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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Emission Factors for Flux Core Rod Used in Gas Shielded Processes

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
National Steel and Shipbuilding Company
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Final Report

Emission Factors for Flux Core Rod Used in Gas Shielded Processes
Project No. N1-98-1 Subtask 43

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FACILITIES AND ENVIRONMENTAL EFFECTS PANEL

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Emission Factors for Flux Core Rod Used in Gas Shielded Processes

Introduction:

The shipbuilding and repair industry uses a wide variety of welding rods and wires in combination with various welding processes. These processes include, but are not limited to, gas metal arc welding (GMAW), flux core arc welding (FCAW), shielded metal arc welding (SMAW), and submerged arc welding (SAW). There are presently some emission factors for welding operations that have been developed by the United States Environmental Protection Agency (USEPA) and other regulatory agencies.

It has recently been determined that some shipyards use gas shielding welding processes with flux core welding wire. This is done to ensure that there is no potential for oxidation at the point of the weld. It is currently unknown as to how using flux core wires in gas shielded welding processes affect the emission factors. Until this can be empirically determined, many regulatory agencies will continue to use the FCAW emission factors when determining potential health risks.

The goal of this project is to provide the basic test data from which more accurate, and regulatory agency accepted, emissions factors for welding fumes can be derived.

Background:

The structural framework of most ships is constructed of various grades of mild and high strength steel. Steel provides the formability, machineablity, and weldability required, combined with the strength needed for ocean going vessels. Various grades of steel predominate most ships, although aluminum and other nonferrous materials are used for some superstructures (deck-houses) and other specific areas within the ship. Other materials found on ships, like stainless steel, galvanized steel, and copper nickel alloy, are used for a variety of corrosion resistant purposes and structural integrity. Nonferrous materials are used in far less quantity than steel. Shipboard systems (i.e. ventilation, combat, navigational, piping, etc.) are usually where the more “exotic” materials are used. These materials are required to perform a wide variety of functions including the ship propulsion systems, backup power, kitchens, pump stations for fuel transfer and combat systems.

Steel used for construction can be subdivided into three types: mild, high-strength, and high alloy steel. Mild steels have valuable properties and are easy to produce, purchase, form, and weld. On the other hand, high-strength steels are mildly alloyed to provide mechanical properties that are superior to the mild steels. Extremely high-strength steels have been developed specifically for use in naval construction. In general, the high strength and high yield steels are called HY-80, HY-100, and HY-130. They have strength properties in excess of the commercial grade high strength steels. Welding processes are more complicated for high-strength steels in order to prevent deterioration of their properties. Specific weld rods are needed for high-strength steel and weld joint heating (preheating) is usually required. A third general class of steels, the high-alloy steels, are made by including relatively large amounts of alloying elements, such as nickel, chromium, and manganese. These steels, which include stainless steels, have valuable corrosion resistance properties and also require special welding processes.

Steel is an excellent material for shipbuilding purposes and the choice of welding electrode is critical in all welding applications during construction. The standard goal is to obtain a weld with equivalent strength characteristics to the base metal. Since minor flaws are likely to occur in production welding, welds are often designed and welding electrodes chosen to produce welds with properties in excess of those of the base metal.

Common Welding Processes

Shipyard welding processes, or more specifically fusion welding, is performed at nearly every location in the shipyard environment. The process involves joining metals by bringing adjoining surfaces to extremely high temperatures to be fused together with a molten filler material. A heat source is used to heat the edges of the joint permitting them to fuse with molten weld filler metal (electrode, Wire or rod). An electric arc or a gas flame usually generates the required heat. Shipyards choose the type of welding process based on customer specifications, production rates, and a variety of operating constraints. For commercial shipbuilding, welding processes are subject to review and approval by the regulatory bodies of the United States Coast Guard (USCG) and/or the classification societies of the American Bureau of Shipping (ABS). In the U.S. most oversight and inspection is performed by the ABS, operating under a memorandum of understanding with the USCG. The ABS Rules for Building and Classing steel vessels contains a section on the required procedures and practices of welding for hull construction and outfitting.

The U.S. Navy has established similar standards and requirements for naval ship construction, repair, and modification. Standards for military vessels are usually more stringent than commercial vessels.

An important factor with respect to the fusion welding processes is arc shielding to protect the weld pool. The temperature of the weld pool is substantially higher than the adjoining metals melting point. At extremely high temperatures, a reaction with oxygen and nitrogen in the atmosphere is rapid and has negative affects on the weld strength. Should oxygen and nitrogen from the atmosphere become trapped within the weld metal and molten rod, embrittlement of the weld area will occur. To protect against this weld impurity and ensure weld quality, shielding from the atmosphere is required. In most welding processes, shielding is accomplished by addition of a flux a gas, or a combination of the two. Where a flux material is used, gases generated by vaporization and chemical reaction at the electrode tip, result in a combination of flux and gas-shielding that protect the weld from nitrogen and oxygen entrapment.

In electric arc welding, a circuit is created between the work-piece and an electrode or wire. When the electrode or wire is held a short distance away from the work piece, a high-temperature arc is created. This arc generates sufficient heat to melt the edges of the work piece and the tip of the electrode or wire to produce a fusion welding system. There is a number of electric arc welding processes suitable for use in shipbuilding. All processes require shielding of the weld area from the atmosphere. The processes may be subdivided into flux-shielded and gas-shielded processes.

Shielded Metal Arc Welding (SMAW)

Flux-shielded electric arc welding processes are distinguished primarily by their manual or semiautomatic nature and the type of consumable electrode used. The SMAW process utilizes a consumable electrode (12 to 18" in length) with a dry flux coating, held in a holder and fed to the work piece by the welder.

The electrode consists of the solid metal filler rod core, made from either drawn or cast material covered with a sheath of metal powders. SMAW is also frequently refereed to as “Stick Welding” and “ARC Welding”. The electrode metal is surrounded by flux that melts as welding progresses, covering the deposited molten metal with slag and enveloping the immediate area in an atmosphere of protective gas. Numerous electrodes are available, as classified by the American Welding Society (AWS). The choice of electrode is base on the ABS or Military Specification that is based on the required composition and properties of the deposited weld metal and strength requirements of the structure.

Submerged Arc Welding (SAW)

Submerged arc welding (SAW) is another flux-shielded electric arc welding process used in many shipyards. In this process, a blanket of granulated flux is deposited on the work piece, followed by a consumable bare metal wire electrode. Generally, the electrode serves as the filler material, although is some cases metal granules are added to the flux. The arc, submerged in the blanket of flux, melts the flux to produce a protective insulated molten shield in the weld zone. High heat concentration permits heavy weld deposits at relatively high speeds. After welding, the molten metal is protected by a layer of fused flux that is subsequently removed and may be recovered.

Gas Metal Arc Welding (GMAW)

A second major category of electric arc welding is the gas-shielded processes. These processes generally use bare were electrodes with an externally supplied inert active, or a combination of inert and active shielding gases.

The first type of welding process is called gas metal arc welding (GMAW) or it is commonly referred to as metal inert gas (MIG) welding.

GMAW uses a consumable wire electrode that is automatically fed to the weld point that is submerged in a continuous flow of shielding gas. GMAW is the answer to a long-sought method of being able to weld continuously without the interruption of changing electrodes, which necessitated an automatic wire feeder. A wire spooling system provides the electrode/wire filler rate that is at a constant speed or the speed fluctuates with a voltage sensor. At the point where the electrode meets the weld arc, an argon or helium being used as the shielding gas is supplied by the welding gun. It was found that for welding steel, a combination of CO2 and/or an inert gas could be used. Often, a combination of the gases is used to optimize cost and weld quality.

Flux Core Arc Welding (FCAW)

Flux cored arc welding uses equipment similar to GMAW in that the Wire is fed continuously to the arc. The main differences are that the FCAW electrode is a tubular electrode wire with a flux core center that helps with localized shielding in the welding environment. Some flux cored wire provide adequate shielding with the flux core alone. However, many FCAW processes used in the shipbuilding environment require the addition of gas shielding for the quality requirements of the shipbuilding industry (i.e. ABS and the NAVY).

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Construction of Sample Collection Equipment

Introduction

Emission factor development testing was completed at the Atlantic Marine Inc. (AMI) facility in Jacksonville, Florida during the period from September 13 through October 20, 2000. In order to develop emission factors for shipyard welding operations, it was necessary to design and construct a facility to collect and exhaust welding fumes and allows collection of exhaust samples. Welding was conducted within the test facility and fumes were vented through the system exhaust, from which the samples were taken.

Test Facility

To configure the Conex1 box as the sample collection chamber some modifications were made to meet USEPA's requirements for a temporary total enclosure while still allowing safe access for the welding team. A standard Conex box, measuring 8 by 8 by 40 was employed as the test chamber. The front (door) end of the box was sealed with a temporary panel that included an access door and electrostatic micro-particle pleated fabric filters panels. An opening was cut into the back end of the box, through which the ventilation fan (5500 CFM at 40" static pressure) was connected. A sampling duct, constructed by AMI, was attached to the test chamber, allowing air samples to be collected during the welding tests.

In this configuration, the test facility met the specifications of USEPA Method 204, *Criteria for and Verification of a Permanent or Temporary Total Enclosure* and 100% fume capture was assumed.

The inlet air to the test facility was filtered with standard HVAC filters. The exhaust duct was of horizontal configuration and measured 20 by 20 inches square by approximately 32 feet long. Six sets of three, three-inch diameter, sample ports were installed in the vertical portion of the exhaust duct at distances of 3, 6, 9, 12, 15, and 18 feet downstream of the exhaust blower transition. All sample ports met the criteria of USEPA Method 1, *Sample and Velocity Traverses for Stationary Sources*.

Welding Rods/Wires Test Procedure

A series of several welding rod/wires were selected to performed emissions testing. The selection were based upon the reported usage of specific rods/wires that were used in FCAW with and without a shielding gas. Additionally, each rod/wire was testing using the GMAW process, if a GMAW type wire was available.

Table 1 below lists the rod/wires used with each welding process.

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1 Corrugated Steel Marine Freight Container

Table 1: Welding Rods/Wires and Process

Welding Rod/Wire Tested	
Rod/Wire	Welding Process
309 series	FCAW w/ shielding gas
309 series	FCWA w/o shielding gas
309 series	GMAW w/shielding gas
316 series	FCAW w/shielding gas
316 series	FCWA w/o shielding gas
316 series	GMAW w/shielding gas
70 series	FCAW w/shielding gas
70 series	FCWA w/o shielding gas
70 series	GMAW w/shielding gas
71 series	FCAW w/shielding gas
71 series	FCWA w/o shielding gas

Welding was completed within the test facility by a team of two2 experienced welders3 and all fumes were vented through the exhaust duct. Total usage of welding wire was tracked, along with the source testing data to establish emission factors for the various combinations of welding methods and rods/wires.

Sample Collection

Sampling equipment was set up along the exhaust duct and samples were collected and analyzed for various components as summarized in Table 2 below. Three replicate samples for each analytical parameter were taken for each test burn of a rod/wire. Additional, a set sample blanks and background samples were taken.

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2 Two welders were used to ensure continuous and sufficient fume generation.

3 Special thanks to Mr. Garey Jeter and Mr. Richard Buckhold, who performed the majority of the welding for this study.

Table 2: Analytical Parameters

Summary of Analytical Parameters for Emission Factor Testing
Total suspended particulate (TSP)
Nickel
Manganese
Lead
Cadmium
Total chromium
Hexavalent chromium

Sample Collection Test Equipment Photos

Figure 1: Exterior of Conex Box Test Chamber

Figure 2: Test Chamber Ventilation Fan

Figure 3: Sample Duct and Equipment

Figure 4: Sample Collection

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Collection and Analysis of Fume Samples

Introduction

Welding was conducted under controlled test conditions within the test enclosure. Metal parts were welded utilizing the combination of methods and rods/wires and shielding described previously. Each test run was approximately two hours in duration. Three replicate samples were collected for each set of test conditions. U.S. EPA Reference Methods were utilized for sampling the welding fumes within the enclosure exhaust duct.

Test Parameters and Methods

The test methods and contaminants analyzed are summarized in Table 1 followed by brief summaries of each method.

Table 1: Parameters and Test Methods Utilized for Emission Factor Development

Parameter	Test Method
Flow Rate	U.S. EPA Reference Method 1, *Sample and Velocity Traverses for Stationary Sources*
	U.S. EPA Reference Method 2, *Determination of Stack Gas Velocity and Volumetric Flow Rate (Type-S Pitot Tube)*
Moisture	U.S. EPA Reference Method 4, *Determination of Moisture Content in Stack Gas*
Total Suspended Particulate	U.S. EPA Reference Method 5, *Determination of Particulate Emissions from Stationary Sources*
Metals – Nickel, Manganese, Lead, Cadmium, and Total Chromium	U.S. EPA Reference Method 29, *Determination of Metals Emissions from Stationary Sources*
Metals – Hexavalent Chromium	U.S. EPA Reference Method 306, *Determination of Chromium Emissions from Decorative and Hard Chromium Electroplating and Anodizing Operations*

Total Particulate

Particulate emissions were determined in accordance with USEPA Reference Method 5, *Determination of Particulate Emissions from Stationary Sources*. In this method, gaseous and particulate pollutants were withdrawn isokinetically and collected on a glass fiber filter. The particulate mass, which includes any material that condenses at or above the filtration temperature, was determined gravimetrically after removal of uncombined water.

Metals (excluding hexavalent chromium)

The enclosure exhaust was sampled for metal emissions (other than hexavalent chromium) in accordance USEPA Reference Method 29, *Determination of Metals Emissions from Stationary Sources*. With this method, metals in the sample gas were withdrawn isokinetically and collected in the sample train on a filter and in acidic impinger reagents. Recovered samples were digested and analyzed for total chromium (Cr), cadmium (Cd), nickel (Ni), manganese (Mn), and lead (Pb) in accordance with Method 29.

Hexavalent Chromium

Hexavalent chromium emissions were determined in accordance with USEPA Reference Method 306. With this method, gaseous pollutants were withdrawn isokinetically and collected in an alkaline solution. The collected samples were analyzed by an ion chromatograph equipped with a post-column reactor (IC/PCR) for hexavalent chromium.

Chemical Analysis of Fume Samples

Fume samples were analyzed in accordance with the USEPA Reference Methods specified in above. Using the analytical data, source sampling data and measured exhaust duct flow rate, mass emission rates were calculated for each test. These data, along with the rod/wire use amounts were used to calculate emission factors for each test. The emission factors are presented on a mass emission rate per mass of rod-consumed basis.

Calculations

The total mass of rod/wire consumed was measured and recorded for each test. Emission rates were calculated for TSP, Metals and Hexavalent Chrome in accordance with the respective test methods. These data, along with the usage data for the rods/wires, were utilized for emission factor development. Emission factors were calculated based on a mass emission rate per unit measure of rod/wire utilized.

Analytical Results

The analytical results are presented in the attached tables. Table 1 summarizes the calculated emission factors and averages for each test run on a pound of emissions per pound of wire consumed basis. Tables 2 – 4 provides the results of the TSP, metals and hex-chrome data.

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Data Analysis and Discussion

Introduction

The main pollutants of concern generated during welding operations are particulate matter and particulate phase hazardous air pollutants. Only electric arc welding generates pollutants in quantities of major concern. Resistance welding using certain materials also may generate hazardous pollutants. Due to the lower temperatures of the other welding processes, fewer fumes are released.

The quantity of emissions released depends largely on the type of welding process used and its operating conditions. Depending on the choice of electrode and its diameter and composition, emissions are reduced or increased. The work piece composition also affects the quantity of fume released. Coatings on the work piece generate organic and metallic fumes (e.g., galvanized coatings, cleaners, oils, paints, etc.), depending on the particular application. Operating conditions that influence fume emissions include travel speed, voltage, current, arc length, polarity, welding position, electrode angle, and deposition rate.

The welding fume is formed by the vaporization and recondensation of metallic elements upon cooling in ambient air. As such, the particulate matter produced is generally submicron in size with approximately 50% to 75% of the particles having diameters in the range of 0.4 to 0.8 μm. The amount of the emissions generated can vary substantially from process to process.

The elemental composition of the fume varies with the electrode and work piece composition. Hazardous metals listed in the 1990 Clean Air Act Amendments, which have been detected in welding fume include manganese, nickel, chromium, cobalt, and lead. Additionally, the hexavalent form of chrome (Chrome $^{+}6$) is also found in some welding fume emissions. The emissions of toxic air contaminates during welding have potential adverse human health impacts. Occupational exposures to welding fumes are typically controlled with ventilation and personal protective equipment. Environmental exposures are more difficult to define and potential health impacts are usually predicated using computer dispersion models and health risk assessments. As the results of the dispersion models (and therefore the health risk assessment) are directly dependent upon the emission rate of a contaminant, it is important to quantify the emissions factors of the various toxic air contaminants as accurately as possible.

Development of Emission Factors

Emission factors were developed for the TSP particulates, several metals and hexavalent chrome. The emission factors were derived using the following equation.

Equation 1: Emission Factors

$$\frac{\text{Analytical Results (lbs)}}{\text{Meter Box Reading (dscf)}} \times \text{Air Volume (cuft/min)} \times \frac{\text{Lenght of Test (min)}}{\text{Mass of Rod (lbs)}} = \text{Emission Factor}$$

where:

Analytical Results = the mass in pounds of variable measured.

Meter Box Reading = the amount of air volume in cubic feet drawn through the sample collection equipment.

Air Volume = the airflow in cubic feet per min through the sampling duct.

Length of Test = the amount of time in minutes the testing was conducted.

Mass of Rod = the mass of welding rod or wire consumed during the test period.

This equation results in an emission factor ("EF") for each variable, expressed in units of pounds emitted/pound welding rod consumed.

An average EF was calculated based upon the result of each of the three replicate samples taken during each test run. The resultant emission factors are presented in the following section.

Welding Rod/Process Emission Factors

Particulate Emission Factors

TSP emission factors for the four welding wires and three welding processes are presented in Table 1 below:

Table 1: TSP Emission Factors

Type of Welding Wire	Type of Welding Process	Gas Shielding	TSP Emission Factors lbs emissions/lbs wire
309	FCAW	Gas Shielded	1.97E-01
309	FCAW	Not Gas Shielded	3.00E-01
309	GMAW	Gas Shielded	1.73E-01
71-M	FCAW	Gas Shielded	1.37E-01
71-T GS	FCAW	Not Gas Shielded	5.51E-01
770	FCAW	Gas Shielded	1.60E-01
70T	FCAW	Not Gas Shielded	1.81E-01
70-S-6	GMAW	Gas Shielded	2.76E-01
316	FCAW	Gas Shielded	3.83E-01
316	FCAW	Not Gas Shielded	3.73E-01
316	GMAW	Gas Shielded	2.50E-01

The emission factors calculated for particulate matter in this study are in general agreement with the results of other studies performed previously. These include the following observations:

1. TSP emissions from the same type wire using gas shielded welding process is generally less than the same type wire used in a welding process without shielding gas.

2. The amount of rod that is converted to fume varies within a range of 15 to over 30 percent.

Charts of TSP emission factors are attached in Appendix 1.

Metals Emission Factors

TSP emission factors for the four welding wires and three welding processes are presented in Table 2 below:

Table 2: Metals Emission Factors

Type of Welding Wire	Type of Welding Process	Gas Shielded	Metals Emissions Factors – lbs emissions/lbs wire				
			Cadmium	Chrome	Lead	Manganese	Nickel
309	FCAW	Gas Shielded	5.98E-06	2.70E-03	4.26E-05	6.99E-03	1.04E-01
309	FCAW	Not Gas Shielded	7.09E-06	2.07E-04	6.46E-05	4.21E-03	5.75E-03
309	GMAW	Gas Shielded	0.00E+00	5.89E-03	2.04E-05	1.46E-02	6.04E-01
71M	FCAW	Gas Shielded	4.24E-06	1.60E-04	3.26E-05	1.76E-02	6.64E-03
71-T	FCAW	Not Gas Shielded	0.00E+00	1.25E-04	2.88E-04	2.81E-02	6.29E-02
770	FCAW	Gas Shielded	1.27E-05	4.58E-05	8.66E-05	2.56E-02	1.06E-02
70T	FCAW	Not Gas Shielded	6.41E-06	8.85E-05	5.01E-05	1.18E-02	8.61E-03
70S-6	GMAW	Gas Shielded	0.00E+00	7.42E-05	1.78E-04	1.04E-02	2.53E-03
316	FCAW	Gas Shielded	0.00E+00	2.45E-03	0.00E+00	1.69E-02	1.91E-01
316	FCAW	Not Gas Shielded	4.00E-06	7.90E-03	2.94E-05	1.44E-02	3.46E-01
316	GMAW	Gas Shielded	0.00E+00	1.03E-03	0.00E+00	2.99E-03	7.73E-02

With regard to metals emissions from welding, the following general observations can be made:

1. The effect of gas shielding the wire during welding does not have a consistent effect in reducing or increasing metal emissions. This inconsistency is observed both between different wires and within the same type wire.

Charts of Metals emission factors are attached in Appendix 2.

Hexavalent Chrome Emission Factors

Hexavalent Chrome ("Chrome-6") emission factors for the four welding wires and three welding processes are presented in Table 3 below:

Table 3: Hexavalent Chrome Emission Factors

Type of Welding Wire	Type of Welding Process	Gas Shielded	Chrome-6 Emission Factors lbs emissions/lbs wire
309	FCAW	Gas Shielded	6.84E-05
309	FCAW	Not Gas Shielded	1.28E-04
309	GMAW	Gas Shielded	6.11E-05
71-M	FCAW	Gas Shielded	2.67E-05
71-T GS	FCAW	Not Gas Shielded	3.87E-05
70-S-6	GMAW	Gas Shielded	1.35E-06
70T	FCAW	Not Gas Shielded	9.00E-06
770	FCAW	Gas Shielded	1.71E-06
316	FCAW	Gas Shielded	5.59E-05
316	FCAW	Not Gas Shielded	2.60E-04
316	GMAW	Gas Shielded	2.34E-05

With regard to Chrome-6 emissions from welding, the following general observations can be made:

1. Both the gas shielded FCAW and GMAW processes consistently resulted in lower emission factors for chrome-6 over the FCAW without gas shielding.

Charts of Hexavalent Chrome emission factors are attached in Appendix 3.

Discussion of Project Results

The development of emission factors for welding processes and the associated types of rod and wire that can be used in those processes is difficult for several reasons. Perhaps the most important is that arc welding is a multivariate process that is difficult to subject to precisely controlled testing. Uncontrolled variables in the testing procedure can result in significant variations in the measured test parameters necessary to calculate an emission factor.

The emission factors derived from this study are believed to be accurate within the established test parameters. A review of the available literature concerning emission factors for particulates and metals, including AP-42, indicate that while the emission factors for particulates are generally similar to other studies, the emission factors for metals are general lower than other published reports. As the testing, sampling and analytical protocols are not consistent between the various published studies and our study, we cannot identify any specific set of reasons why the emission factors derived from this study would be inconsistent with other research results.

The testing procedure designed for this study is believed to be representative of actual shipyard welding conditions, for these processes and materials. For this reason, the emission factors derived are believed to be an accurate representation of welding emission from shipyards.

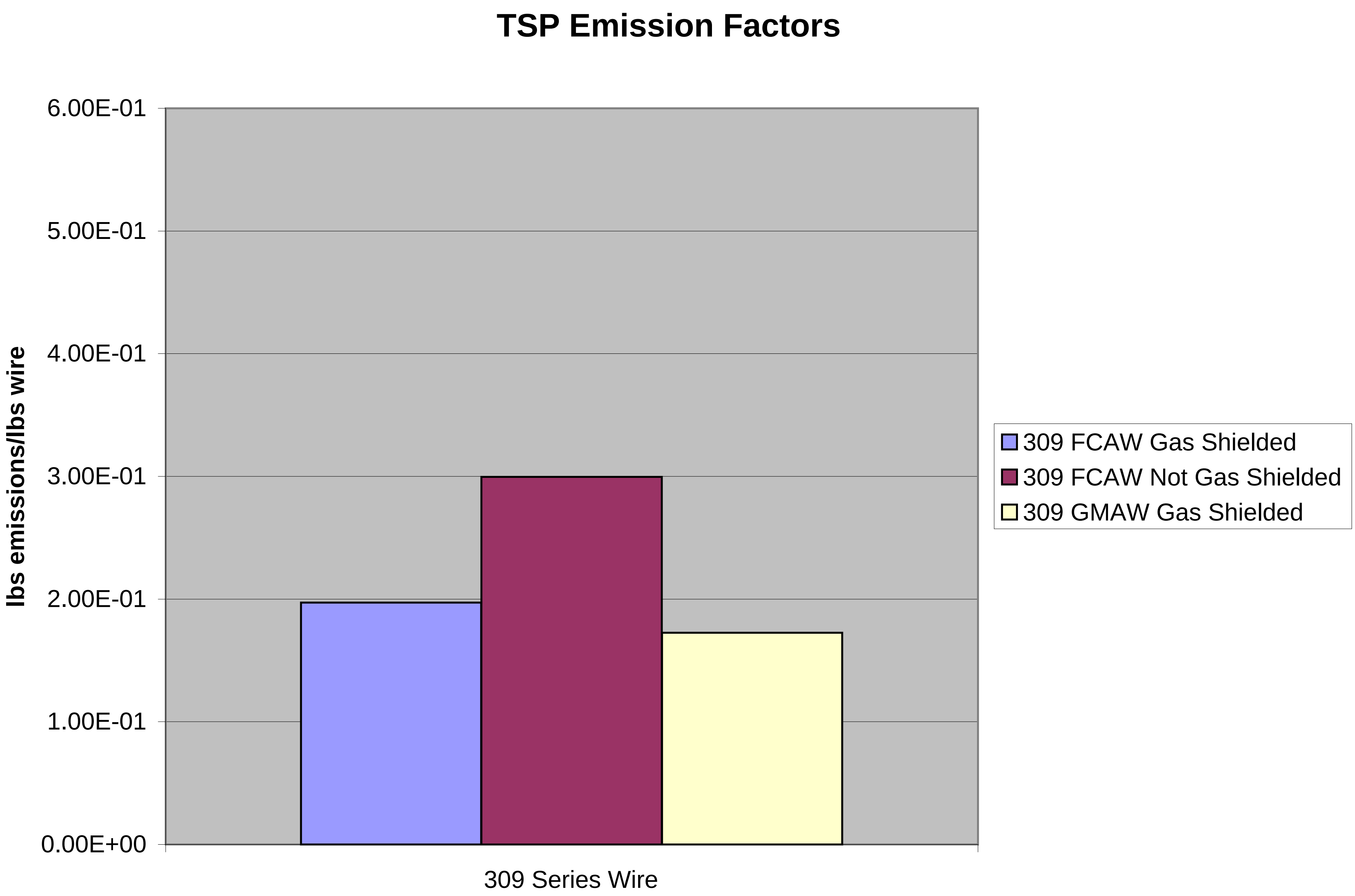
Appendix 1

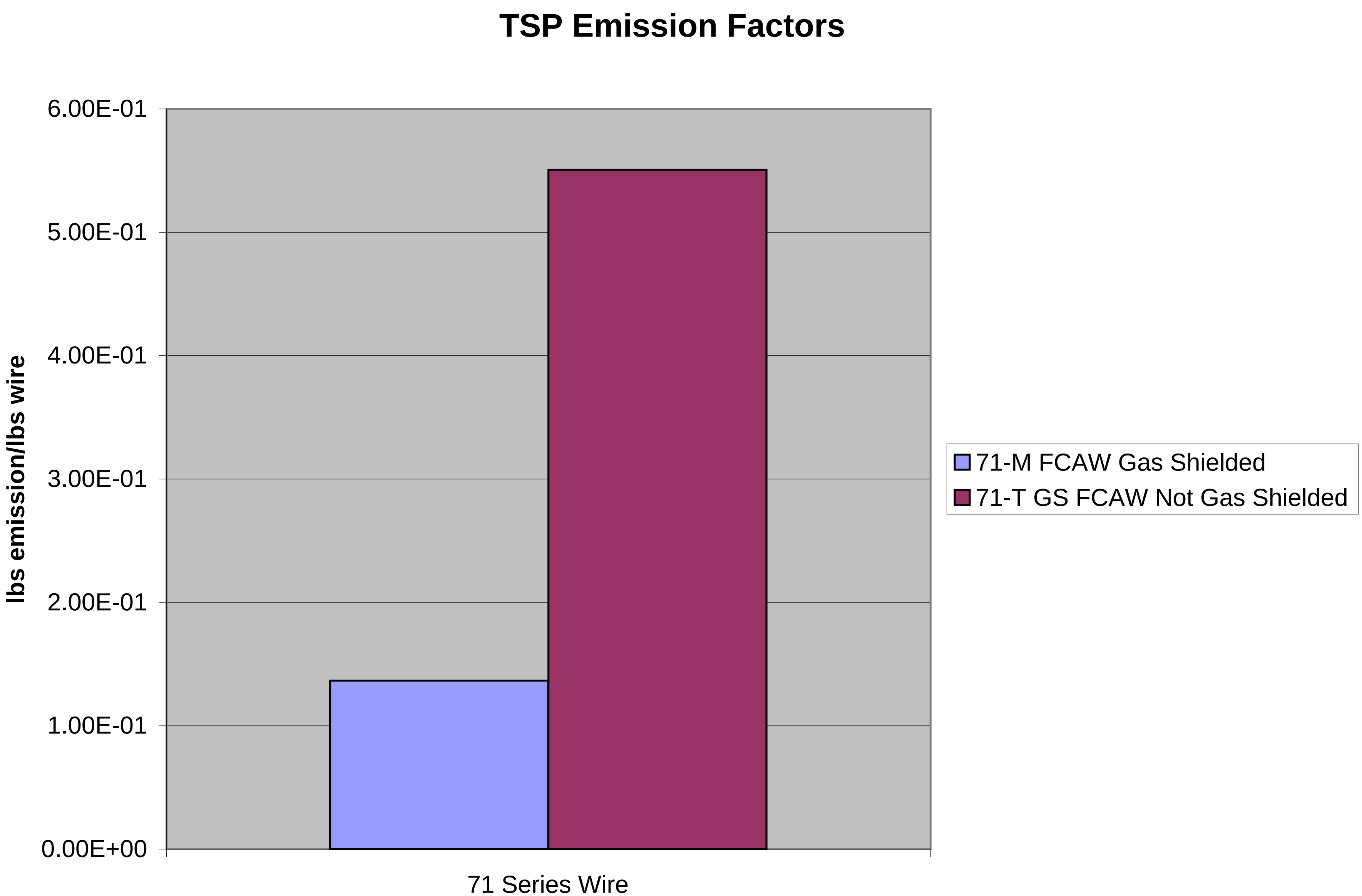
Table 1: Summary of Test Data & Average of Replicates

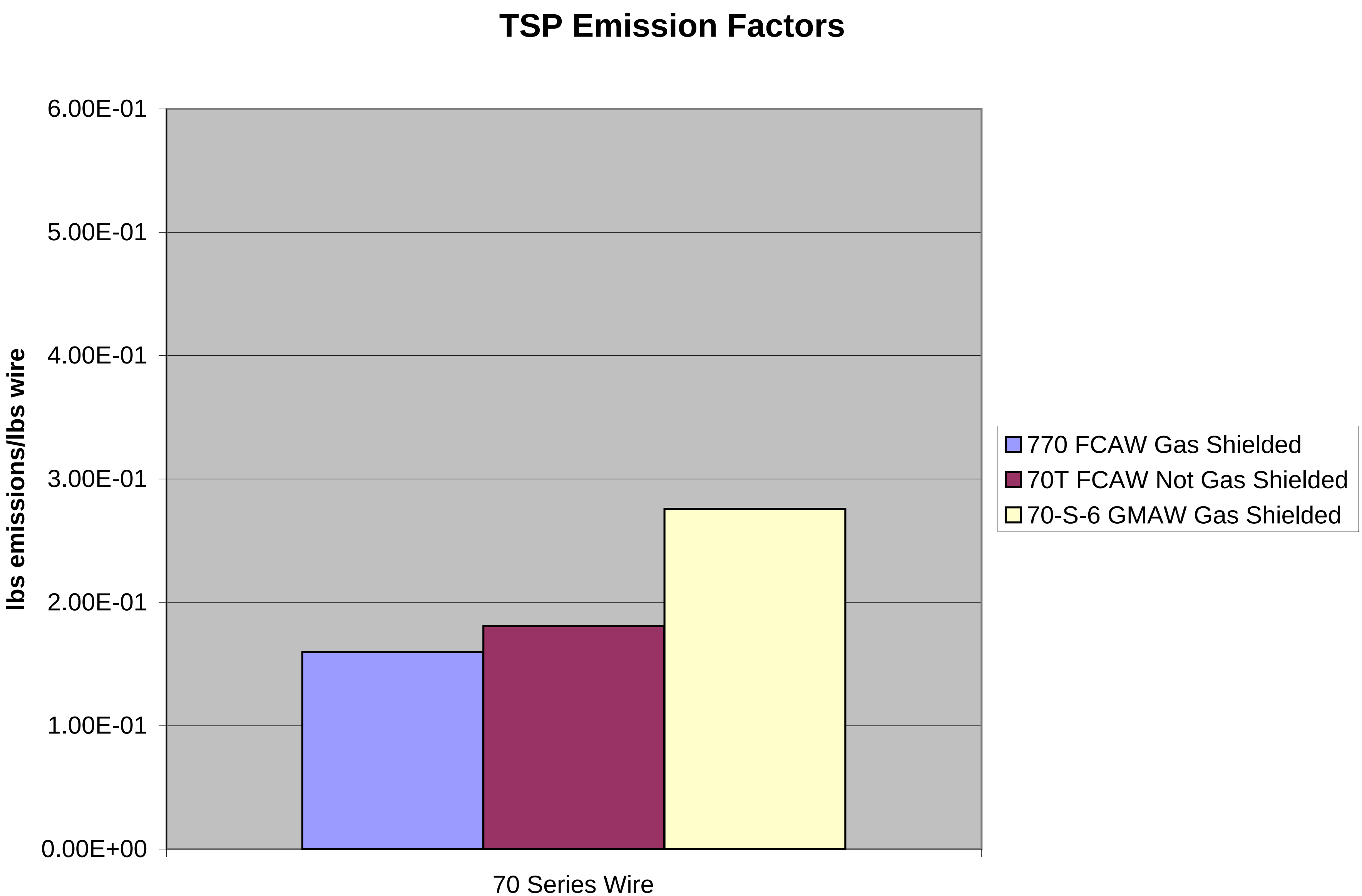
NSRP Welding Emission Factor Development

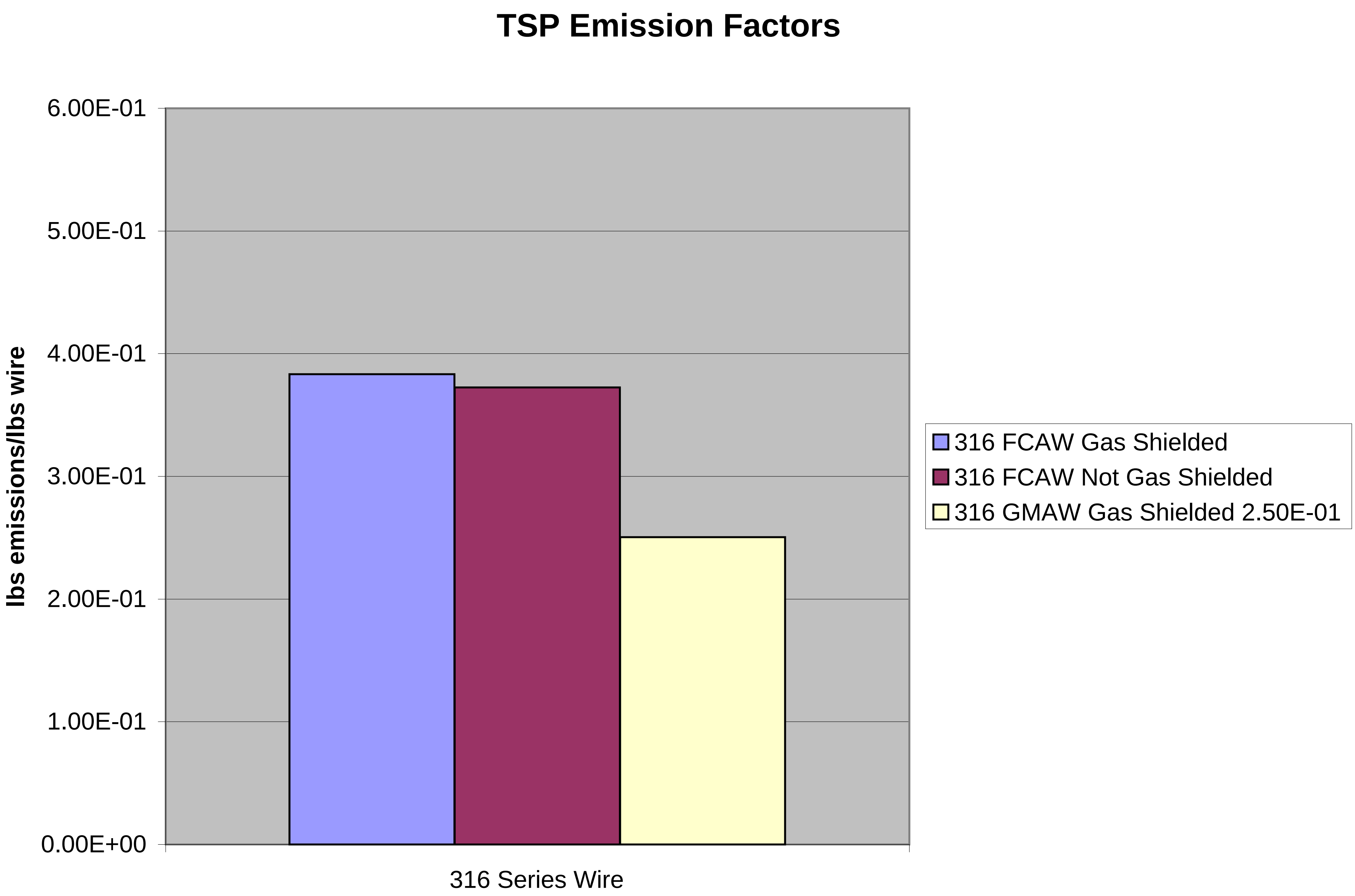
Run No.	Replicate No.	Welding Wire and Process			Emission Factors (lbs emissions/lbs wire consumed)						
		Type	Wire	Gas	TSP	Cadmium	Total Chromium	Lead	Manganese	Nickel	Hexavalent Chromium
3		309	FCAW	No	3.08E-01	2.13E-05	2.07E-04	1.06E-04	4.04E-03	5.31E-03	2.529E-04
	2	309	FCAW	No	2.71E-01	0.00E+00	N/A	0.00E+00	4.44E-03	4.72E-03	8.175E-05
	3	309	FCAW	No	3.19E-01	0.00E+00	2.06E-04	8.75E-05	4.16E-03	7.21E-03	4.952E-05
	Average				3.00E-01	7.09E-06	2.07E-04	6.46E-05	4.21E-03	5.75E-03	1.28E-04
4	1	71-T GS	FCAW	No	5.28E-01	0.00E+00	9.31E-05	2.64E-04	2.93E-02	0.00E+00	3.845E-05
	2	71-T GS	FCAW	No	5.01E-01	0.00E+00	1.58E-04	3.71E-04	4.55E-02	0.00E+00	5.560E-05
	3	71-T GS	FCAW	No	6.24E-01	0.00E+00	N/A	2.30E-04	9.54E-03	1.89E-01	2.211E-05
	Average				5.51E-01	0.00E+00	1.25E-04	2.88E-04	2.81E-02	6.29E-02	3.87E-05
5	1	70-S-6	GMAW	Yes	3.29E-01	0.00E+00	6.83E-05	1.41E-04	8.02E-03	2.56E-03	N/A
	2	70-S-6	GMAW	Yes	2.40E-01	0.00E+00	8.01E-05	2.15E-04	1.28E-02	2.50E-03	0.000E+00
	3	70-S-6	GMAW	Yes	2.59E-01	N/A	N/A	N/A	N/A	N/A	4.047E-06
	Average				2.76E-01	0.00E+00	7.42E-05	1.78E-04	1.04E-02	2.53E-03	2.02E-06
6	1	71-M	FCAW	Yes	1.24E-01	0.00E+00	1.96E-05	5.21E-05	1.34E-02	0.00E+00	8.694E-07
	3	71-M	FCAW	Yes	1.22E-01	1.27E-05	5.09E-05	4.58E-05	2.18E-02	0.00E+00	5.082E-05
	5	71-M	FCAW	Yes	1.64E-01	0.00E+00	4.10E-04	0.00E+00	N/A	1.99E-02	2.832E-05
	Average				1.37E-01	4.24E-06	1.60E-04	3.26E-05	1.76E-02	6.64E-03	2.67E-05
7	1	770	FCAW	Yes	1.72E-01	0.00E+00	2.42E-05	6.73E-05	2.07E-02	8.62E-03	2.652E-06
	2	770	FCAW	Yes	1.71E-01	2.39E-05	5.09E-05	9.88E-05	3.26E-02	1.20E-02	0.000E+00
	3	770	FCAW	Yes	1.36E-01	1.42E-05	6.24E-05	9.36E-05	2.36E-02	1.11E-02	2.464E-06
	Average				1.60E-01	1.27E-05	4.58E-05	8.66E-05	2.56E-02	1.06E-02	1.71E-06
8	1	309	GMAW	Yes	1.66E-01	0.00E+00	4.76E-03	0.00E+00	1.23E-02	5.03E-01	6.649E-05
	2	309	GMAW	Yes	1.82E-01	0.00E+00	6.40E-03	0.00E+00	1.79E-02	7.05E-01	6.318E-05
	3	309	GMAW	Yes	1.70E-01	0.00E+00	6.51E-03	6.13E-05	1.37E-02	N/A	5.361E-05
	Average				1.73E-01	0.00E+00	5.89E-03	2.04E-05	1.46E-02	6.04E-01	6.11E-05
9	1	70T	FCAW	No	1.88E-01	0.00E+00	6.72E-05	0.00E+00	1.00E-02	1.04E-02	1.000E-05
	2	70T	FCAW	No	1.92E-01	1.92E-05	8.46E-05	8.85E-05	1.46E-02	9.23E-03	7.685E-06
	3	70T	FCAW	No	1.62E-01	0.00E+00	1.14E-04	6.19E-05	1.09E-02	6.19E-03	9.307E-06
	Average				1.81E-01	6.41E-06	8.85E-05	5.01E-05	1.18E-02	8.61E-03	9.00E-06
10	1	770	FCAW	Yes	2.18E-01	0.00E+00	3.12E-05	9.71E-05	2.21E-02	1.35E-02	3.410E-06
	2	770	FCAW	Yes	2.15E-01	1.59E-05	1.35E-04	1.15E-04	3.31E-02	2.46E-02	1.187E-05
	3	770	FCAW	Yes	2.40E-01	7.07E-06	4.95E-05	9.19E-05	2.25E-02	1.24E-02	3.292E-06
	Average				2.24E-01	7.66E-06	7.19E-05	1.01E-04	2.59E-02	1.68E-02	6.19E-06
11	1	309	FCAW	Yes	1.94E-01	8.32E-06	2.42E-03	6.38E-05	6.35E-03	8.88E-02	1.12E-04
	2	309	FCAW	Yes	2.09E-01	9.63E-06	2.82E-03	0.00E+00	6.90E-03	1.12E-01	6.67E-05
	3	309	FCAW	Yes	1.89E-01	0.00E+00	2.86E-03	6.40E-05	7.72E-03	1.10E-01	2.65E-05
	Average				1.97E-01	5.98E-06	2.70E-03	4.26E-05	6.99E-03	1.04E-01	6.84E-05
12	1	316	FCAW	Yes	3.34E-01	0.00E+00	1.86E-03	0.00E+00	2.22E-02	1.60E-01	7.07E-05
	2	306	FCAW	Yes	4.42E-01	0.00E+00	3.04E-03	0.00E+00	2.85E-02	2.21E-01	3.35E-05
	3	316	FCAW	Yes	3.74E-01	0.00E+00	N/A	0.00E+00	0.00E+00	N/A	6.34E-05
	Average				3.83E-01	0.00E+00	2.45E-03	0.00E+00	1.69E-02	1.91E-01	5.59E-05
13	1	316	FCAW	No	3.47E-01	0.00E+00	7.29E-03	8.83E-05	1.32E-02	3.18E-01	5.16E-04
	2	316	FCAW	No	4.44E-01	1.20E-05	8.52E-03	0.00E+00	1.56E-02	3.73E-01	2.37E-04
	3	316	FCAW	No	3.26E-01	N/A	N/A	0.00E+00	N/A	N/A	2.78E-05
	Average				3.73E-01	6.00E-06	7.90E-03	2.94E-05	1.44E-02	3.46E-01	2.60E-04
14	1	316	GMAW	Yes	2.61E-01	0.00E+00	8.98E-04	0.00E+00	2.73E-03	7.16E-02	4.57E-05
	2	316	GMAW	Yes	2.85E-01	0.00E+00	1.30E-03	0.00E+00	3.52E-03	9.44E-02	1.69E-05
	3	316	GMAW	Yes	2.06E-01	N/A	8.99E-04	0.00E+00	2.71E-03	6.59E-02	7.40E-06
	Average				2.50E-01	0.00E+00	1.03E-03	0.00E+00	2.99E-03	7.73E-02	2.34E-05

Appendix 2

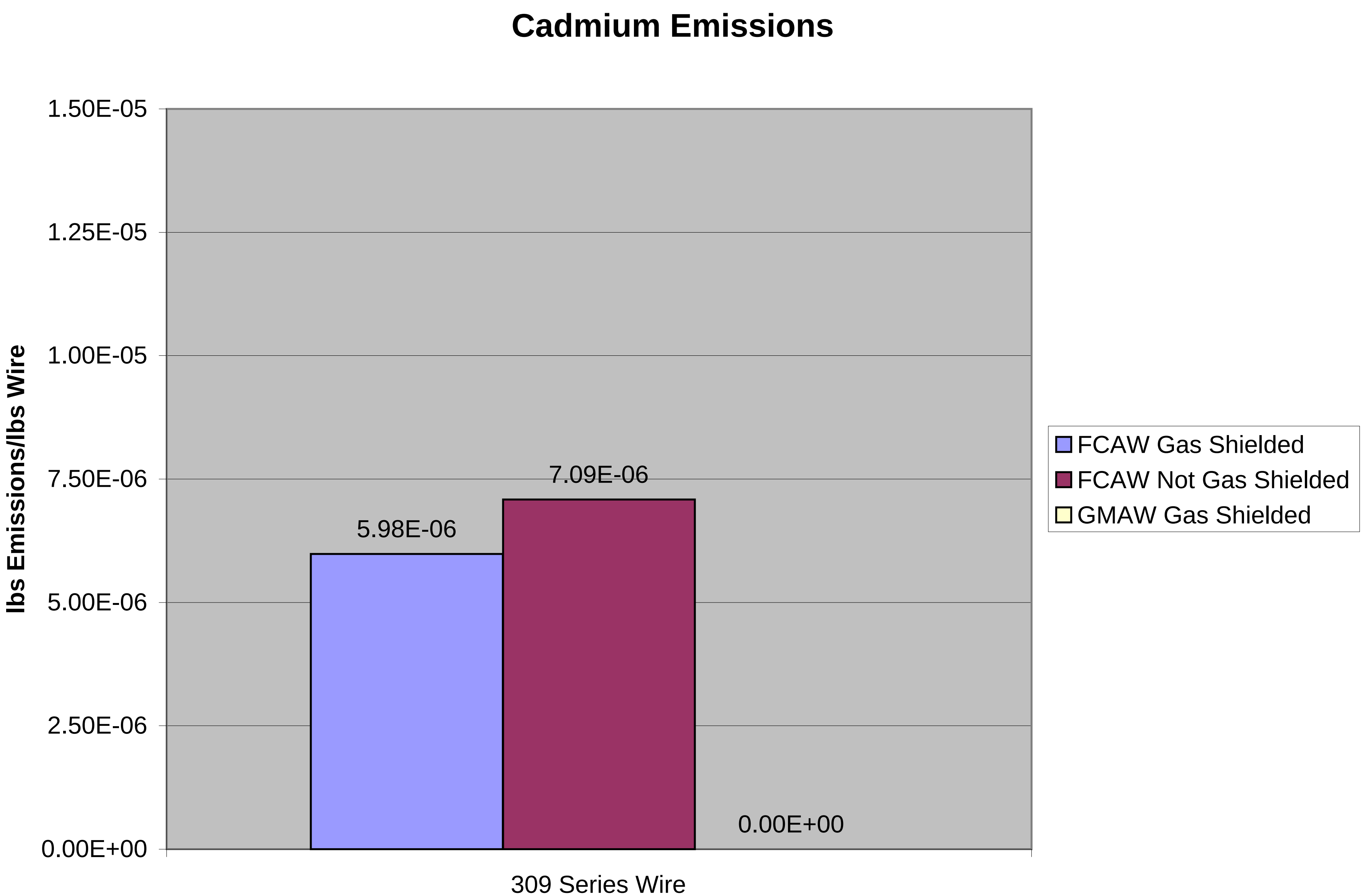

TSP Emission Factors
lbs emissions/lbs wire
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
309 Series Wire
309 FCAW Gas Shielded
309 FCAW Not Gas Shielded
309 GMAW Gas Shielded

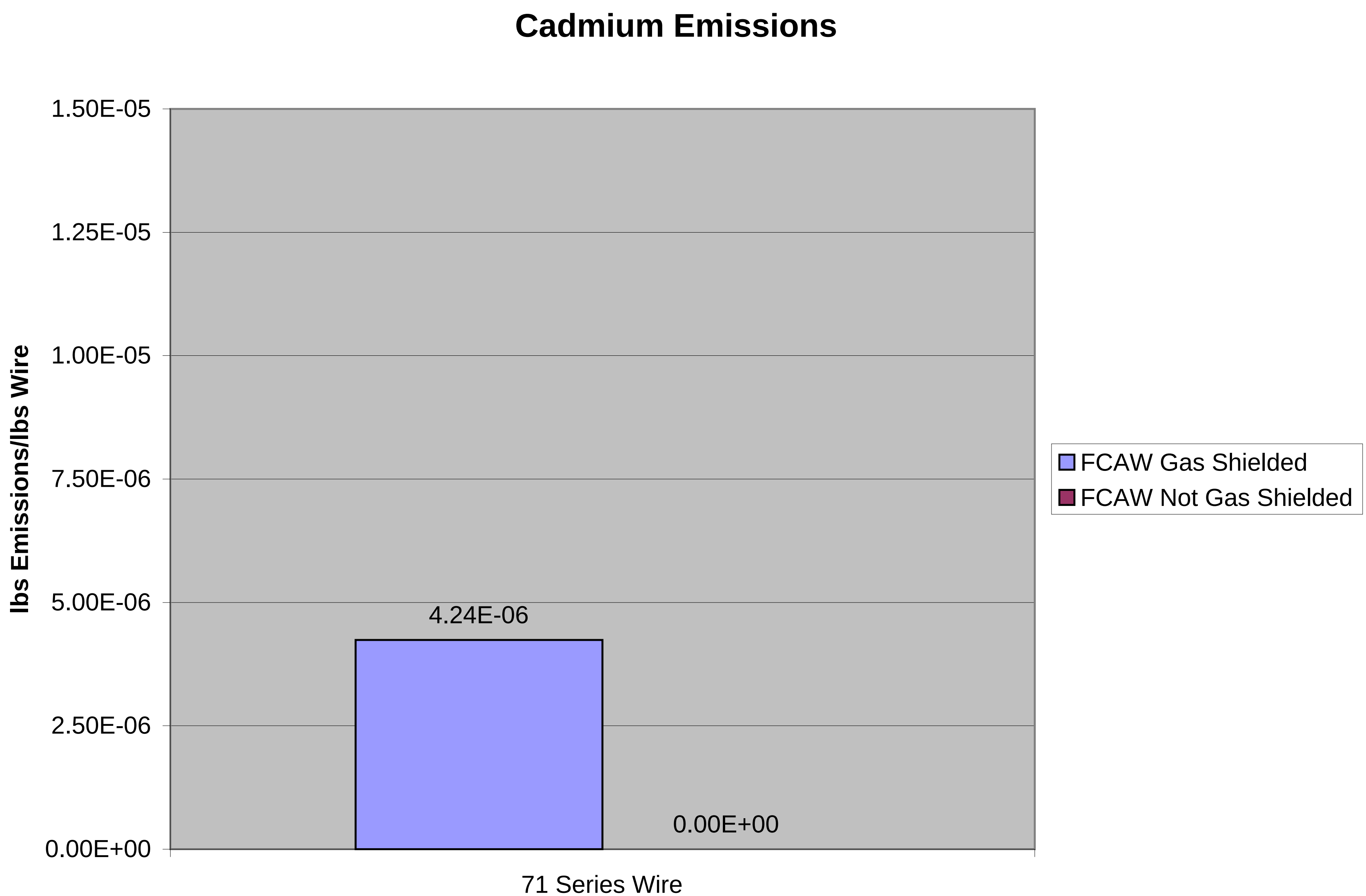

TSP Emission Factors
lbs emission/lbs wire
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
71 Series Wire
71-M FCAW Gas Shielded
71-T GS FCAW Not Gas Shielded

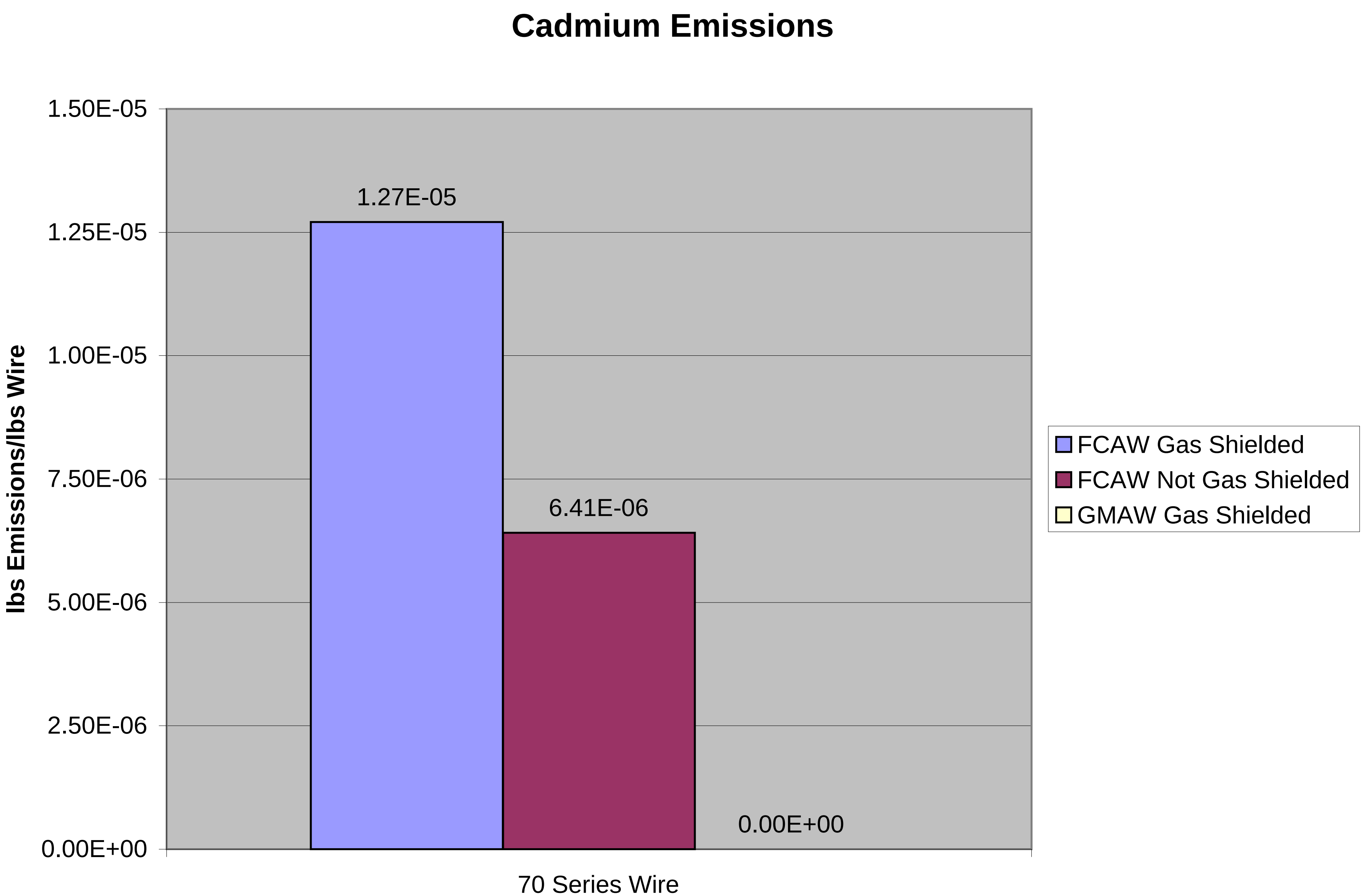

TSP Emission Factors
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
lbs emissions/lbs wire
70 Series Wire
770 FCAW Gas Shielded
70T FCAW Not Gas Shielded
70-S-6 GMAW Gas Shielded


TSP Emission Factors
lbs emissions/lbs wire
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
316 Series Wire
316 FCAW Gas Shielded
316 FCAW Not Gas Shielded
316 GMAW Gas Shielded 2.50E-01

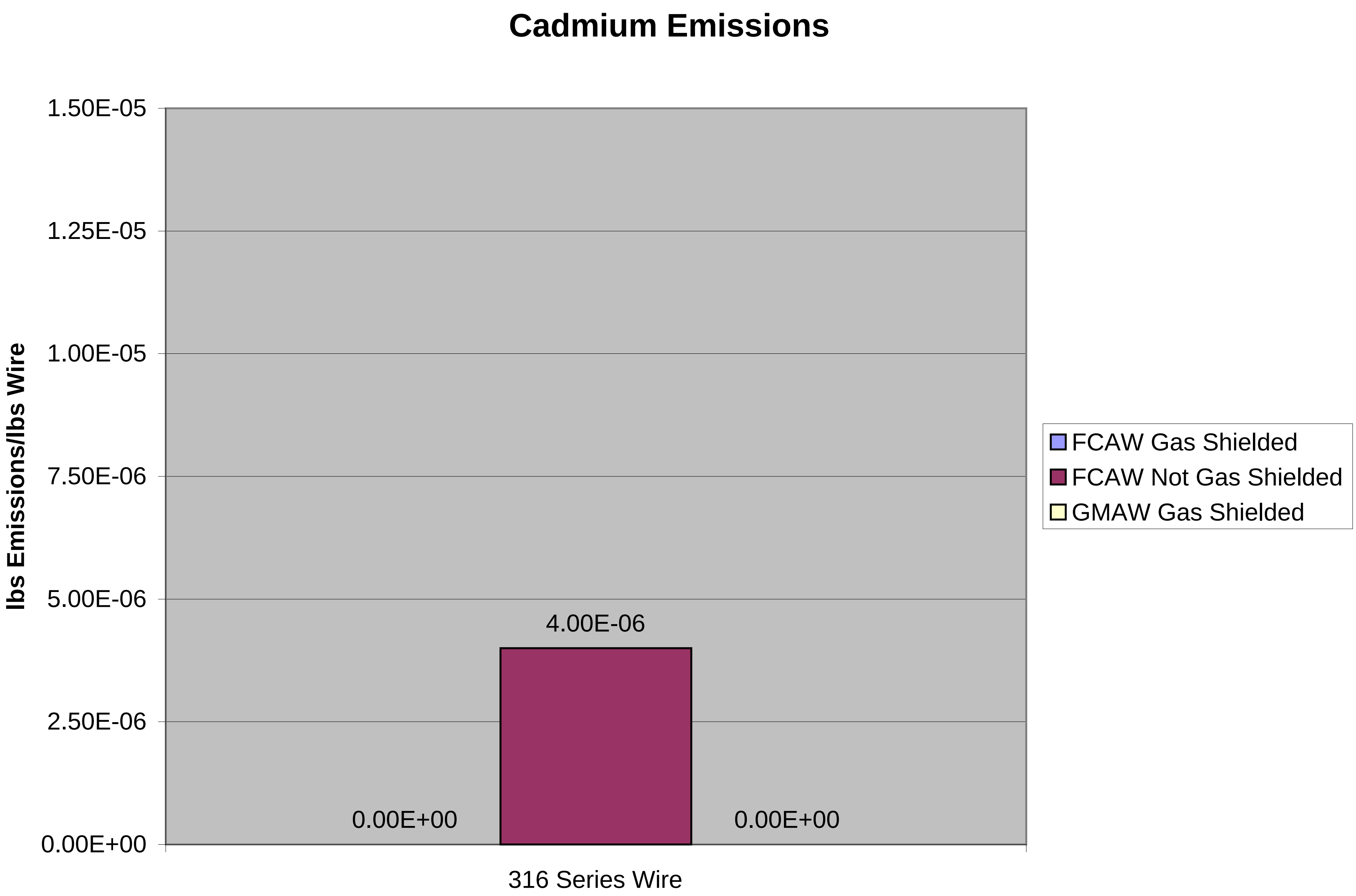
Appendix 3

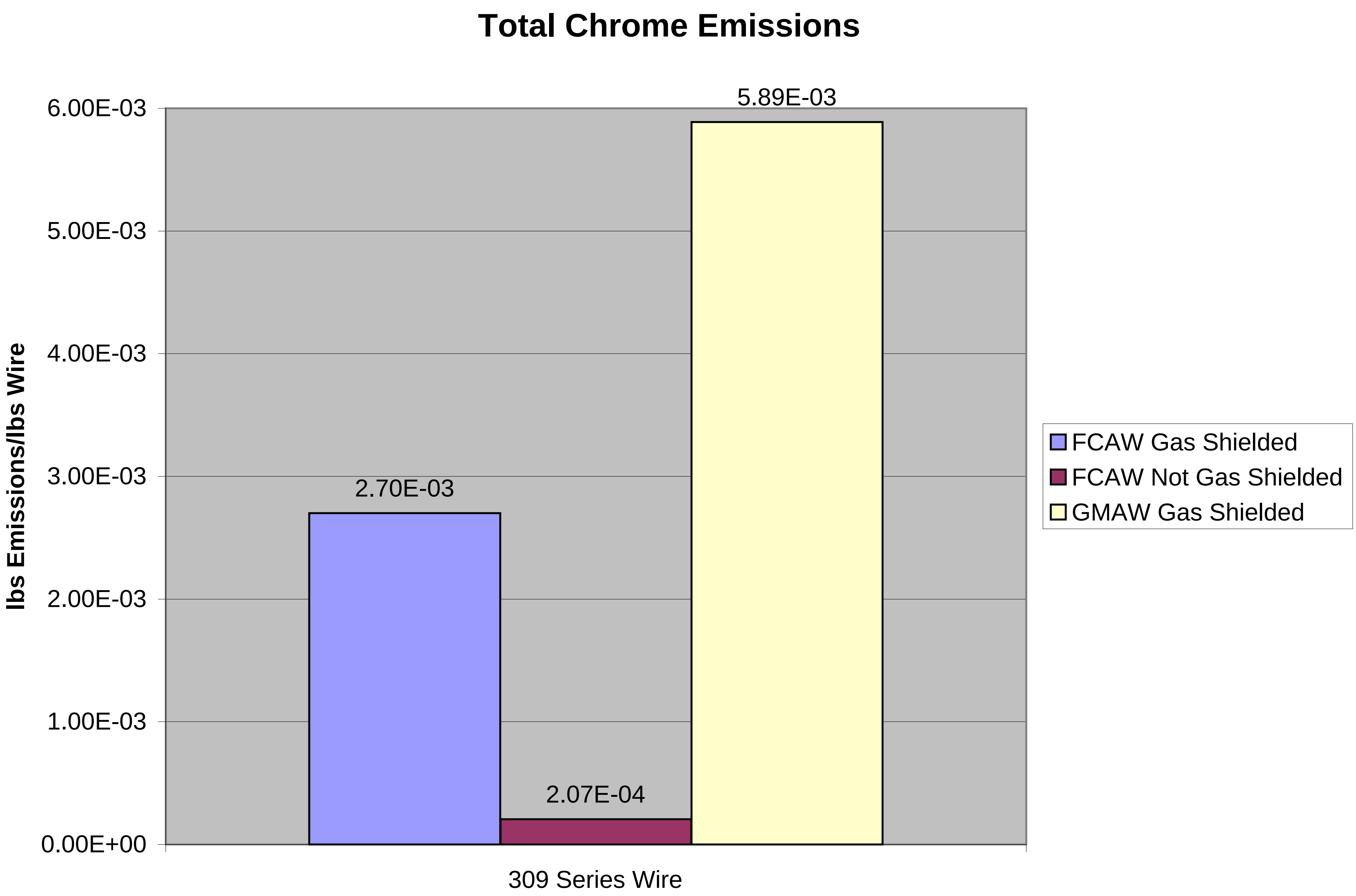

Cadmium Emissions
lbs Emissions/lbs Wire
1.50E-05
1.25E-05
1.00E-05
7.50E-06
5.00E-06
2.50E-06
0.00E+00
5.98E-06
7.09E-06
0.00E+00
309 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded


Cadmium Emissions
lbs Emissions/lbs Wire
1.50E-05
1.25E-05
1.00E-05
7.50E-06
5.00E-06
2.50E-06
0.00E+00
4.24E-06
0.00E+00
71 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded

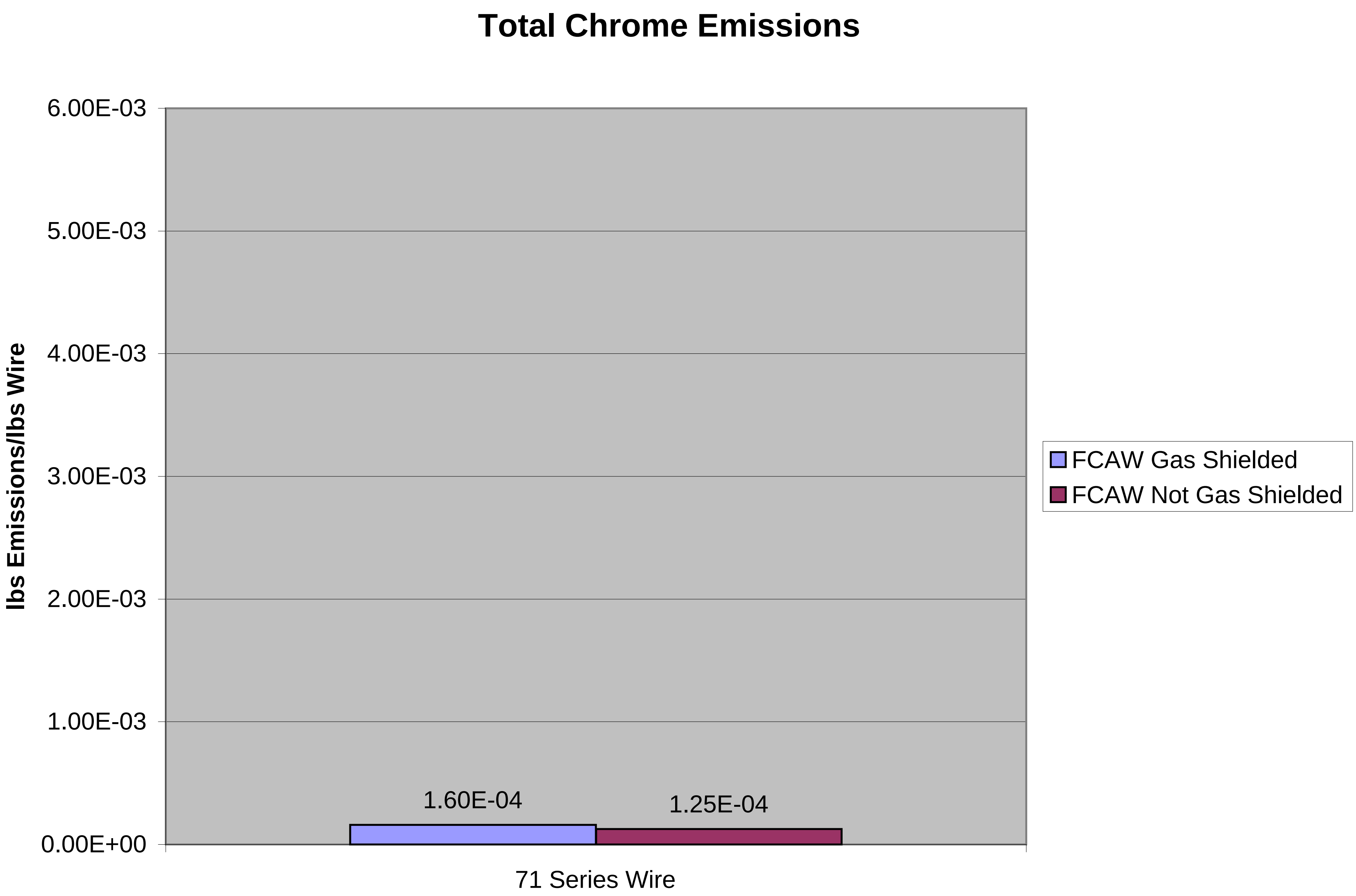


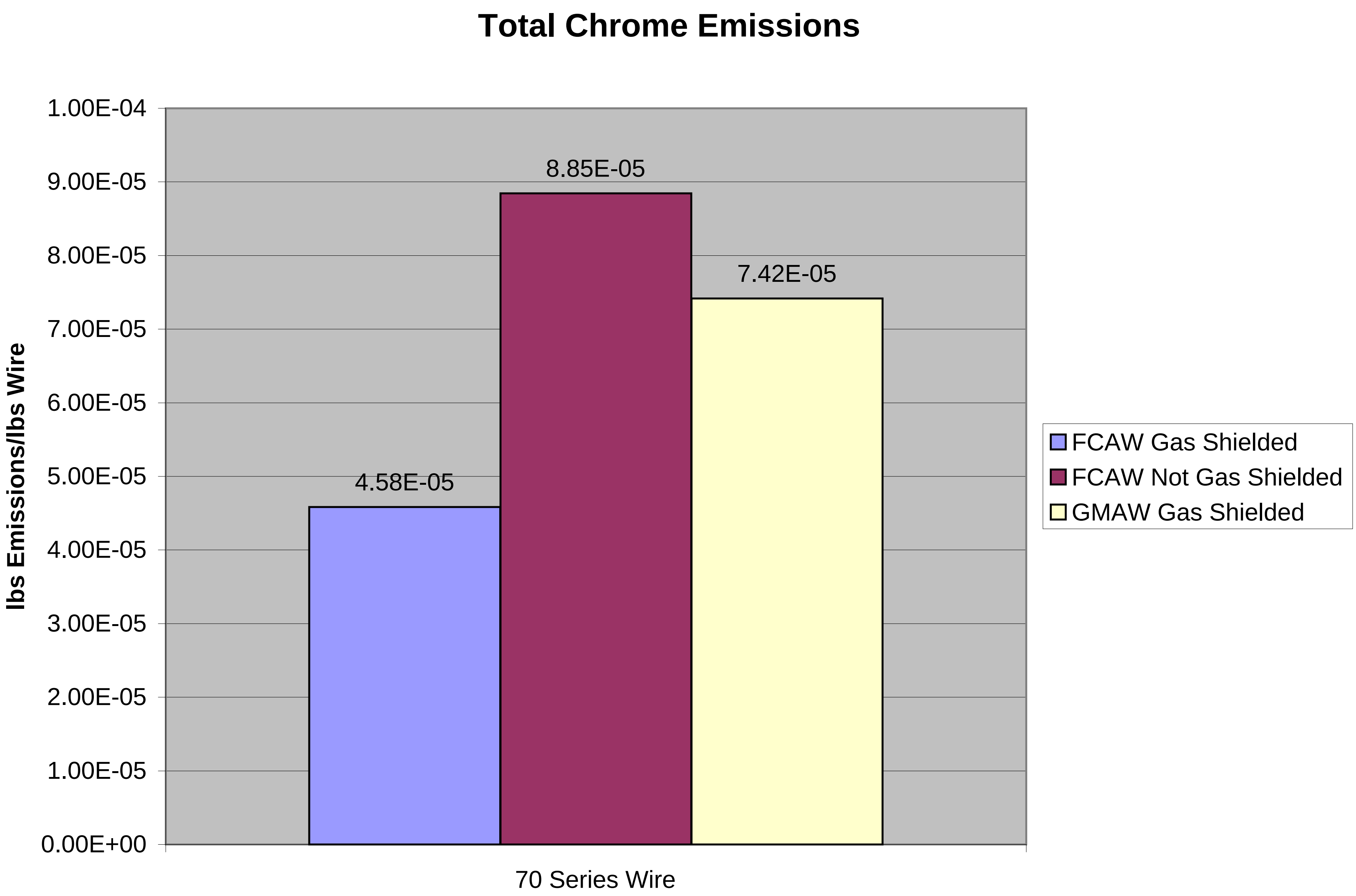
Cadmium Emissions
lbs Emissions/lbs Wire
1.50E-05
1.25E-05
1.00E-05
7.50E-06
5.00E-06
2.50E-06
0.00E+00
1.27E-05
6.41E-06
0.00E+00
70 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded

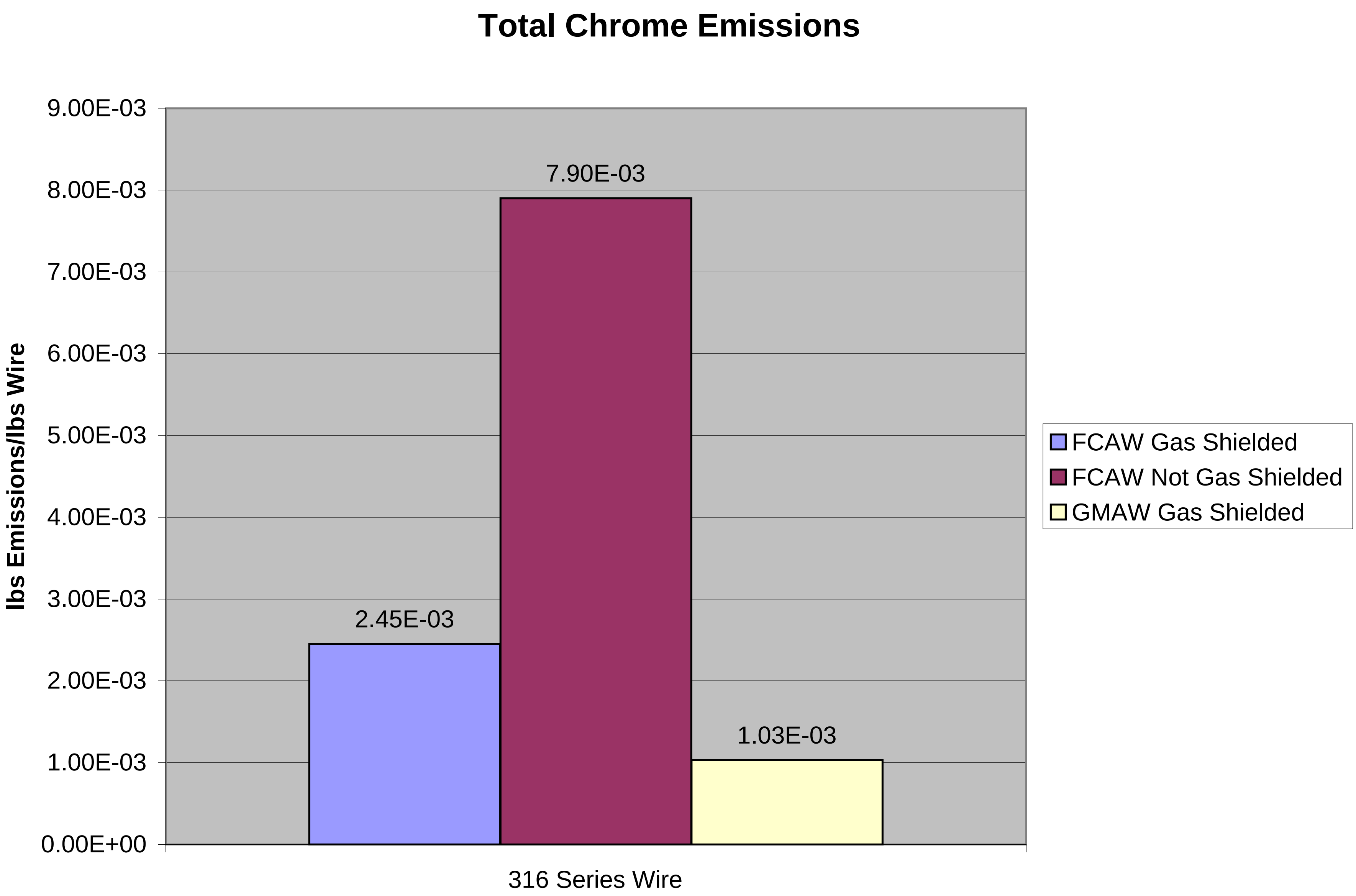

Cadmium Emissions
lbs Emissions/lbs Wire
1.50E-05
1.25E-05
1.00E-05
7.50E-06
5.00E-06
2.50E-06
0.00E+00
4.00E-06
0.00E+00
0.00E+00
316 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded



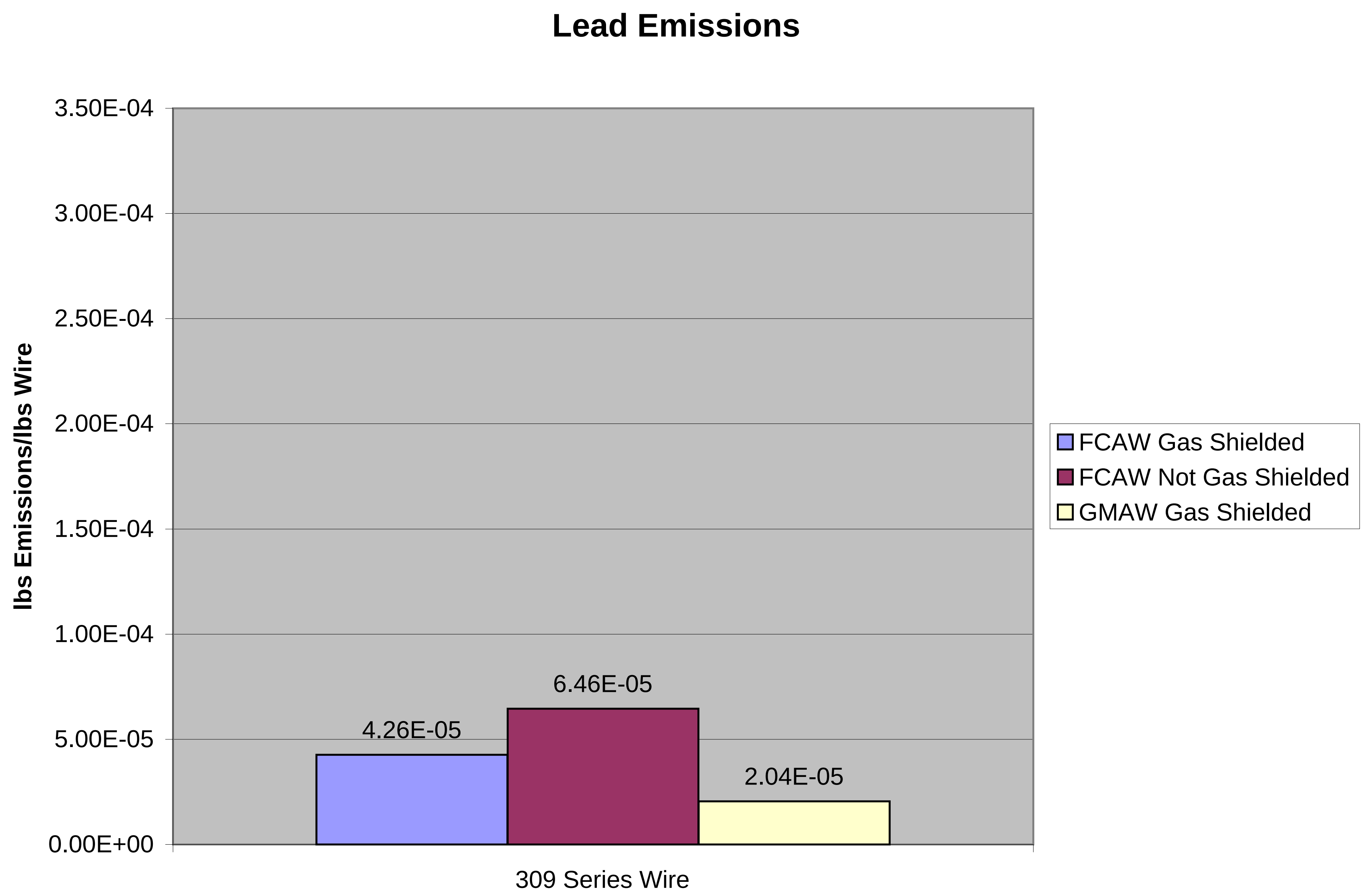
Total Chrome Emissions
lbs Emissions/lbs Wire
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
2.70E-03
2.07E-04
5.89E-03
309 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded

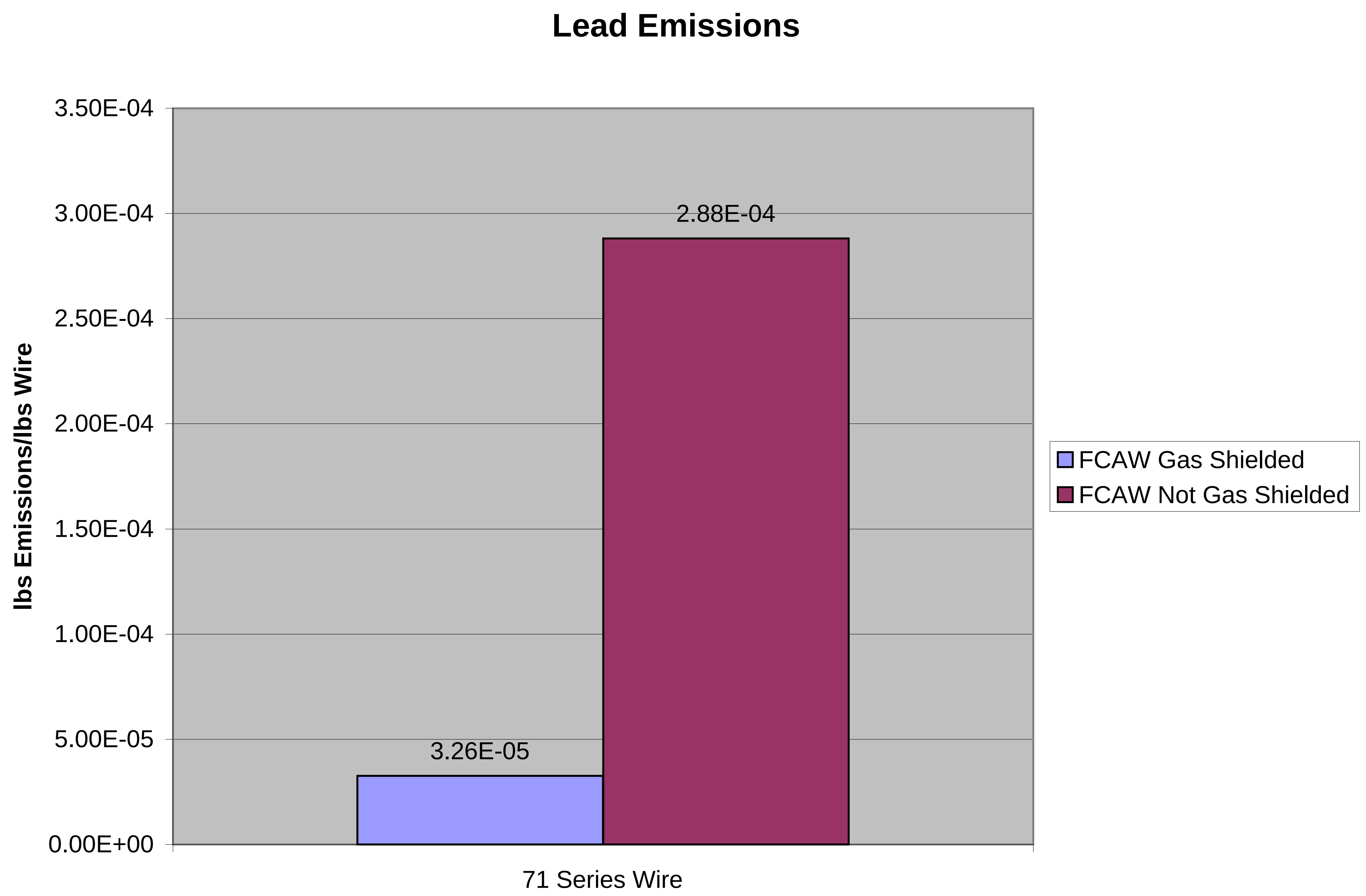

Total Chrome Emissions
lbs Emissions/lbs Wire
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
1.60E-04
1.25E-04
71 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded

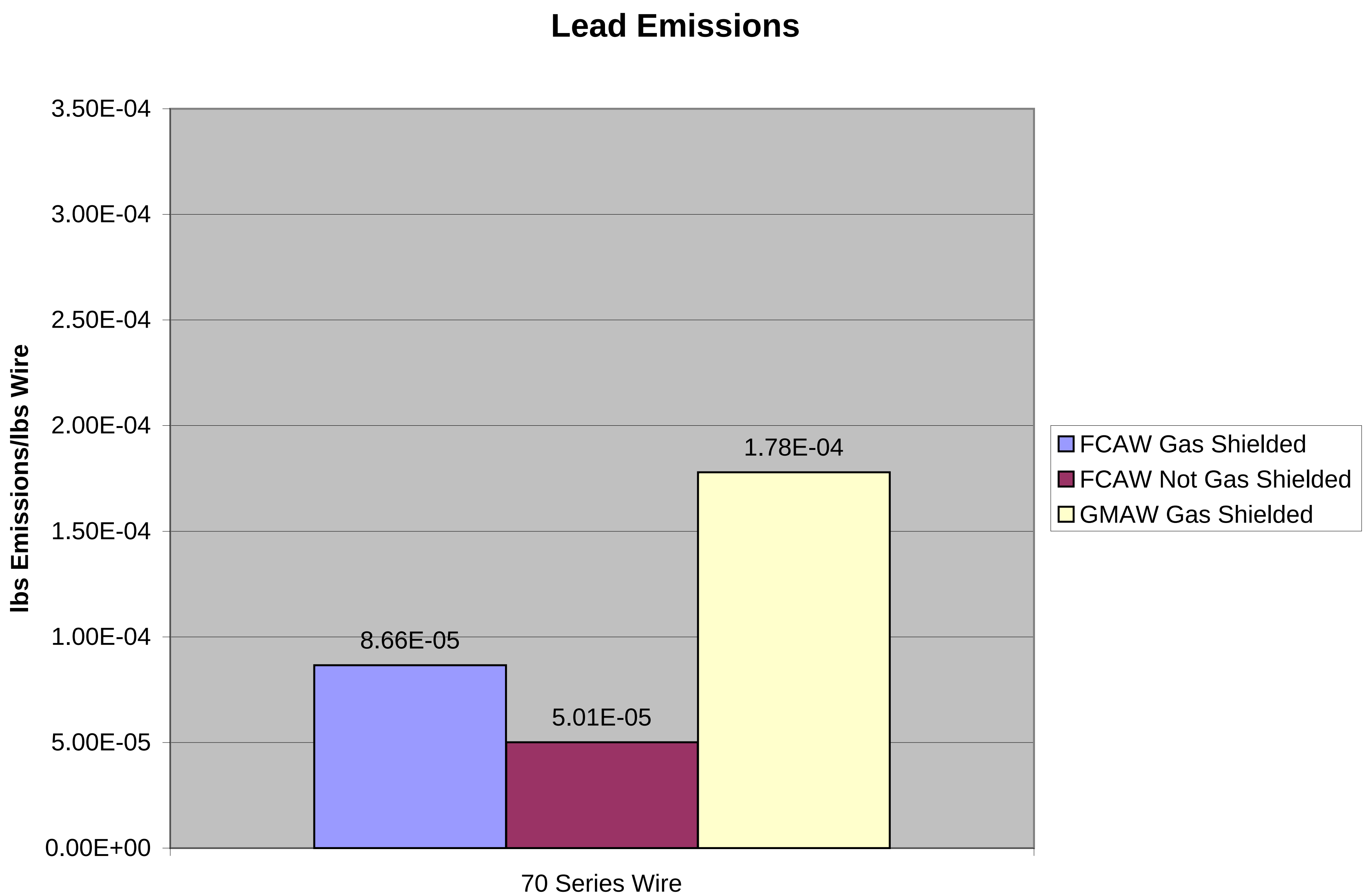

Total Chrome Emissions
lbs Emissions/lbs Wire
1.00E-04
9.00E-05
8.00E-05
7.00E-05
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
4.58E-05
8.85E-05
7.42E-05
70 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded



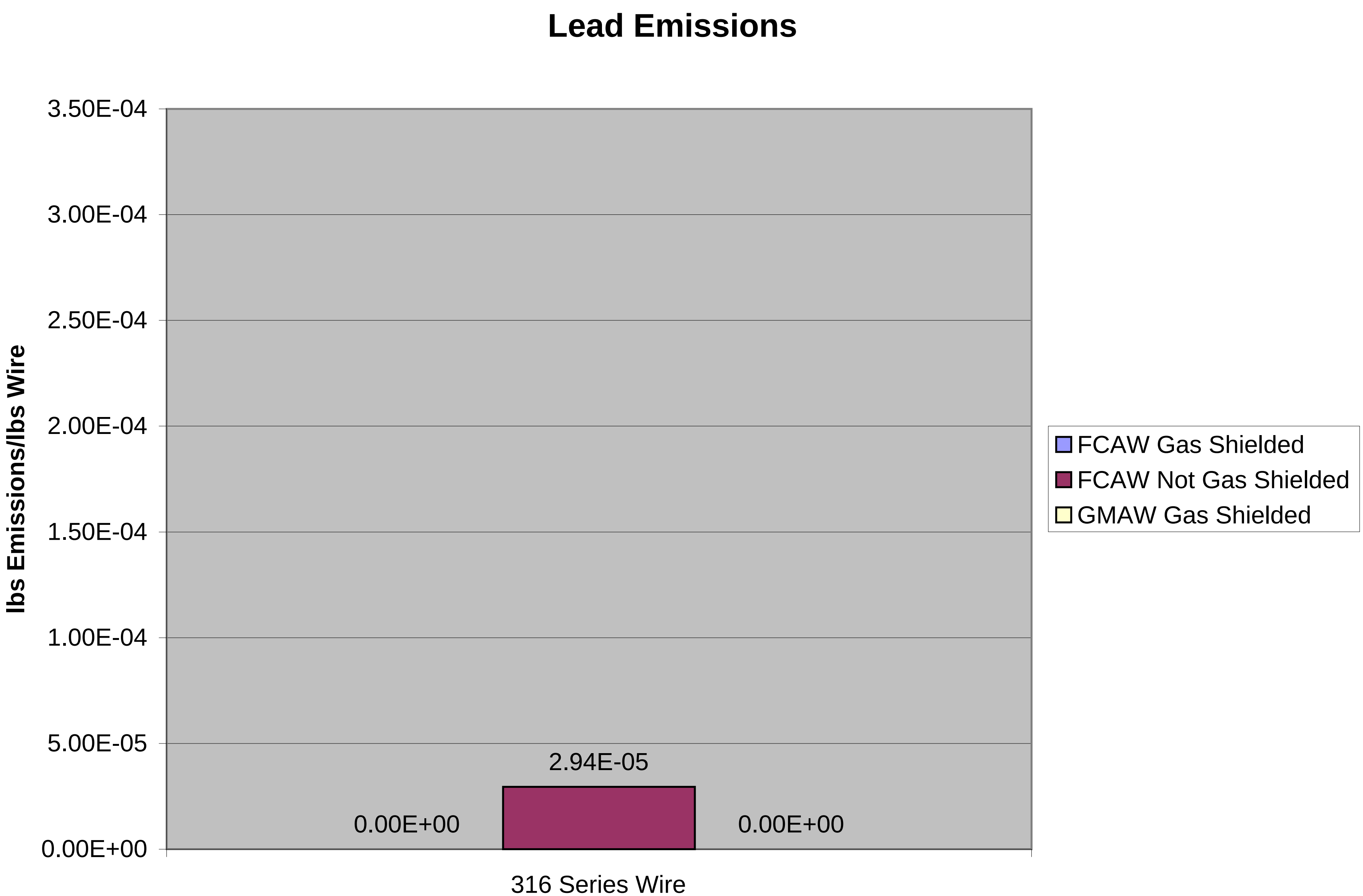
Total Chrome Emissions
lbs Emissions/lbs Wire
9.00E-03
8.00E-03
7.00E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
7.90E-03
2.45E-03
1.03E-03
316 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded


Lead Emissions
lbs Emissions/lbs Wire
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
4.26E-05
6.46E-05
2.04E-05
309 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded

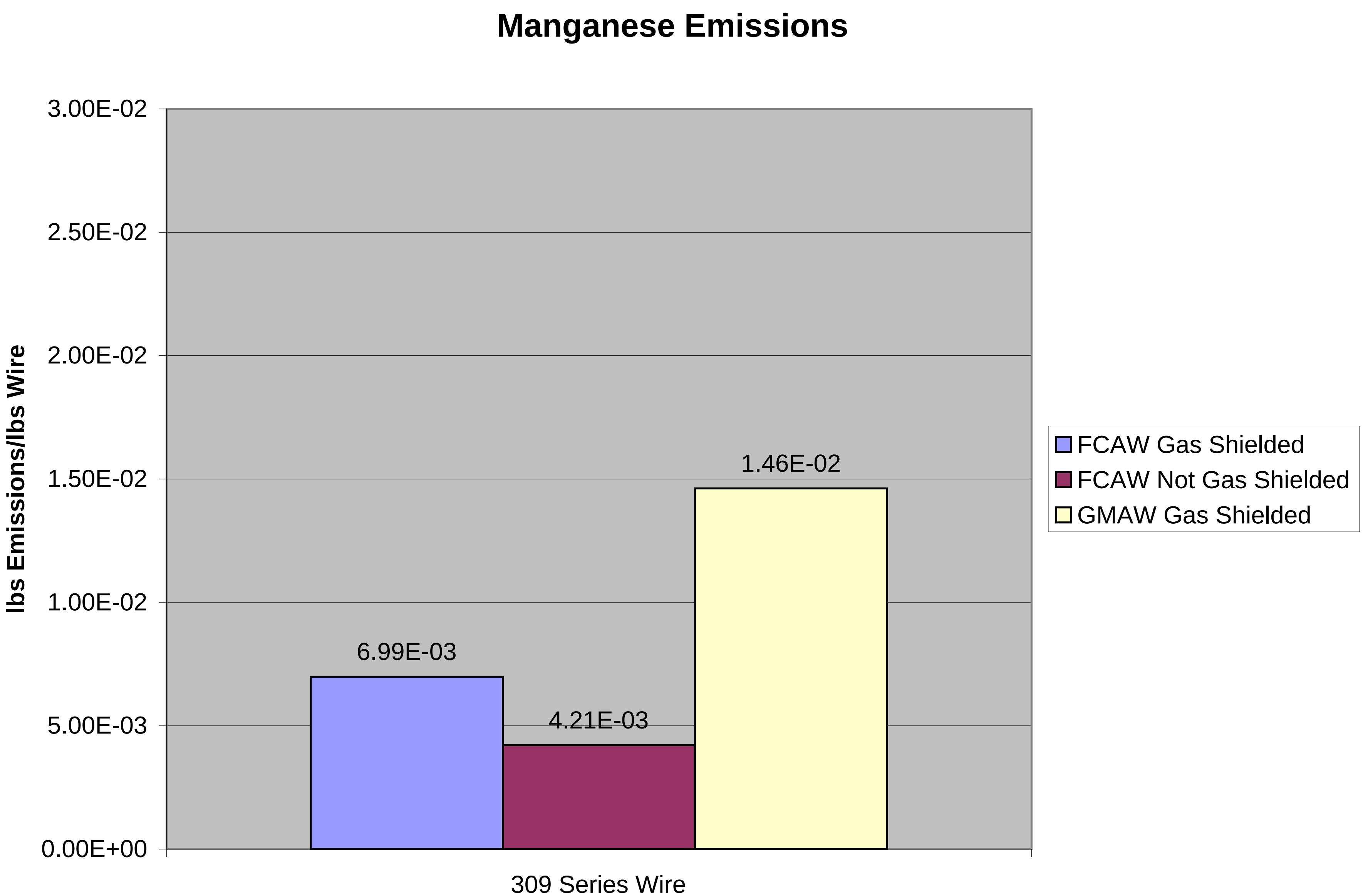

Lead Emissions
lbs Emissions/lbs Wire
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
2.88E-04
3.26E-05
71 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded

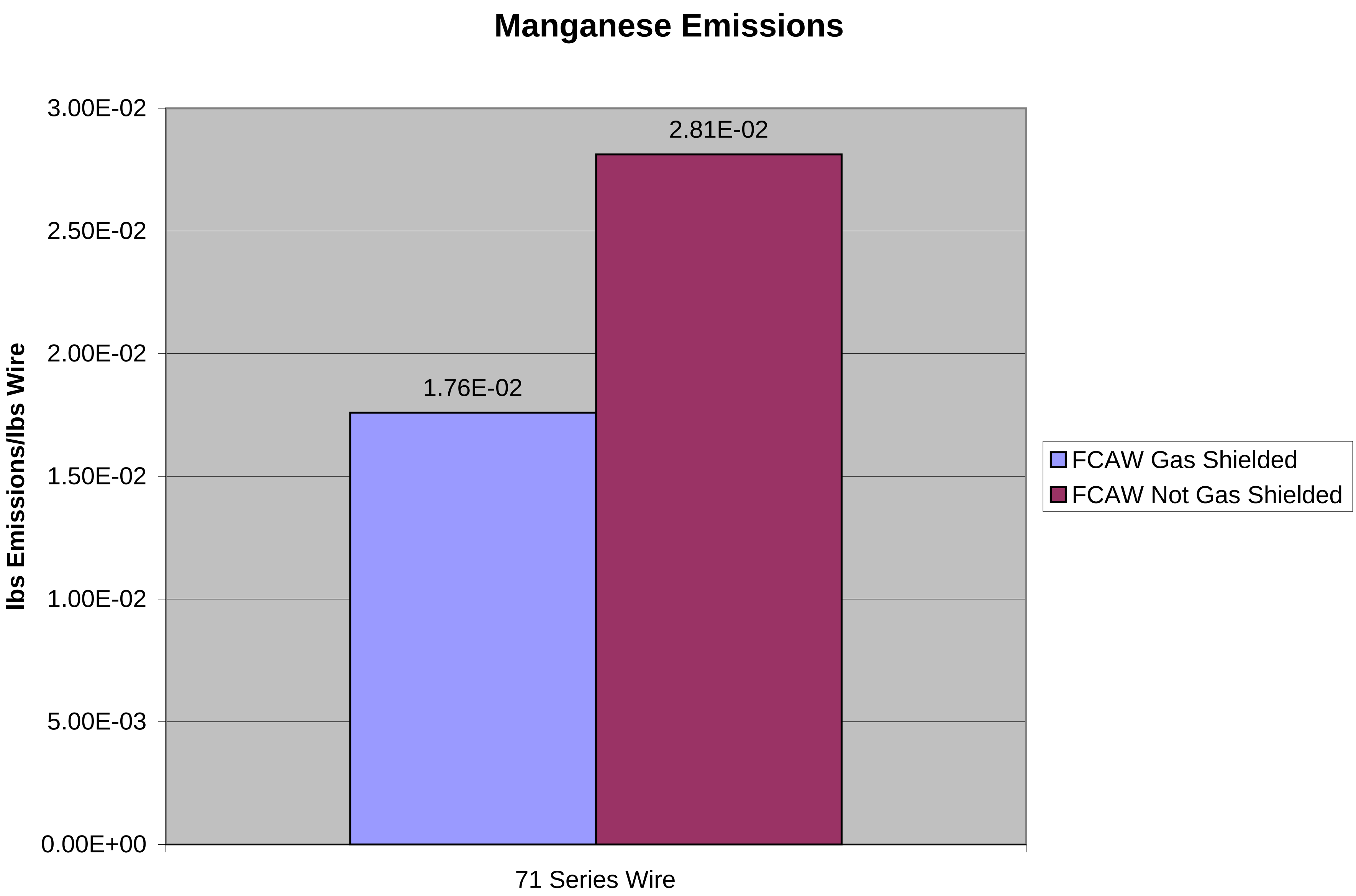


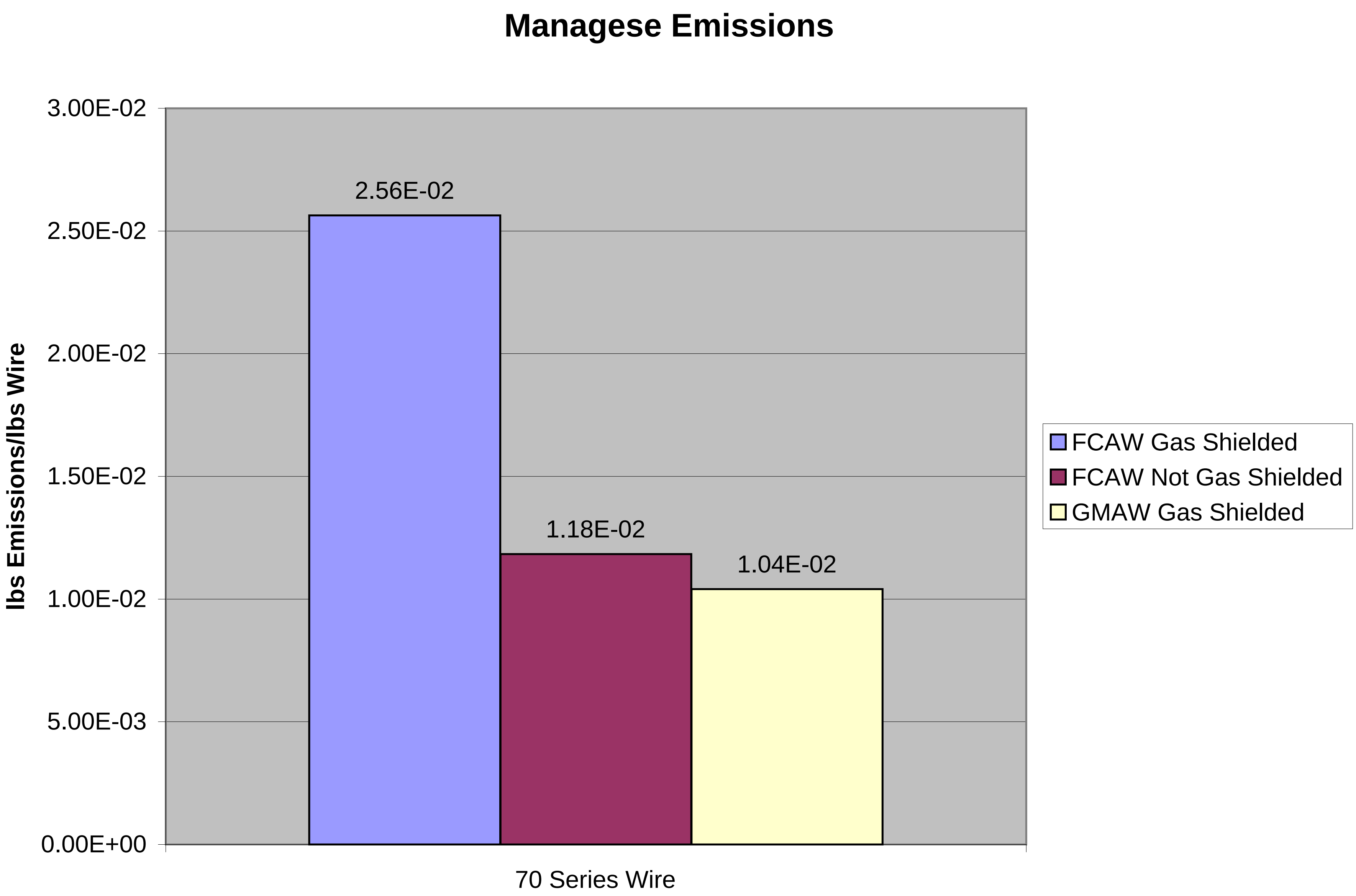
Lead Emissions
lbs Emissions/lbs Wire
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
8.66E-05
5.01E-05
1.78E-04
70 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded



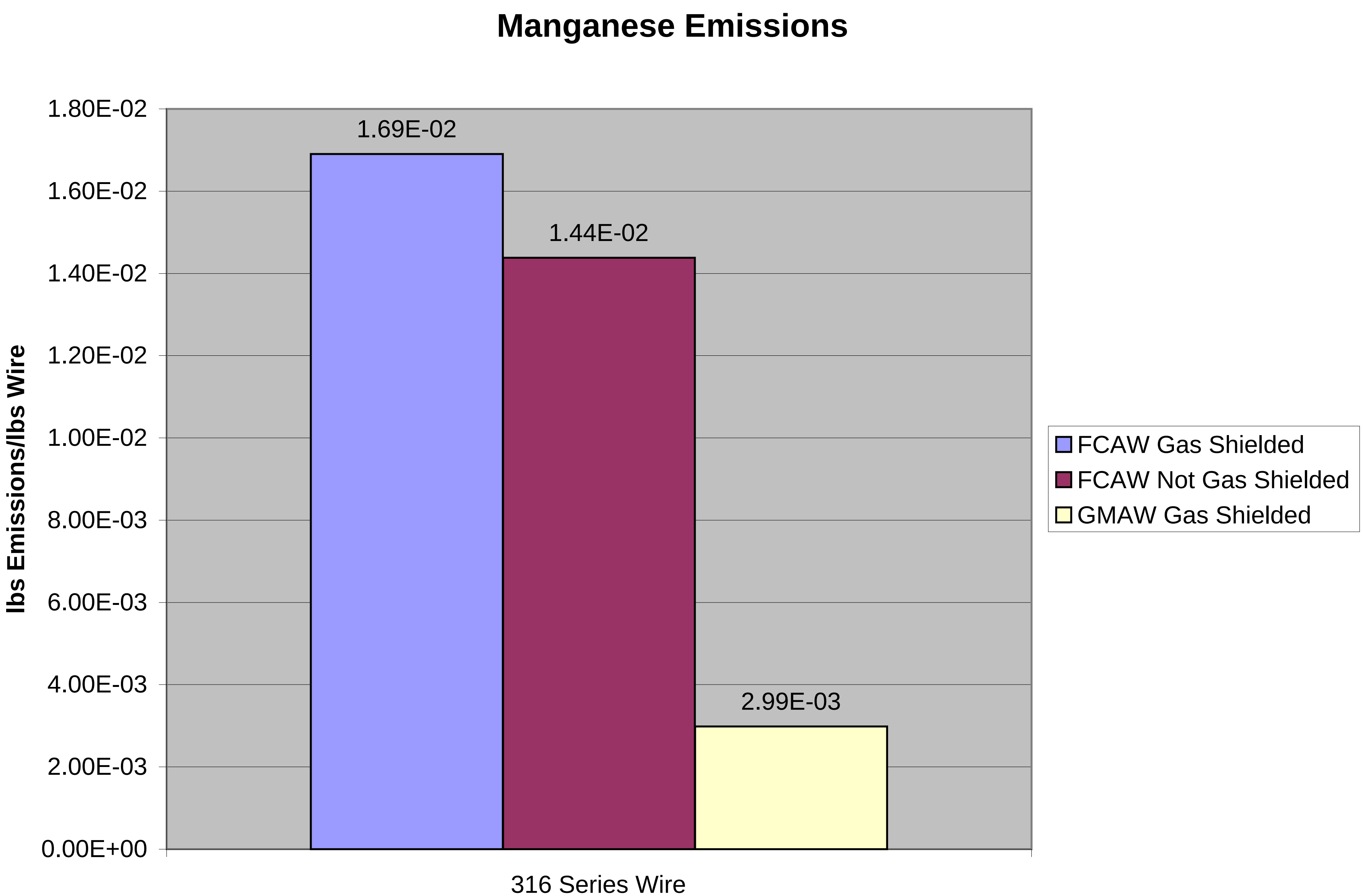
Lead Emissions
lbs Emissions/lbs Wire
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
2.94E-05
0.00E+00
0.00E+00
316 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded


Manganese Emissions
lbs Emissions/lbs Wire
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
6.99E-03
4.21E-03
1.46E-02
309 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded

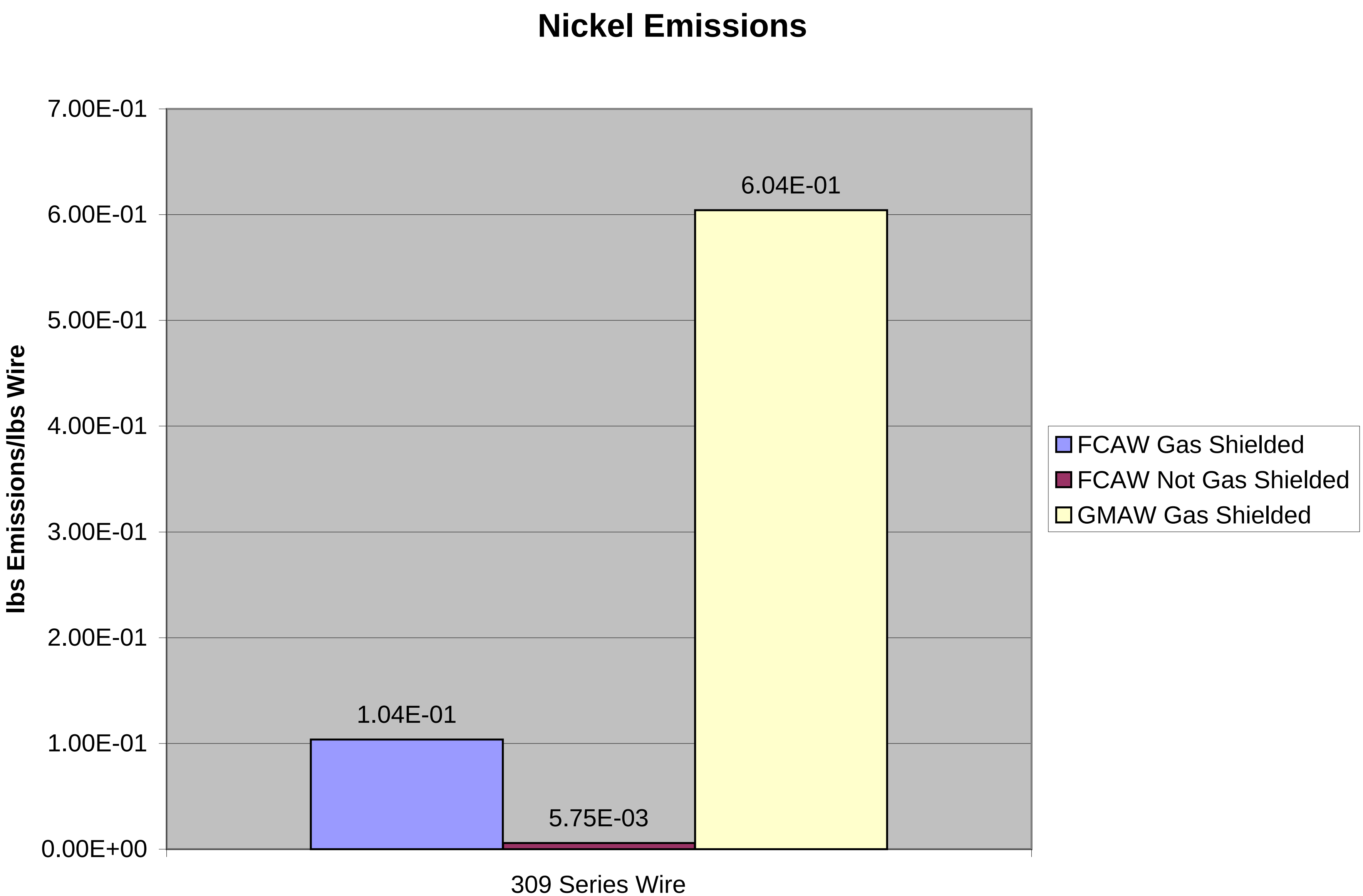

Manganese Emissions
lbs Emissions/lbs Wire
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
2.81E-02
1.76E-02
71 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded

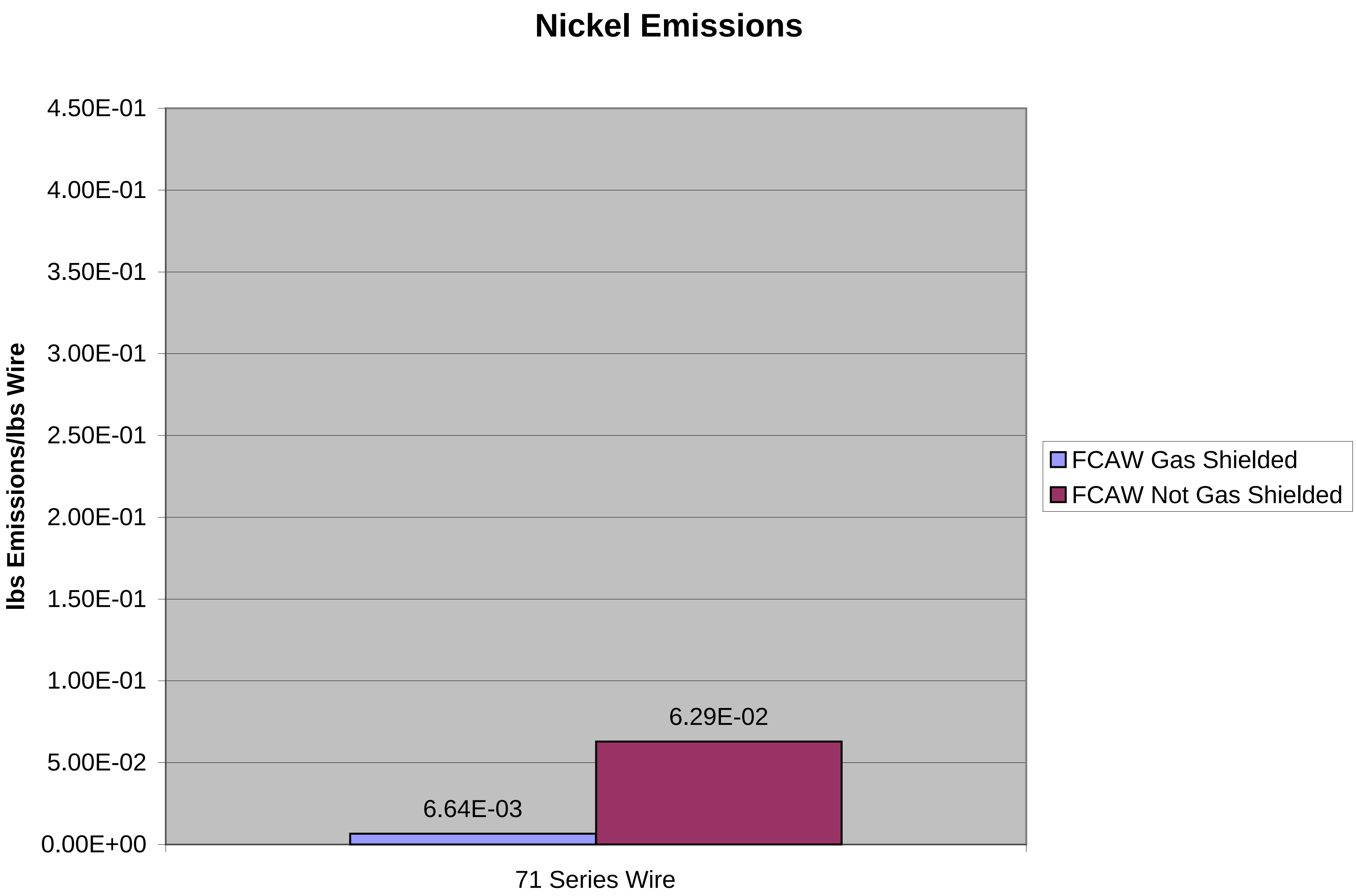


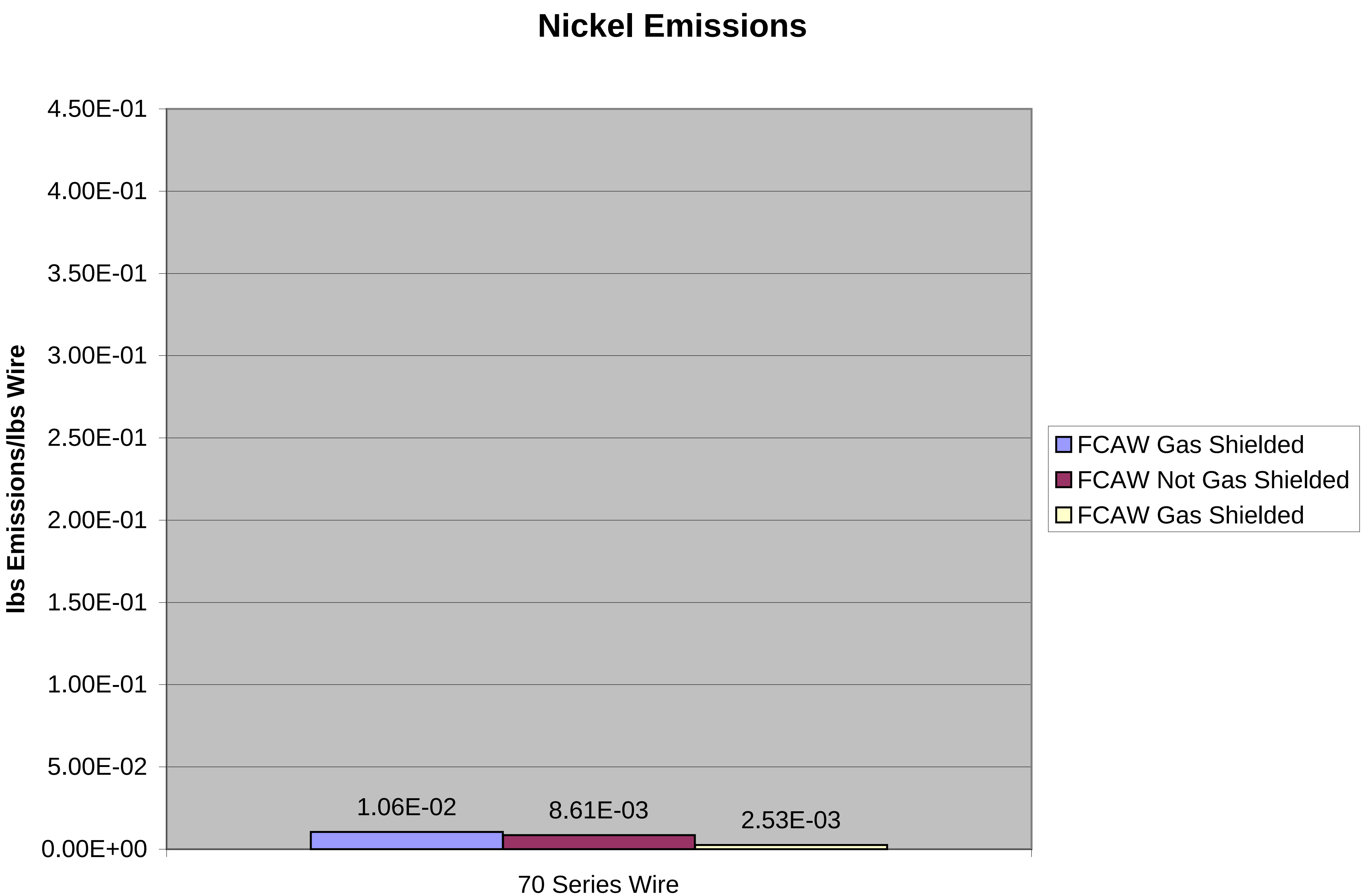
Managese Emissions
lbs Emissions/lbs Wire
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
2.56E-02
1.18E-02
1.04E-02
70 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded

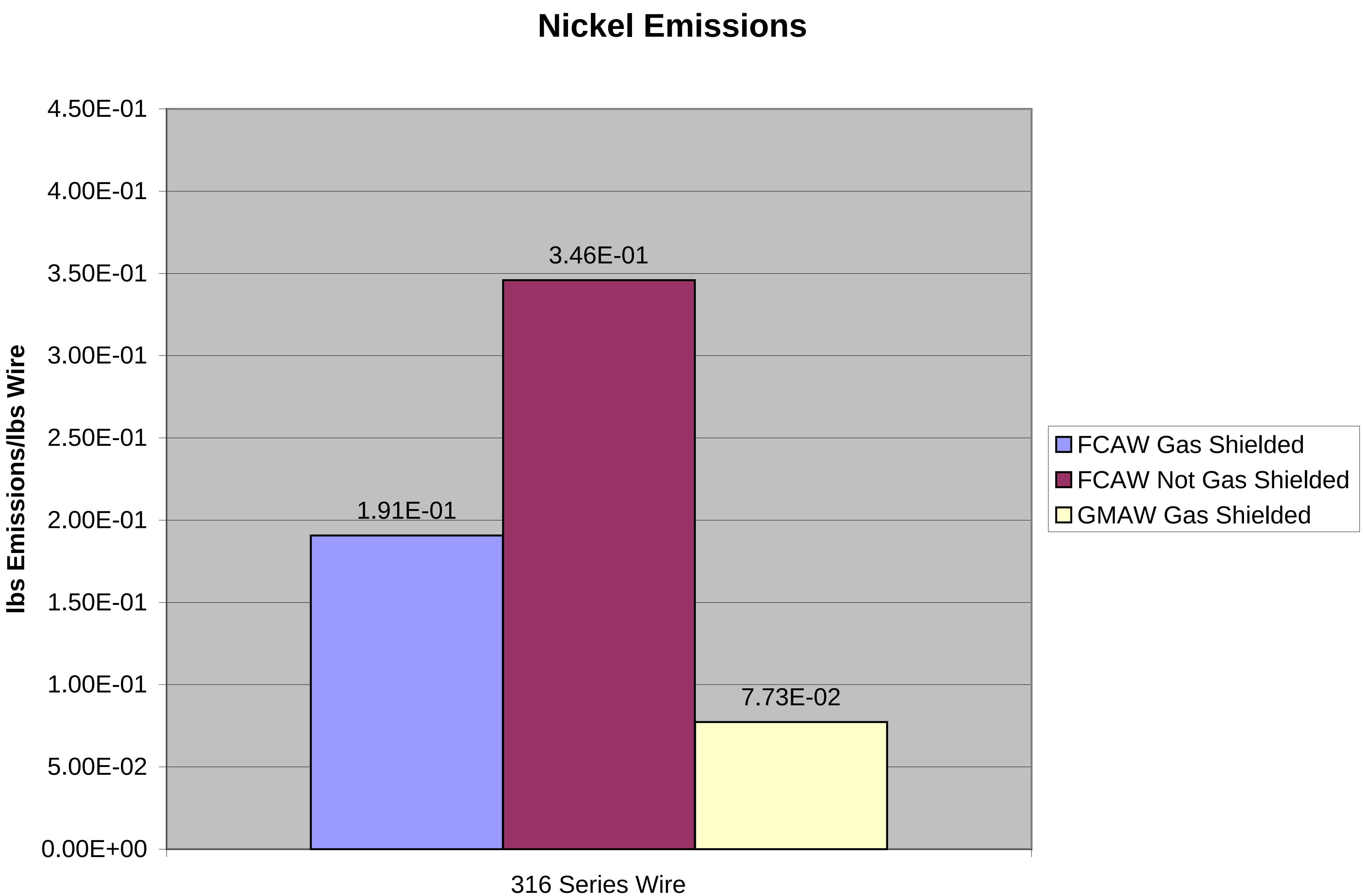


Manganese Emissions
lbs Emissions/lbs Wire
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
1.69E-02
1.44E-02
2.99E-03
316 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded


Nickel Emissions
lbs Emissions/lbs Wire
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
6.04E-01
1.04E-01
5.75E-03
309 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded

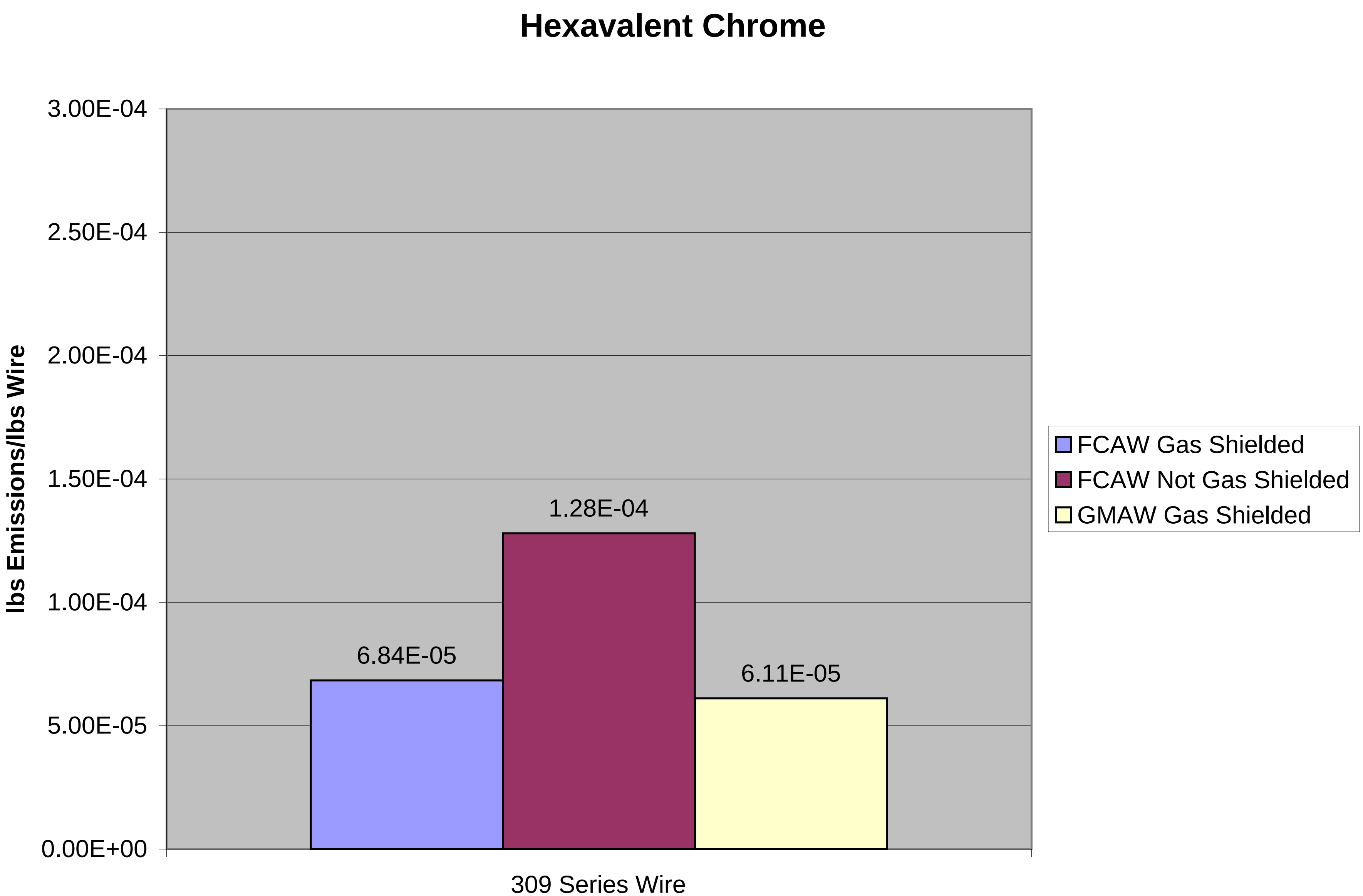

Nickel Emissions
lbs Emissions/lbs Wire
4.50E-01
4.00E-01
3.50E-01
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
6.64E-03
6.29E-02
71 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded

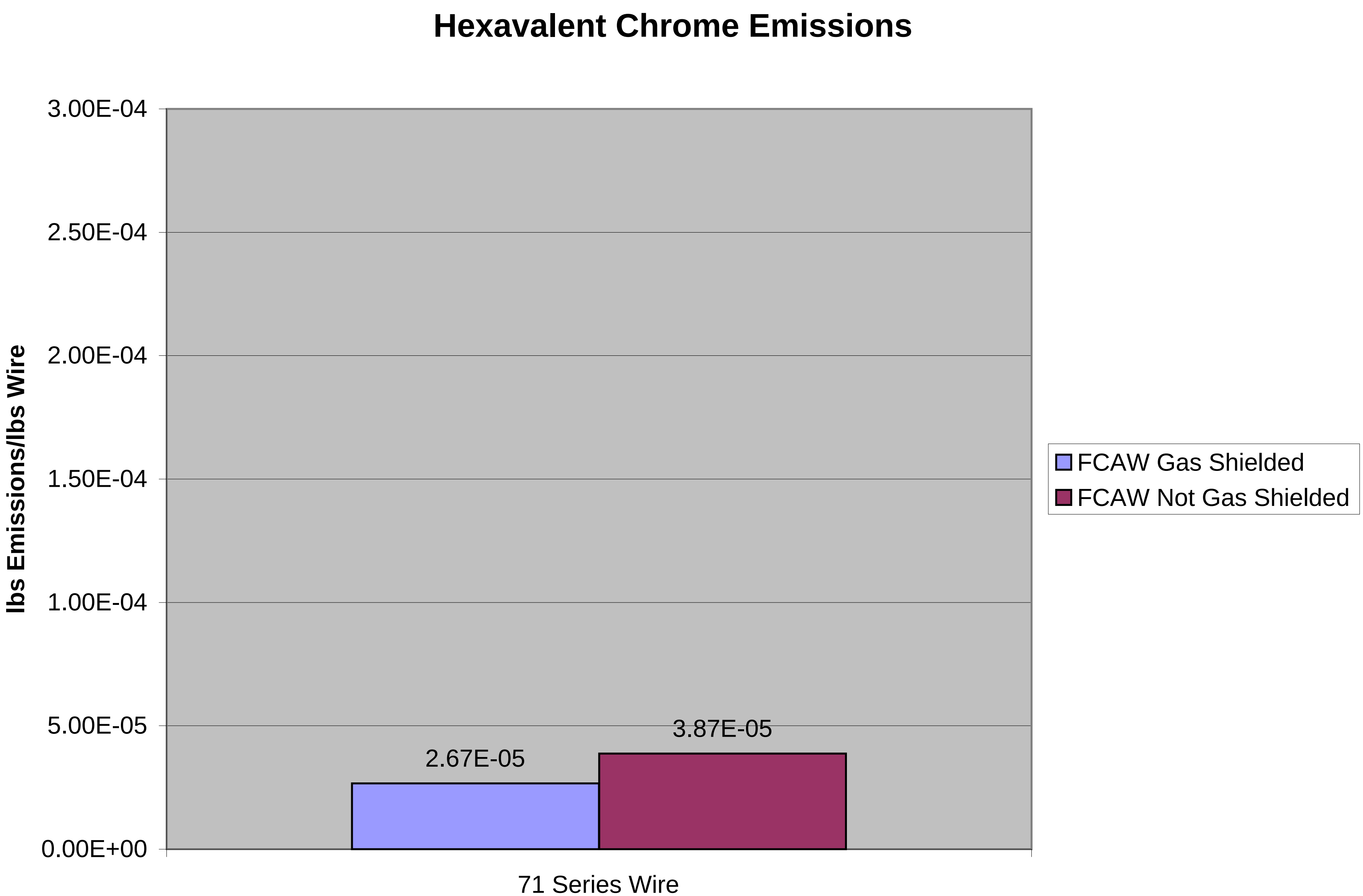

Nickel Emissions
lbs Emissions/lbs Wire
4.50E-01
4.00E-01
3.50E-01
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
1.06E-02
8.61E-03
2.53E-03
70 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
FCAW Gas Shielded



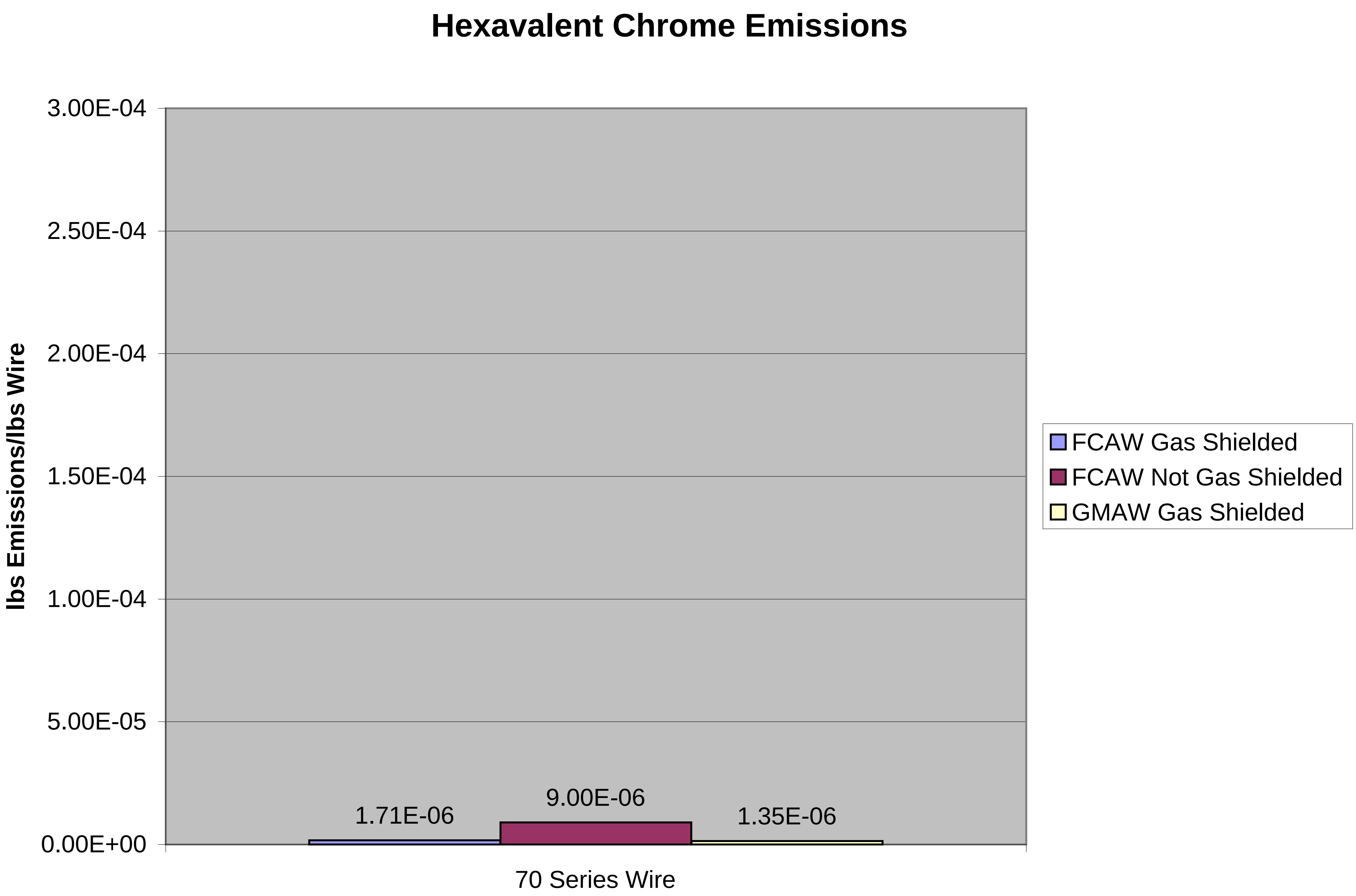
Nickel Emissions
lbs Emissions/lbs Wire
4.50E-01
4.00E-01
3.50E-01
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
1.91E-01
3.46E-01
7.73E-02
316 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded

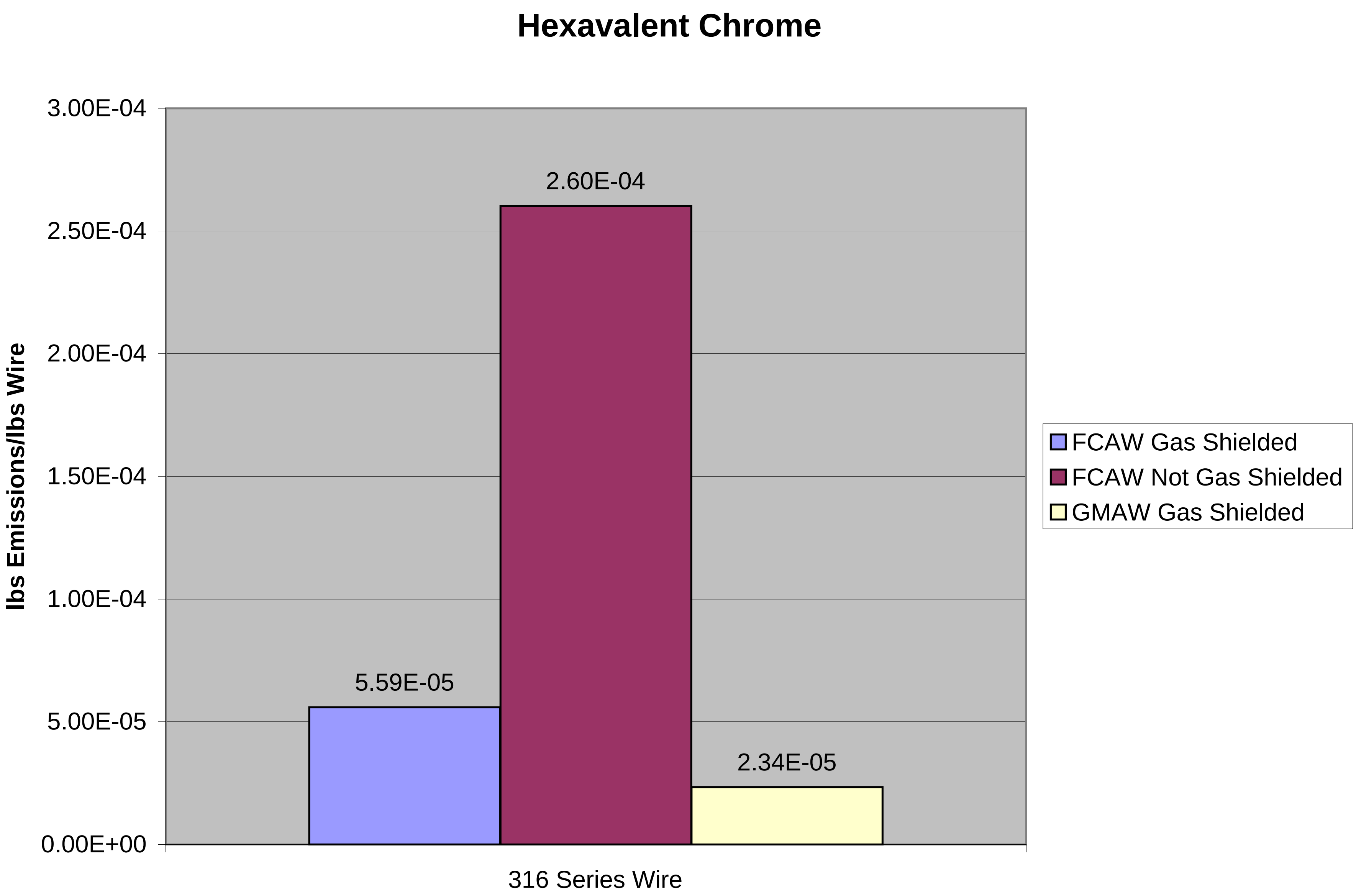
Appendix 4


Hexavalent Chrome
lbs Emissions/lbs Wire
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
6.84E-05
1.28E-04
6.11E-05
309 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded



Hexavalent Chrome Emissions
lbs Emissions/lbs Wire
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
2.67E-05
3.87E-05
71 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded


Hexavalent Chrome Emissions
lbs Emissions/lbs Wire
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
1.71E-06
9.00E-06
1.35E-06
70 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded



Hexavalent Chrome
lbs Emissions/lbs Wire
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
2.60E-04
5.59E-05
2.34E-05
316 Series Wire
FCAW Gas Shielded
FCAW Not Gas Shielded
GMAW Gas Shielded

For more information contact:
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