for metal casting emissions. Additional work will continue to further develop and validate such instruments. Such validation efforts would not be possible without a SIVL capability.

5.4 Future (3rd Generation) Technologies – Chemical and Physical Sensors

A great deal of progress has been made during the past fifteen years on the development of low-cost, robust chemical sensors for monitoring air pollutants. Currently available sensors have been developed for the continuous monitoring of CO, NO, CH_4, SO_2, CO_2, O_2, NO_2, THC, HCl, NH_3, Hg, HF, opacity, particulates and gas flow. Additional details are provided in Appendix III.

5.5 Future Challenges

Although regulatory agencies have the objective of implementing CEMS for nearly all major stationary sources during the next five years, there is still a great deal of development and validation work that will be required to meet this objective.

The availability of inexpensive and reliable CEMS systems for the casting industry would also have direct applicability to other industries such as refineries, stationary power generating stations and steel mills. These CEMS technologies could also be integrated with manufacturing process control systems (e.g. metal melting processes) to monitor and optimize processes for reducing waste and emissions. In addition to helping reduce costs and optimize manufacturing processes, the SIVL Center could provide additional benefits by serving as a training site for casting plant personnel, local EPA agencies and others.

The automotive industry and regulatory agencies have expended hundreds of millions of dollars on the development and validation of CEMS for vehicles during the past 30 years. A major objective of this effort should be to build upon this knowledge base for the development of CEMS for stationary sources. In addition, this project should be coordinated with relevant government, industry and academic organizations.

THIS PAGE INTENTIONALLY LEFT BLANK

6.0 The Need for a "Systems Integration and Validation Laboratory" (SIVL) and Conceptual Design

Casting emissions present a unique set of sample handling issues. The pyrolysis products generated from metal pouring processes are highly reactive in air and readily condense and polymerize to form dense organic coatings on any surface. These coatings can significantly reduce the durability of CEMS instruments. Instrument developers and manufacturers lack the facilities to test and validate their new or improved sampling and measurement technologies in the metal casting emissions environment because they do not have ready access to metal casting plants and reproducible sources of casting plant emissions

A well-run SIVL center could provide the following:

- A controlled testing environment for the prove-out of new or improved sampling and measurement technologies, including CEMS.
- Comparison and validation of competing instruments and technologies under real metal casting operating conditions.
- Validation of the total system accuracy and robustness from the point of emissions collection through analysis and data storage.
- Development of validation and testing protocols for individual casting operations to follow.
- A source for standard reference materials of casting emissions measurements.
- Training and technical workshops for casting industry personnel.

Although individual equipment, network and software suppliers provide specifications for their products, it is only when these products are integrated into a dynamic system, that the components within the system can be tested. This feature was experienced during the development of CEMS for vehicle emissions.

6.1 SIVL Conceptual Design

The major components of the envisioned SIVL are shown in Figure 4. These components include:

- Metal casting emission samples from actual mold production, core making, metal melting and metal pouring, cooling and shakeout processes under controlled conditions (Section 6.2)
- Metal casting emission samples from laboratory simulators that produce constant, reproducible sources of emissions (Section 6.3).

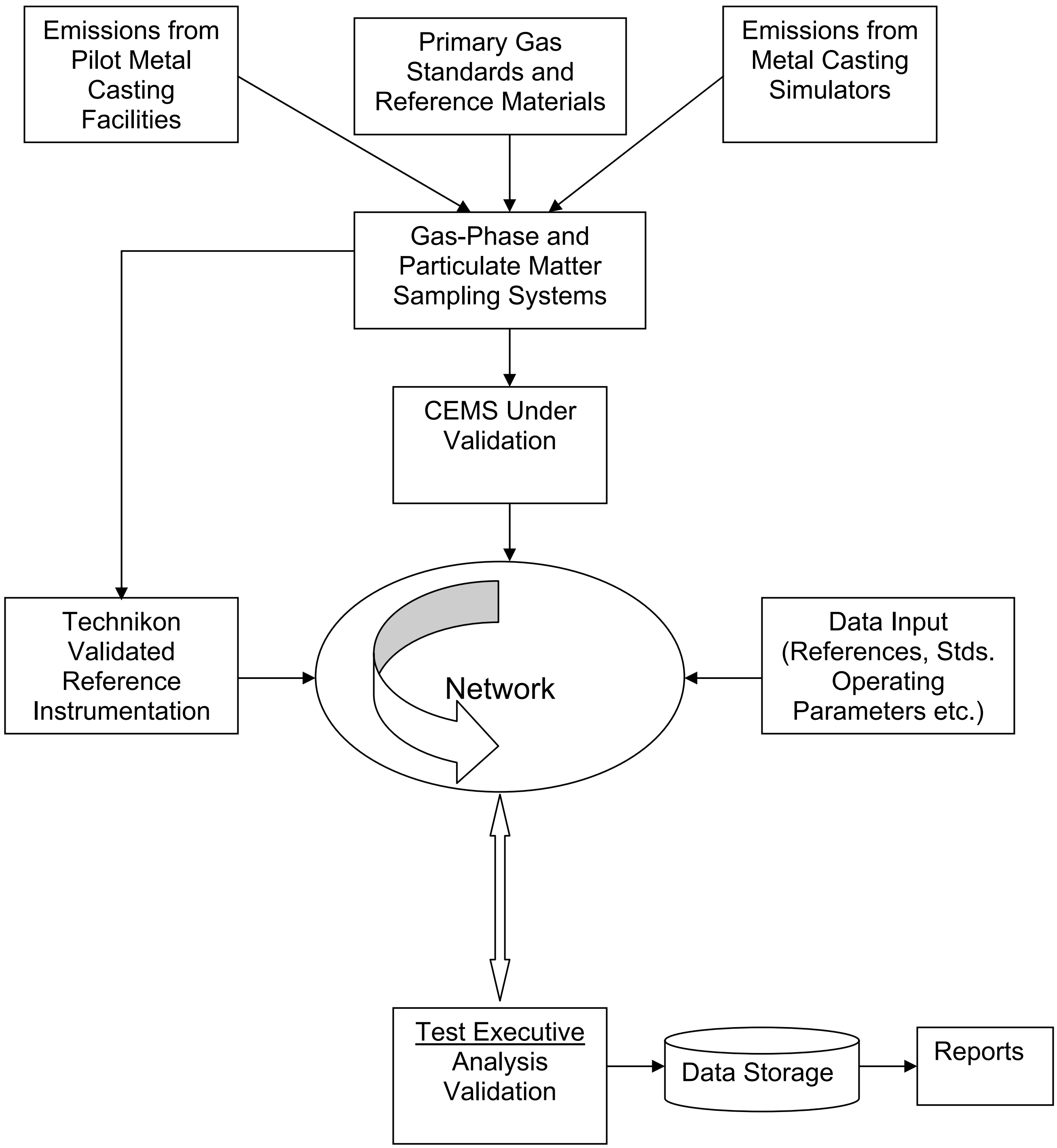
- Primary gas standards that have been certified to within 1-2% accuracy and standard reference materials (SRMs) such as certified mixtures of polynuclear aromatic hydrocarbons (PAHs), from the National Institute of Standards and Materials (NIST) (Section 6.4).
- Prototype 2nd generation and 3rd generation continuous emissions monitoring systems (CEMS) for testing and validation (Sections 5.2, 5.3, 5.4 and Appendix III).
- Sampling systems for gas-phase and particulate matter emissions (Section 4.1).
- Instruments and analytical techniques that have been validated by Technikon and used as reference techniques for the prototype CEMS under test (Section 4.3).

The CEMS instrument under test and the Technikon validated reference instrumentation could be interfaced to a network. This network would contain information needed for the validation process. Such information would include libraries of metal casting emissions data, spectroscopic and chromatographic data, instrument operating parameters and other records needed for the validation of the prototype CEMS under test.

As outlined in Appendix III, a number of instrument manufacturers, academic institutions and government laboratories has developed prototype instruments that may be ideal for the future (3rd generation) CEMS of metal casting emissions, as well as emissions from other manufacturing plants. However, as stated earlier, these organizations do not have the capability to effectively validate these instruments.

The output from the prototypes can be compared with data obtained simultaneously from well-established instrumentation, previously validated for the measurement of metal casting emissions. The network could include software packages for data analysis, validation and reporting (Figure 4).

Figure 4 Major Components of the Envisioned SIVL



6.2 Controlled Test Environments - Technikon Pilot Metal Casting Facility

The CERP Center has a unique capability to reproducibly generate emissions from mold production, core making, metal melting and metal pouring, cooling and shakeout processes under controlled conditions (Figures 5 and 6). This center has a general purpose, non-automated metal casting plant, which has been adapted and instrumented to generate, collect and measure emissions, using methodologies based on EPA protocols for pouring, casting, cooling and shakeout processes on discrete mold and core packages under tightly controlled conditions not feasible in a commercial foundry.

This pre-production foundry utilizes a green sand Muller to mix sand for 24"x 24" and 10" x 10" cope and drag molds to pour American Foundry Society (AFS) step block castings. In order to obtain reproducible emission samples, a number of process parameters are carefully controlled as listed in Table 2.

Process and stack parameters include the weights of the casting mold, sea coal additions and core; loss-on-ignition (LOI) values for the mold prior to the test and at shakeout; LOI for the core; percent clays; metallurgical data; and stack parameters including temperature, pressure, volumetric flow rate and moisture content. The process parameters are maintained within prescribed ranges in order to ensure the reproducibility of the tests.

Table 2 Process Parameters Controlled for the Generation of Standard Reference Sources of Casting Emissions

Process Parameter	Analytical Equipment and Methods
Core Weight	Mettler PJ8000 Digital Scale (Gravimetric)
Mold Weight	Standard Weight (Gravimetric)
Casting Weight	Standard Weight (Gravimetric)
Seacoal Weight	Simpson Technology (Calibrated Volumetric)
Resin Weight	Mettler PJ8000 Digital Scale (Gravimetric)
LOI% at mold	Denver Instruments XE-100 Analytical Scale (AFS procedure 212-87-S)
Core LOI%	Denver Instruments XE-100 Analytical Scale (AFS procedure 321-87-S)
Clay, % at mold	Dietert 535A MB Clay Tester (AFS Procedure 210-87-S)
Metallurgical Parameters	
Pouring temperature	Electro-Nite DT 260 (T/C immersion pyrometer)
Carbon/Silica	Electro-Nite Datacast 2000 –(Thermal Arrest)
Alloy Weights	Ohaus DS10 (Gravimetric)
Mold Compact ability	Dietert 319A Sand Squeezer (AFS procedure 221-87-S)

The mold is placed under a hood for pouring, cooling and shakeout so that all emissions are collected for analysis (Figures 5 and 6). This "general purpose foundry" has been adapted and instrumented to allow the collection of organic emission measurements.

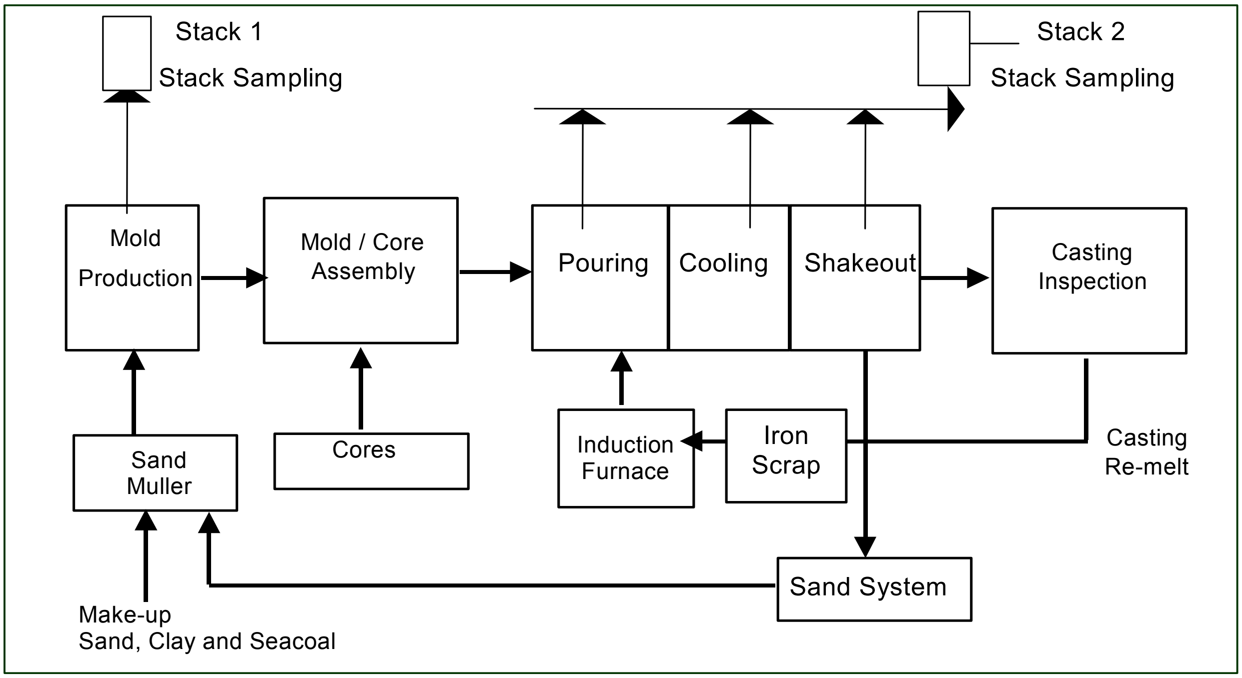
Figure 5 CERP Pilot Foundry Used for the Generation of Reproducible, Standard Reference Sources of Emissions

6.3 Laboratory Emissions Simulator

Although the pilot foundry produces representative, real-world emission samples from various binder-sand mold, cast metal systems, the cost of producing such samples is high, and the concentration of emission constituents vary with time. Therefore, it would be of great value if laboratory metal casting process simulators could be developed to produce a constant, reproducible source of emissions. This section describes the types of metal casting process simulators that need to be developed.

The most widespread chemical binder systems are organic in nature. These systems are chemically and/or thermally cured to harden the sand mold. The pouring of molten metal, in the range from 1200 ^{o}F to nearly 3000 ^{o}F, causes the organic polymer to undergo pyrolysis. During this metal pouring process, the mold is heated non-uniformly, which causes incomplete combustion of the organic polymer to produce a multitude of pyrolysis products.

Figure 6 CERP Production Foundry Processes and Air Emission Sources



6.3.1 Phenolic Urethanes

One of the most widely used binder systems is phenolic urethanes. These binders are produced from a three-part system consisting of a modified phenolic resin, a polymeric isocyanate, and tertiary amine catalyst. The active ingredients in a phenolic urethane cold-box resin system consists of polyols and polyisocyanates. The polyol representing one of the components is a phenol-formaldehyde resin exhibiting benzylic ether character. The polyisocyanate is an oligomeric product of 2,4'- and 4,4' diphenylmethanediisocyanate (commonly referred to as MDI). Both the phenolic resin component and the polymeric isocyanate are usually dissolved in organic solvents, due to the very high viscosity of both materials.

The difference in polarity of the polyisocyanate and phenolic resin limits the choice of appropriate solvents that are compatible with both components. Polar solvents, such as dibasic esters (DBE) (e.g. dioctyl adipate - DOA), are very appropriate solvents for phenolic resins, but less so for isocyanates. DOA is used in most PUCB systems as plasticizers and solubilizers. The preferred non-polar solvents are mixtures of high-boiling aromatic hydrocarbons, exhibiting a boiling range above 150^{o}C. These solvents produce volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) during the production and storage of cores and molds, and particularly during pouring, cooling and shakeout operations.

6.3.2 Cold Box Systems

The cold box core systems introduce more petroleum-based solvents into the molding process, which will mix with and tend to solublize a portion of the organic material driven out of the green sand. The more recent cold-box systems use plant-based solvents (methyl esters of vegetable oils) for the resins and co-reactants. These solvents are odorless and much more environmentally friendly than the solvents described above. The typical VOC content for traditional cold-box systems varies from 25-45%.

6.3.3 Green Sand

The use of sea coal (powdered bituminous coal) in the green sand mix provides gas generation and reducing atmospheres within the mold, which greatly contributes to the production of high quality castings. The gas generation from the sea coal is directly analogous to the generation of gases in the core pyrolysis process. Partial pyrolysis of the coal produces a plethora of organic compounds that condense within the green sand, are vented from the mold via the vents or are released at cope pick-off and shake-out of the castings.

Additional organic emissions are generated from the use of cores and a number of green sand additives. Green sand additives can include wood, flour, waxes, oils and mold release agents. The various core-making processes each add their own specific compounds to the mix. These compounds include the partial or complete products of combustion of the resins, carriers and additives; hence the mix of organics emitted by the cores varies with the amount of core material used in the mold.

6.3.4 Metal Melting Processes

Melting of metals is accomplished using a variety of furnace types over a wide range of sizes and capabilities. The type of furnace, metal being melted, quality of charge material and the size of the furnace all have significant impacts on the quality and quantity of emissions. Returned scrap from the foundry can constitute up to half of the charge. The balance of the charge can be a combination of briquettes, bundles, plate, pigs and other scrap. The tramp materials contained in scrap may include rust, dirt, ash, coke, breeze, paint, oil, grease, insulation, coatings, rubber and plastic. All of these materials can volatilize, pyrolize or burn to generate gaseous and solid emissions.

Very fine particulate matter is generated in this process from the vaporization and conversion of galvanized coating to zinc vapor and then to zinc oxide fumes. Similar processes occur for lead, aluminum and other low melting point metals. The greases, paints, plastics and rubber products can contain both metals and sulfur compounds, which in turn can produce metallic fumes and sulfur oxides. Carbon dioxide reacts with the hot coke above the combustion zone to produce significant quantities of CO.

The emissions simulators for each of the major casting processes described above will need to generate emissions that are qualitatively similar to "real-world" processes. It is not necessary that these simulators quantitatively reproduce emissions from actual metal casting processes; however, it is important that the quantity of emissions produced is relatively constant with time.

6.4 Development of Standard Reference Emission Sources for Metal Casting Processes

Several types of standard reference materials (SRMs) are needed for developing, standardizing and certifying new and improved measurement methodologies and continuous emissions monitoring systems (CEMS) for stationary sources. These SRMs include individual and mixed gas standards for instrument calibration and "real-world" emission samples. These "real-world" samples can be generated in the shorter term using the Technikon foundry and for the longer term the successful development of a laboratory simulator would significantly reduce validation costs.

6.5 Quality Assurance Procedures

The US EPA specifies reference methods that can be used to substantiate the accuracy and precision of CEMS. These performance specifications are used for evaluating the acceptability of CEMS during or shortly after installation. Quality assurance procedures have been recommended by EPA (***US EPA - 40 CFR 60, 2002***) to evaluate the effectiveness of quality control (QC) and quality assurance (QA) procedures and the quality of data produced by any CEMS that is used for determining compliance with the emission standards on a continuous basis. A predictive emission monitoring system (PEMS) has been developed to determine emission rates using process operating parameter measurements. A draft protocol for assessing the accuracy and precision of PEMS has been developed and may be proposed sometime in the near future.

7.0 Estimated Economic Impact of a SIVL on MACT Monitoring and Reporting for the Metal Casting Industry

This section provides several scenarios for assessing the potential economic impact of MACT emissions monitoring and reporting on the U.S. metal casting industry. It describes the estimated costs for the average metal casting plant that will need to meet these standards during fiscal years 2004 through 2007 (the fiscal year used in this report runs from Oct 1-Sept. 30). The scenarios developed in this section include:

Scenario I: Estimated costs to the industry without a SIVL capability using current (1st generation) monitoring and reporting capabilities.

Scenario II: Estimated costs to the industry with a SIVL capability and successful development, validation and implementation of 2nd generation CEMS during fiscal years 2004-2006

Scenario III: Estimated costs to the industry with a SIVL capability and successful development, validation and implementation of 3rd generation CEMS during fiscal years 2007 and beyond.

SIVL Costs: Estimated costs for establishment and operation of a SIVL at Technikon during fiscal years 2004-2007.

The costs estimates developed in this section include the following items:

Capital costs
Emissions monitoring equipment
Data system and applications software

Operating and Maintenance (O&M) Costs
Equipment maintenance (routine and corrective)
Expendables (gases, chemicals, heated sampling lines, etc)
Quality Assurance (QA)/Quality Control (QC) activities
Reporting and record keeping
Training

Stationary-source emissions testing companies, instrument manufacturers, systems integrators (see www.activeset.org/regions for a listing of U.S. companies), university groups and government laboratories were contacted to help determine the costs associated with current and future emissions monitoring and reporting. The same basis and assumptions were used to compare costs for the three scenarios.

1. It is assumed that 200 of the currently operating 2,500 U.S. metal-casting plants will be required to carry out the MACT emissions monitoring and reporting beginning in Jan. 2004 (J. Stone; G. Mosher, 2003).

2. The control systems will be implemented in 2006 after a three-year phase-in.
3. On the average, the processes affected in these 200 plants will include metal melting (2 stacks), Mold Lines (3 stacks) and Core Making Lines (1 stack) (J. Stone and G. Crandell, 2003). This average plant will be referred to as the ***Average MACT Affected Metal Casting Plant.***
4. The costs are annualized over a four-year period (fiscal years 2004-2007).
5. The pollutant species to be monitored and the estimated range of concentrations expected for each source type are summarized in Table 3.

Table 3 Metal Casting Plant Emission Sources, Components and Expected Range of Concentrations for the Average MACT Affected Metal Casting Plant

Emission Component	Average Stack Concentrations
Mold Lines (3 stacks requiring 3 CEM systems)	
Hydrocarbons (as hexane)	15-150 ppm
Carbon Monoxide	100-1,000 ppm
Particulate Matter (PM)	1,000-20,000 ug/m3
Metal Melting (2 stacks requiring 2 CEM systems)	
Hydrocarbons (as hexane)	15-150 ppm
Carbon Monoxide	100-1,000 ppm
Particulate Matter (PM)	1,000-20,000 ug/m3
Core Making (1 stack requiring 1 CEM system)	
Triethylamine (TEA)	0.5-500 ppm

7.1 Scenario I - Estimated Costs to the Industry without a SIVL Capability Using Current (1^{st}) Generation Monitoring and Reporting Capabilities

This Scenario estimates the costs to the ***Average MACT Affected Metal Casting Plant*** using currently available techniques. Two estimates were made: a) the casting plant prefers to contract their emissions monitoring and record keeping to an external testing company or, b) they prefer to develop an internal capability to handle their emissions monitoring and record keeping. Details for the cost estimates are provided in Appendix II.

There is limited cost data for emissions monitoring and record keeping for the casting industry. Therefore, our analysis was based upon current projected costs for metal casting plant monitoring from environmental consulting groups and instrument companies. In addition, cost data was used from the compliance monitoring of emissions from other industries (e.g. - power plant emissions).

The power plant industry has found that O&M costs over a 10-year period may exceed initial capital costs by a factor of about three (Berry, 1997). This translates to a 30% annualized cost for O&M. Based on information from eight utilities, data validation, reporting and record keeping efforts constitute approximately 30 to 35 percent of these costs. Daily checks, routine maintenance and training account for another 35 to 40 percent.

7.1.1 Contract to External Testing Company

This analysis assumes that the ***Average MACT Affected Metal Casting Plant*** contracts their MACT emissions testing and data analysis to an external testing company and that this testing company will use current (1st) generation CEMS and EPA approved batch techniques (see **Appendix II**). As based upon the authors (D. Schuetzle) experience in contracting plant environmental testing services to outside environmental consulting companies, it is estimated that the cost for these contract services will be $225,000 **(a)**. This figure is derived from 1.5 engineer-years of work at an average consulting industry-billing rate of $150,000/engineer/year. The contractor will be responsible for installing permanent sampling systems on each of the six stacks at a total cost of $45,000, that these sampling lines will need to be replaced every 2 years **(b)** and that $15,000/year will be required in expendables (gases, chemicals, etc.)(**c).** The cost of a plant data system and application software is estimated at $25,000 **(d)**. Based upon experience, it is estimated that the ***Average MACT Affected Metal Casting Plant*** casting plant will need to budget about 50% of an in-house engineers time to manage this contract. The internal cost per year for this engineer would be $67,500, assuming a fully accounted cost of $135,000 engineer **(e).** Therefore, the total cost to each casting plant will be $355,000/year/plant **(f)** or $71.0 million/year for the first 200 affected metal casting plants.

7.1.2 Develop an Internal Testing Capability

This analysis assumes that the ***Average MACT Affected Metal Casting Plant*** has chosen to develop an internal testing capability using current (1st) generation CEMS and EPA approved techniques for stationary sources. The cost of that approach would be $364,400/year/plant as outlined in **Appendix II**. The 200 metal casting plants would incur a total cost of $364,400/year/plant ***(j)*** or $72.9 million/year for the first 200 affected metal casting plants.

In conclusion, the estimated costs to the industry without a SIVL capability is about the same if the ***Average MACT Affected Metal Casting Plant*** contracted this effort to an external testing company or if they developed an internal testing capability. The average of these two scenarios is $359,770/plant/year or $71.9 million/year for the first 200 affected metal casting plants. Therefore, the average industry cost for years 2004 – 2007 is $71.9 million/year. (See Table 4).

Table 4 Cost/Benefit Analysis for MACT Emissions Monitoring and Reporting, with and without the Support of a SIVL Capability

	Costs and Benefits ($ millions)			
	2003/2004	**2004/2005**	**2005/2006**	**2006/2007**
Scenario I Estimated Industry Cost Without SIVL Using 1st Generation CEMS and EPA Batch Techniques	$71.9	$71.9	$71.9	$71.9
Scenario II Estimated Industry Cost With SIVL and 2nd Generation CEMS	$50.6	$50.6	$50.6	-
Scenario III- Estimated Industry Cost With SIVL and 3rd Generation CEMS	-	-	-	$35.0
Industry Benefit Estimated Industry Benefit With SIVL and 2nd Generation CEMS (Scenarios I-II)	$21.3	$21.3	$21.3	-
Industry Benefit Estimated Industry Benefit With SIVL and 3rd Generation CEMS (Scenarios 1-III)	-		-	$36.9
SIVL Cost Estimated **Cost** for Establishing SIVL	$0.43	$0.56	$0.56	$0.56
Benefit /Cost				
Scenario II	49.7	38.0	38.0	-
Scenario III	-	-	-	65.7

7.2 Scenario II - Estimated Costs with a SIVL Capability and Successful Development, Validation and Implementation of 2nd Generation CEMS During Fiscal Years 2004-2006

Scenario II considers that the ***Average MACT Affected Metal Casting Plant*** implements CEMS using next (2nd Generation) instruments developed, recommended and validated by the proposed SIVL (see Appendix II for financial details). The estimated capital cost of the equipment (items a-d), annualized over a 4-year period, is $67,500/year **(d)**. Since most manufacturing companies currently prefer to outsource their O&M costs, we assumed that most manufacturing plants would choose this approach. As outlined in Appendix II, the total cost would be 253,000/year/plant **(e)** or $50.6 million/year for the first 200 affected metal casting plants. Therefore, the average industry cost for years 2004 – 2006 is $50.6 million/year (see Table 4 for a summary of results).

7.3 Scenario III – Estimated Costs with a SIVL Capability and Successful Development, Validation and Implementation of 3rd Generation CEMS During Fiscal Years 2007 and Beyond

Scenario III considers that the ***Average MACT Affected Metal Casting Plant*** implements CEMS using next (3rd Generation) instruments developed, recommended and validated by the proposed SIVL (see Appendix II for financial details). The estimated capital cost of the equipment (items a-d), annualized over a 4-year period, is $30,000/year. Since most manufacturing companies prefer to outsource their O&M costs, we assumed that most manufacturing plants would choose this approach. As outlined in Appendix II, the total cost would be 175,000/year/plant or $35.0 million/year for the first 200 affected metal casting plants.

7.4 SIVL Costs - Estimated Costs for Establishment and Operation of an SIVL at Technikon During Fiscal Years 2004-2007

Details on the estimated costs for establishment and operation of an SIVL are provided in Appendix II. Since Technikon has established an excellent baseline capability for the generation and measurement of emissions from metal casting operations, the cost for establishment of a SIVL at Technikon will be much less than if this capability was initiated from ground-zero.

Most of the costs for establishing and operating SIVL at Technikon during the current fiscal year (2003/2004) will be primarily to support the efforts of 2.3 engineers. Expendables, such as gases, chemicals and electronic components, have been budgeted at $10,000.

Technikon will work with instrument manufacturers to identify high promise 2nd generation instrumentation. Resources of $75,000 have been budgeted to provide in-kind support to instrument manufacturers for instrument modification and their validation at the SIVL center. Therefore, the total cost for establishment and operation of the SIVL during the first year is $429,000.

During 2005-2007, efforts will be increased to modify, test and validate 2nd and 3rd generation CEMS instruments. Support to instrument manufacturers for instrument modification and SIVL validation will be increased from $75,000/year to $90,000/year. A significant effort will need to be initiated during 2004/2005 for technology and knowledge transfer to the industry, CEMS suppliers, environmental agencies and others. A budget of $90,000/year is estimated for this results dissemination effort.

7.5 Cost-Benefit Analysis Results

Table 4 summarizes the results of the cost-benefit analysis for fiscal years 2004-2007. The industry benefit accrued during 2004-2006 is determined by totaling the estimated industry cost with SIVL and the successful implementation of 2nd generation CEMS (**Scenario II**) and subtracting that total from the **Scenario I** costs. It is concluded from this analysis that the industry could save up to $21.3 million/year during 2004 – 2006 if the benefits for the establishment of the SIVL are fully realized. If 3rd generation CEMS capabilities can be successfully developed and implemented by 2007, then the savings to the industry could be as high as $36.9 million.

7.6 Comparisons with Other Cost-Benefit Studies

Parker and Kiefer (2003) carried out a study on the cost of CEMS vs. the benefits of sulfur dioxide emissions trading for the power generation industry. It was determined that CEMS would cost the industry $203.5 million for CEMS and $700–1,300 million for stack emissions control. These estimates were based upon a cost per CEMS unit of $380,900/year, cost-averaged over a three-year period.

Another study assessed the costs associated with continuous monitoring of emissions from waste incinerators (Institute of Clean Air Companies, 1997). They estimated that the total capital investment for installing a CEMS for particulate matter, carbon monoxide and oxygen would be $82,000-$140,500 with an annual operating cost of $30,900-$40,100. Assuming a four-year depreciation schedule, the total cost for this CEMS averaged $63,310/year or $379,986/year for six CEMS units. This estimate is close to our estimate of $359,770/plant/year for the implementation of six the CEMS units installed on the ***Average MACT Affected Metal Casting Plant.***

EPRI believes that the development and implementation of advanced "sensors-on-a-chip," the improvement of sample-conditioning systems (a major difficulty with all monitors), and the development of automatic and diagnostic systems for continuous emissions monitoring (CEM). They believe that the implementation of these CEMS could result in projected savings of 50%-80% by reducing operating and maintenance staff requirements.

7.7 Potential Additional Cost Benefits

We expect that there could be additional cost reduction benefits from implementation of CEMS including the streamlining of data collection, analysis and reporting process, which will reduce the amount of time required for casting plant personnel to handle this task. Other projected cost savings to the metal casting industry include the use of this information to better control processes, reduce episodes of non-compliance with standards and reduce complaints from local communities.

7.8 Discussion of Financial Impacts

Cost benefit analysis (CBA) methodology uses three performance measures to evaluate investment opportunities: payback period, net present value (NPV), and internal rate of return (IRR). The payback period is the time period required to recover all of the capital investment with future cost-benefits. The NPV is the difference between the present value of capital investments and future annual cost benefits. The IRR is the discount rate at which NPV is equal to zero. NRV and IRR account for the time value of money, and discount the future capital investments or annual cost benefits to the current year.

Table 5 summarizes the results of the financial impacts for fiscal years 2004-2007. It is concluded that the average payback period with SIVL is 0.02. The NPV for establishing the SIVL is $1.9 million. The NPV of industry benefits is $92.2 million. The IRR for establishing the SIVL, based upon industry benefits, is 123.8%.

All of these metrics, shown here, are very positive by commercial standards and appear to firmly justify establishment of the SIVL capability.

Table 5 Financial Impact for MACT Emissions Monitoring and Reporting, with and without a SIVL Capability

Years	2003/2004	2004/2005	2005/2006	2006/2007	
Payback Period					
SIVL Cost (see Table 4)	$0.429	$0.562	$0.562	$0.562	
Industry Benefit (see Table 4)	$21.3	$21.3	$21.3	$36.9	
Payback Period	0.02	0.03	0.03	0.02	
Average					0.02

Net Present Value for Establishing SIVL					Total
Estimated **Cost** for Establishing SIVL (see Appendix II)	$429,000	$561,500	$561,500	$561,500	$2,113,500
Discount Rate Source: 2003 Discount Rates for OMB Circular Number A-94. Average of 3-year and 5-year Nominal Discount Rates					3.6%
Net Present Value of SIVL	$415,015	$525,452	$507,933	$491,200	$1,939,599

Net Present Value of Industry Benefit					Total
Industry Benefit (see Table 4)	$21,340,000	$21,340,000	$21,340,000	$36,940,000	$100,960,000
Discount Rate Source: 2003 Discount Rates for OMB Circular Number A-94. Average of 3-year and 5-year Nominal Discount Rates					3.6%
Net Present Value of Industry Benefit	$20,644,316	$19,969,972	$19,304,164	$32,315,112	$92,233,564

Table 5 – Financial Impact for MACT Emissions Monitoring and Reporting, with and without a SIVL Capability (continued)

Internal Rate of Return for Establishing SIVL					
Industry Benefit (see Table 4)		$21,340,000	$21,340,000	$21,340,000	$36,940,000
Estimated **Cost** for Establishing SIVL (see Appendix II)		$429,000	$561,500	$561,500	$561,500
Net Cash Flow (Industry Benefit less Estimated Cost of SIVL)		$20,911,000	$20,778,500	$20,778,500	$36,378,500
	Period	Cash Flow	IRR %		
2003/2004 Cost of SIVL	0	-$429,000	0.0		
2003/2004 Industry Benefit	1	$21,340,000	1.0		
2004/2005 Net Cash Flow	2	$20,778,500	37.3		
2005/2006 Net Cash Flow	3	$20,778,500	68.4		
2006/2007 Net Cash Flow	4	$36,378,500	123.8		

THIS PAGE INTENTIONALLY LEFT BLANK

8.0 Conclusions and Recommendations

Although the proposed EPA MACT standards for the metal casting industry have changed several times during the past two years, these standards will be finalized and promulgated during the fall of 2003 with an implementation period through 2007. Our conservative cost-benefit analysis was based upon the anticipated final EPA requirements. If EPA changes their anticipated requirements subsequent to the publication of this report, then an addendum will be published to reflect those changes.

Although there are nearly 2500 U.S. casting plants, not all of these plants will be required to meet the MACT standards. It was estimated that approximately 200 of the U.S. casting plants would need to meet these standards. As based upon the anticipated EPA MACT standards, our study concludes that the estimated cost for emissions monitoring, record keeping and reporting will average $71.9 million/year for the industry during fiscal years 2004-2007.

In addition to this significant financial burden to the industry, there are not enough core measurement competencies in the U.S. to handle this task. Continuous monitoring techniques have not been adequately validated for metal casting plants, and the metal casting industry does not have the capability for the development, systems integration, validation and certification of continuous emissions monitoring systems (CEMS), and batch sampling and analysis techniques.

During the past three decades, the pattern has been for EPA to initially recommend batch emissions sampling and analysis techniques with a trend toward CEMS. As a result, CEMS has become the only methodology currently used for monitoring vehicle emissions, power plant emissions and emissions from major painting operations. It is expected that CEMS will be required for nearly all other stationary sources within the next few years.

Those industries, that have already implemented CEMS, have found that there are many advantages of CEM over batch sampling and analysis techniques including:

- A reduction in the cost of monitoring and reporting emissions over the long term
- On-line process information that can provide the plant with valuable information for optimizing manufacturing systems and assessing the operational efficiency of emissions control equipment.
- On-line process control data for optimizing manufacturing and other stationary production processes, thus reducing costs from avoided outages, reduced energy and decreased materials use.
- A decrease in community complaints related to odor, particulates and other pollutants. In the past, such community complaints have been primarily responsible for a number of plant closures in the U.S.
- Reduced episodes of non-compliance that may result in fines and/or plant shutdowns
- Inaccurate emissions measurements that can result in fines

- Government incentives for plants that have installed CEMS at an early point in the regulatory phase.

Although, regulatory agencies have the objective of implementing CEMS for nearly all major stationary sources during the next five years, there is still a great deal of development and validation work that will be required to meet this objective.

It is recommended that a national Systems Integration and Validation Laboratory (SIVL) Center should be established for the development, validation and transfer of cost-effective and accurate CEMS as necessary to effectively meet current and future metal casting MACT emissions standards. This Center would help insure that emissions can be accurately monitored at a reduced cost to the industry. The cost analysis provided in this paper forecasts that the established of a SIVL Center, and the successful development of inexpensive and reliable 2nd generation CEMS systems, could save the industry up to $21.3 million/year for 2004-2006 and up to $36.9 million/year for 2007 and beyond if 3rd generation CEMS systems can be successfully developed, validated and implemented.

The Technikon Environmental Development Center in McClellan Park, CA operates the CERP program. This Center offers an ideal location for the establishment of a SIVL, since Technikon already has a state-of-the-art capability for the generation, measurement and reporting of metal casting emissions. The technologies developed and validated as a result of these efforts will also have direct applicability to other industries such as refineries and emerging industries such as co-generation and integrated gas combined cycle (IGCC) power plants. In addition to helping reduce costs and optimize manufacturing processes; the SIVL Center could provide additional industry benefits by serving as a training site for manufacturing plant personnel, academic organizations and regulatory agencies.

In order to better understand the future monitoring and reporting needs of the casting industry, we recommend that workshops and industry focus groups be organized that include:

- The development of industry surveys to better assess current and future emissions monitoring needs
- The presentation of technical papers at major scientific meetings to publicly disseminate information and obtain feedback from technical experts and instrument manufacturers
- The development and offering of an Internet accessible Web database containing information and links concerning existing and emerging characterization and monitoring technologies.
- The identification of emerging new technologies, which may meet the characterization and monitoring needs of the industry, and that have potential for commercialization

9.0 References

American Society for Standards and Testing Materials, www.annex4.org/WKBT (June 24, 2003).

Argonne National Lab Research Program on Chemical Sensors (www.transporation.anl.gov./sensors) (2003)

Berry, R. S., Paper presented at the 1997 EPRI CEM Users Group Meeting, Denver, Colorado (May 14-16, 1997)

California Air Resources Board, Rule 213 for Continuous Emissions Monitoring (www.arb.ca.gov/DRDB/MBU/CURHTML/R213.HTM) (3/21/2001)

Casting Emission Reduction Program Final Report to the Air Force Logistics Center (August 1999)

Casting Emission Reduction Program Report #RV10024AW (August 1999)

Cole, G.S., Rogers, J.D., Bindbeutel, M., Eppley, D. and Schuetzle, D. American Foundry Society Transactions, Vol. 104, pp. 539-543 (1996a)

Cole, G.S., Schuetzle, D., Rogers, J., Tomazewski, S., Bindbeutel, M., Haukkala, B., Eppley, D., Walden, W., Knight, S. and Dobitz, L., "CERP Program Represents Tomorrow's Foundry," Modern Casting, pp. 39-41 (1996a)

Electric Power Research Institute (EPRI) Destinations, "Continuous Emissions Monitoring," http://www.epri.com/destinations/msview (2003)

Federal Register (40 CFR 60 – Appendix F) (EPA 2002)

Federal Register, Vol. 67, No. 246 (12/23/2002)

Federal Register, Vol. 68, No. 71 (4/14/2003)

Institute of Clean Air Companies, Emissions Measuring Division, "Air Emissions Monitoring for Safe and Efficient Medical Waste Incinerator Operation," (Sept. 1997)

Mosher, G., American Foundry Society, personal communication (April, 2003)

Parker, L. B. and Kiefer, D. W., "Implementing Sulfur Dioxide Allowance Trading: Implications of Transaction Costs and Taxes," (March 12, 1993).

Sacramento Bee Newspaper, "Clinton In Capital" and "Foundry Emissions Target of Joint Program," (October 4, 1993)

Schuetzle, D. and Hammerle, R., "Principals and Applications of Chemical Sensors, ACS Symposium Series #309," American Chemical Society, Washington D.C. (1986)

Schuetzle, D., Presentation to the Media at the Launch of the Casting Emissions Reduction Program, McClellan Air Force Base (October 4, 1993).

Sciulli, Keith, Water Monitoring Goes Wireless, Water and Wastewater Products (March/April 2003).

Stone, J., President, Casting Industry Suppliers Associations (CISA) – personal communication (July 2003).

Thermal Electron Corporation Environmental Products Manufacturing, "In-Situ CEMS", www.thermo.com/tei. (August 2003).

U.S. Air Force, CRADA #94-SM-16 (1994).

U.S. EPA, Evaluation of Particulate Matter Continuous Emission Monitoring Systems, EPA Contract #68-W6-0048, MRI Project # 104703.1.002.07.01. (September 2000).

U.S. EPA, Quality Assurance Requirements for Particulate Matter Continuous Emission Monitoring Systems (40 CFR 60, App. F, draft Revision 2) (November 1998)

APPENDIX I PROPOSED EPA MACT EMISSION STANDARDS FOR METAL CASTING PLANTS

Federal Register, 12/23/2002

Metal Melting (Cupola's and Electric Arc Furnace's)

Existing Sources

Particulate Matter (PM)

0.005 (gr/dscf) grains/dry standard cubic feet
324 *u*g/dscf micrograms/dry standard cubic feet
12,318 ug/m^3 micrograms/cubic meter

Conversion factors:

1 grain = 6.48 x 10^{+4} *u*g (micrograms)
38.02 dscf = 1.00 m^3 (cubic meters).

Lead (Alterative to measurement of PM)

0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide

200 ppmv
(As of August 6, 2003 CO is not likely to be required by MACT for monitoring and control)

Hydrocarbons

20 ppmv (as hexane)

New Sources

Particulate Matter

0.001 gr/dscf
64.8 ug/dscf
2,463 ug/m^3

Lead

0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide
200 ppm

Hydrocarbons
20 ppmv (as hexane)

Electric Induction Furnace and Scrap Pre-heaters

Existing Sources

Particulate Matter
0.001 (gr/dscf)
64.8 *u*g/dscf
2,464 ug/m^3

Lead
0.00002 gr/dscf
13.0 *u*g/dscf
492.4 ug/m^3

Carbon Monoxide
200 ppm

Hydrocarbons
20 ppmv (as hexane)

New Sources

Particulate Matter
0.001 (gr/dscf)
64.8 *u*g/dscf
2,464 ug/m^3

Lead
0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide
200 ppm

Hydrocarbons
20 ppmv (as hexane)

Mold/Core Making

Existing Sources

Particulate Matter

0.001 (gr/dscf)	grains/dry standard cubic feet
64.8 *u*g/dscf	micrograms/dry standard cubic feet
2,464 ug/m^3	micrograms/cubic meter

Lead
0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide
200 ppm

Hydrocarbons
20 ppmv (as hexane)

Triethylamine (TEA)
1.0 ppmv

New Sources

Particulate Matter

0.001 (gr/dscf)	grains/dry standard cubic feet
64.8 *u*g/dscf	micrograms/dry standard cubic feet
2,464 ug/m^3	micrograms/cubic meter

Lead
0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide
200 ppm

Hydrocarbons
20 ppmv (as hexane)

Triethylamine (TEA)
1.0 ppmv

Metal Pouring

Existing Sources

Particulate Matter
0.010 (gr/dscf)
648 *u*g/dscf
24,638 ug/m^3

Lead
0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide
200 ppm

Hydrocarbons
20 ppmv (as hexane)

Triethylamine (TEA)
1.0 ppmv

New Sources

Particulate Matter
0.002 (gr/dscf)
129.6 *u*g/dscf
4,928 ug/m^3

Lead
0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide
200 ppm

Hydrocarbons
20 ppmv (as hexane)

Triethylamine (TEA)
1.0 ppmv

Metal Casting Department
(Mold, Core-Making, Cooling and Shakeout)

Existing Sources

Particulate Matter
0.001 (gr/dscf)
64.8 *u*g/dscf
2,464 ug/m^3

Lead
0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide
200 ppmv

Hydrocarbons
20 ppmv (as hexane)

Triethylamine (TEA)
1.0 ppmv

New Sources

Particulate Matter

0.001 (gr/dscf)	grains/dry standard cubic feet
64.8 *u*g/dscf	micrograms/dry standard cubic feet
2,464 ug/m^3	micrograms/cubic meter

Lead
0.00004 gr/dscf
25.9 *u*g/dscf
984.7 ug/m^3

Carbon Monoxide
200 ppmv

Hydrocarbons
20 ppmv (as hexane)

Triethylamine (TEA)
1.0 ppmv

Fugitive Emissions from Non-Point Sources

Existing Sources

Particulate Matter

Opacity less than 20% (6-minute average)
Opacity less than 27% (one 6-minute average event/hour)

APPENDIX II COST ANALYSIS FOR MACT EMISSIONS MONITORING SCENARIOS

Scenario I (Jan. 2004 – Jan. 2008)

A. Contract to an External Testing Company Using Current Generation Techniques not Validated for Metal Casting Emissions

a). Cost of contract services	$225,000/yr
($150K/year x 1.5 engineer-years)	
(Contract includes on-site validation of techniques)	
b). Expendables (gases, chemicals, etc.)	$15,000/yr
c). Heated sampling lines (replace every 2 yrs.)	$22,500/yr
d). Data system and applications software	$25,000/yr
e). Plant Environmental engineer (50% time)	$67,500/yr
($135K/year x 0.5 engineer-years)	
f). Total ((a) + (b) +(c) + (d) + (e))	**$355,000/yr/plant**

B. Develop an Internal Testing Capability Using Current Generation Techniques not Validated for Metal Casting Emissions

Capital Costs (4 year depreciation schedule)

a). Sampling and analysis equipment	
5 CO instruments (@ $10K each)	$50,000
3 HC instruments (@ $12K each)	$36,000
4 PM instruments (@ $15K each)	$60,000
5 Instrument enclosures (@ $5K each)	$25,000
Systems integration (5 systems) (@ $6K each)	$30,000
b). Plant data system	$25,000
c). Laboratory Construction Costs	
(Hoods, benches, etc.)	$85,000
d). Sub-Total	$311,000
e). Cost/year assuming 4-year depreciation	$77,750/yr

Operational and Maintenance Costs

f). Equipment maintenance (15%/yr)	$46,650/yr
g). Replace sampling systems (every 2 yrs.)	$22,500/yr
h). Expendables (gases, chemicals, etc.)	$15,000/yr
i). Industrial/environmental engineers	
($135K/year x 1.5 engineer-years)	$202,500/yr
j). Total ((e) + (f) + (g) + (h) + (i))	**$364,400/yr/plant**

C. Average of Scenarios IA and IB **$359,700/yr/plant**

Scenario II

Estimated Costs to the Industry with a SIVL Capability and Successful Development, Validation and Implementation of 2nd Generation CEMS for Metal Casting Emissions Beginning in 2004

Capital Costs (4 year depreciation schedule)

a). Continuous Emissions Monitoring Systems (CEMS)	
3 Mold Line CEMS (PM, HC) (@$45K each)	$135,000
2 Cupola CEMS (PM, HC) (@45K each)	$90,000
1 Core Making CEMS (TEA) (@20K each)	$20,000
b). Plant data system	$25,000
c). Total Capital Cost	$270,000
d). Cost/year (4 yr. depreciation schedule)	$67,500/yr

Operational and Maintenance Costs
Manage Via External Contract Services (4 yr. contract)

e). System management, data acquisition Analysis and report preparation	$130,000/yr
f). Expendables (gases, chemicals, etc.)	$15,000/yr
g). Equipment maintenance (15%/yr.)	$40,500/yr
Total cost ((d) + (e) + (f) + (g))	**$253,000/yr/plant**

Scenario III

Estimated Costs to the Industry with a SIVL Capability and Successful Development, Validation and Implementation of 3rd Generation CEMS for Metal Casting Emissions Beginning in 2007

Capital Costs (4-year depreciation schedule)

a). Continuous Emissions Monitoring Systems (CEMS)	
3 Mold Line CEMS (PM, HC) (@$15K each)	$45,000
2 Cupola CEMS (PM, HC) (@$15K each)	$30,000
1 Core Making CEMS (TEA) (@$20K each)	$20,000
b). Plant data system	$25,000
c). Total Capital Cost	$120,000
d). Cost/year (4 yr. depreciation schedule)	$30,000/yr

Operational and Maintenance Costs
Manage Via External Contract Services (4 yr. contract)

e). Systems management, data acquisition Analysis and report preparation	$130,000/yr
f). Equipment maintenance (replace sensors as necessary)	$15,000/yr
Total cost ((d) + (e) + (f))	**$175,000/yr/plant**

SIVL Implementation and Operating Costs

A. *The Costs for Establishment and Operation of a SIVL (Fiscal Year 2004)*

Operational and Maintenance Costs	
a). Development Engineers ($150/year x 2.0 engineer-years)	$300,000
b). Expendables (gases, chemicals, electronics, etc.)	$15,000
c). Miscellaneous (travel, etc.)	$10,000
d). Rental of prototype instruments	$30,000
Contract Costs	
e). External contracts to instrument developers	$29,000
Results Dissemination	
f). Technology and knowledge transfer	$45,000
Total Cost ((a)+(b)+(c)+(d)+(e)+(f))	**$429,000/yr**

B. *The Costs for Establishment and Operation of a SIVL (Fiscal Year 2005)*

Operational and Maintenance Costs	
a). Development Engineers ($155/year x 2.3 engineer-years)	$356,500
b). Expendables (gases, chemicals, electronics, etc.)	$15,000
c). Miscellaneous (travel, etc.)	$10,000
d). Rental of prototype instruments	$45,000
Contract Costs	
e). External contracts to instrument developers	$45,000
Results Dissemination	
f). Technology and knowledge transfer	$90,000
Total Cost ((a) + (b) +(c) + (d) + (e) + (f))	**$561,500/yr**

The projected yearly costs for SIVL during subsequent years (2006 and 2007) are assumed to be the same as those for 2005.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX III AN EVALUATION OF THE FUTURE POTENTIAL FOR LOW-COST 3RD GENERATION CONTINUOUS EMISSION MONITORING SYSTEMS (CEMS)

There are a number of prototype instruments, under development by industry, government and academic R&D organizations, that may be ideal as future, 3rd generation CEMS for metal casting emissions. However, as stated earlier, these instrument companies do not have the capability to effectively validate their instruments.

The 3rd generation CEMS refer to in-situ systems. Several types of in-situ CEMS are currently under development. These include chemical sensors, physical sensors, single-point IR/UV radiation, and cross-stack IR/UV/Visible radiation systems.

The advantages of in-situ CEMS include low cost, ease of installation, no sample extraction hardware and ease of calibration. The disadvantages of these systems include relatively high maintenance costs and the difficulty of dynamically calibrating cross-stack systems.

Chemical Sensors- There are several emerging sensor technologies that may be applicable to the future, low-cost monitoring of emissions from casting plants. Such technologies include Ion Mobility, Surface Acoustic Wave, Ultra-sound and Microwave Cavity Sensors (Figure 8) (Schuetzle, 1986).

> **Ion Mobility Sensors**: These spark-plug-sized devices have the potential of quantifying HC at the parts-per-million level in a high-temperature environment. They work by ionizing exhaust gas in a resistive-coated ion accelerator, then identifying hydrocarbon ions by how long they take to travel to the ion detector.
>
> **Surface Acoustic Wave Sensors**: Surface Acoustic Wave (SAW) and Flexural Plate Wave (FPW) devices can be used as gas sensors when a chemically sensitive coating is applied to the substrate (a piezoelectric crystal for SAW and a thin plate of metal or ceramic for FPW). The sensing ability of the devices is based on the wave velocity. The wave velocity and the frequency between the two transducers on the device are altered when the coating absorbs a chemical. The degree of change provides a quantitative measure of the chemical. The SAW sensor typically operates in the hundreds of MHz frequency range and the FPW sensor operates in the MHz frequency range. Plate Wave (FPW) devices can be used as gas sensors when a chemically sensitive coating is applied to the substrate (a piezoelectric crystal for SAW and a thin plate of metal or ceramic for FPW). The sensing ability of the devices is based on the wave velocity. The wave velocity and the frequency between the two transducers on the device are altered when the coating absorbs a chemical. The degree of change provides a quantitative measure of the chemical. The SAW sensor typically operates in the hundreds of MHz frequency range; the FPW sensor operates in the MHz frequency range.

Low-cost surface acoustic wave sensors absorb target gases on a piezoelectric crystal coated with a chemically selective material. The degree of change in the velocity and the frequency of surface waves in the crystal can identify and quantify the target chemicals.

Ultrasound Sensors: These low-cost, fast-response ultrasonic sensors have been successfully used to measure sub-micron particulate emissions in diesel engine exhaust. The measurement of the ultrasonic wave velocity generated from an air-coupled, high frequency transducer can be used to identify particle concentration, size, and composition.

Microwave Cavity Sensors: These compact, dual-cavity sensors quantify emissions by measuring their absorption properties as a function of microwave frequency. This technology compares reference data collected in a sealed cavity with data collected in a cavity exposed to exhaust gases. The sharp resonance provided by the cavity structure yields detection sensitivities in the parts-per-million range.

Particulate Matter Sensors - Several types of instruments have been developed for the CEMS of particulate matter in stack emissions. These systems are briefly described as follows:

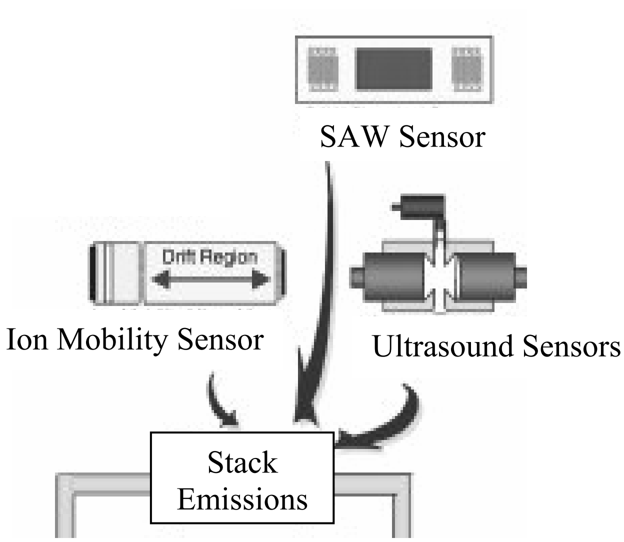
Environmental Systems Corporation has developed a light-scattering CEMS that detects back-scattered light from a collimated, near-infrared light emitting diode (LED). Since this instrument measures in the near infrared, it is less sensitive to changes in particle size, and it has a relatively constant response to particles in the 0.1 to 10 um range. Its measurement range is 0.5 mg/m^3 to 20,000 mg/m^3. Condensed water droplets in the gas stream will produce a positive interference.

Durag Corporation has an instrument that detects particulate matter in the stack by monitoring the light scattered from the particles at 120^{o}F by a 400-700 nm light beam modulated at 1.2kHz. This instrument is sensitive to changes in particle characteristics (e.g., size, shape and color) and the presence of condensed water droplets in the gas stream. The particle measuring ranges are from 0 to 1 mg/m^3 and 0 to 100 mg/m^3. This instrument provides automatic zero and upscale drift checks and automatic compensation for dirt on the optics (although the optics are protected by an air purge system). The German TUV has approved this instrument for all sources. It has also been evaluated by EPA/OSW at a long-term field test at the Dupont Experimental Field Station incinerator. Over 500 of these instruments have been sold to date.

Semi-automated filter tape systems have been used for more than 40 years to collect and measure environmental particulate matter. Some new approaches have been developed that make this an attractive technique for the CEMS of particulate matter from stationary sources.

Durag Corporation has developed a beta gauge type monitor for the quantitative measurement of particles collected on a filter tape during user defined sampling periods (e.g., 4 to 8 minutes). The sample is extracted from a stack at a single point under isokinetic conditions at the normal process operating rates (e.g., isokinetic sampling is not maintained as stack flow changes). This instrument introduces dilution air after the sampling nozzle (1) to minimize particle loss in the sampling system, (2) to accommodate high dust loadings and (3) to sample wet or saturated stack gas. The measuring range is determined by the length of the sampling period and the amount of dilution air introduced in the probe, but the instrument can accommodate a range of up to 6-8 mg of particulates deposited on the filter tape during each sampling period. The filter tape is moved between a carbon 14 (^{14}C) beta particle source and Geiger-Mueller detector. The amount of particulate material on the filter is determined by the reduction in transmission of beta particles between the dirty tape (after sampling) and the clean tape (before sampling). The attenuation of the beta particles is believed to be minimally sensitive to the composition of the particulate. The sampled gas is dried and the flow rate measured, thus allowing reporting of PM concentrations on a dry basis. This instrument provides automatic zero and upscale drift checks to meet daily QC requirements. The zero check is performed by measuring the same location of the filter tape twice in succession with tape transport between measurements, without collecting a sample. The German TUV has approved this instrument for all sources. It has been evaluated by EPA/OSW at a long-term field test at the Dupont Experimental Field Station incinerator and by Eli Lilly at a liquid waste incinerator.

Figure 8 Possible Future Sensor Technologies for Stationary Source CEMS



In combination with the properly designed stack sampling probes, these devices can provide low-maintenance CEMS that incorporate auto calibration protocols and self-regeneration of the sensor. Figure 9 illustrates how these sensors could be used for the CEMS of casting emissions. This particular system utilizes compact fuel cell sensors that can be installed directly on the stack or a duct leading into the stack. Such systems would not require any additional, costly shelters or housings. Beginning in 2005/2006 SIVL should have the capability to assess the operation, sensitivity, durability and calibration of these sensor-based CEMS under laboratory and real-world operating conditions.

Figure 9 A Potential Future Chemical Sensor System for the CEMS of Emissions from Manufacturing Plants