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The Economic Impact of the Gas-Mixture NIST-Traceable Reference Materials Program

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The Economic Impact of the Gas-Mixture NIST-Traceable Reference Materials Program

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List of Acronyms

B/C	Benefit-to-cost ratio
BACT	Best Available Control Technology
CAAA	1990 Clean Air Act Amendments
CEM	Continuous emission monitoring
CRM	Certified Reference Material
CSTL	Chemical Science and Technology Laboratory
DT	Directly traceable
EPA	U.S. Environmental Protection Agency
GMIS	Gas manufacturers' intermediate standard
IRR	Internal rate of return
IT	Indirectly traceable
LAER	Lowest Achievable Emission Rate
MACT	Maximum Achievable Control Technology
NAAQS	National Ambient Air Quality Standards
NAM	National Air Monitoring Station
NBS	National Bureau of Standards
NESHAP	National emissions standards for hazardous air pollutants
NIST	National Institute of Standards and Technology
NMi	Nederlands Meetinstituut
NPV	Net present value
NSPS	New source performance standard
NSR	New source review
NTG	NIST-Traceable Gas

NTRM	NIST-Traceable Reference Materials
OEM	Original equipment manufacturer
OTC	Ozone Transport Commission
PAM	Photochemical Air Monitoring Station
PRM	Primary Reference Material
RATA	Relative Accuracy Test Audit
RECLAIM	South Coast Air Quality Management District's Regional Clean Air Incentives Market
RFF	Resources for the Future
RGM	Reference gas mixture
SGC	Specialty gas company
SIP	State Implementation Plan
SLAM	State and Local Air Monitoring Station
SRM	Standard Reference Material
SRMP	Standard Reference Materials Program
WTP	Willingness to pay

Executive Summary

The NTRM program was created by NIST in collaboration with the U.S. Environmental Protection Agency (EPA) and specialty gas companies (SGCs) to increase the availability of NIST-certified reference materials.

The gas mixture NIST-Traceable Reference Materials (NTRM) program was jointly created by the National Institute of Standards and Technology (NIST), the U.S. Environmental Protection Agency (EPA) and specialty gas companies (SGCs) to increase the availability of NIST-certified gas-mixture reference materials. Under the program, SGCs manufacture gas-mixture standard reference material (SRM) equivalents under NIST's technical specifications and submit these gas mixtures to NIST for certification.

The NTRM program is integral to the supply of highly accurate reference standards that are used by industry to support compliance with environmental regulations. Environmental regulation has become increasingly sophisticated over time and often requires facilities and monitoring organizations to supply real-time information on the pollutants that they are emitting to the environment. To meet these regulations' data acquisition and accuracy needs, regulated establishments are required to calibrate pollution monitoring equipment with reference standards traceable to NIST.

The objective of this study is to conduct a microeconomic impact assessment of the NTRM program to estimate its impact on U.S. industry and determine its economic return. Economic impacts are measured relative to a counterfactual scenario that describes the reference material supply chain in the absence of the NTRM program. The counterfactual scenario specifies the behavior changes that SGCs and users of reference materials (referred to as end users) would likely need to make if NTRMs were not available to produce NIST-Traceable Gases (NTGs).

Based on interviews with SGCs, NIST, and reference gas end users, we projected that the net present value (NPV) of the NTRM program through 2007 is between $49.0 million and $63.1 million. However, the program's benefits may increase significantly as participation in emission trading programs increases and credits are retired under advanced phases of cap and trade programs.
Table ES-1 presents an overview of the economic impacts of the NTRM program from 1990 to 2007.

Table ES-1. Economic Impact of the NIST NTRM Program
Economic impacts reflect benefits and costs from 1990 projected through 2007.[a]

Measure of Economic Return[b]	Lower Bound	Upper Bound
Benefit-to-cost ratio	21.4	27.2
Net benefits (NPV $2001)	$49,015,977	$63,092,986
Social rate of return	221%	228%

[a]The NTRM program began operation in 1992. However, NIST incurred program development costs beginning in 1990.
[b]Based on a 7 percent inflation-adjusted social discount rate.

ES.1 THE ROLE OF THE NTRM PROGRAM IN THE REFERENCE GAS SUPPLY CHAIN

In many ways, the use of SRMs and NTRMs in the reference gas supply chain is essential in that it provides a well-defined traceability to existing primary standards for chemical measurements. To ensure the consistency and accuracy of continuous emissions monitoring, EPA developed procedures and protocols that specify the frequency, accuracy, and traceability of measurement systems. Calibration gases must be linked to NIST primary standards via a traceability chain. Analysts and regulators want to keep the chain as short as possible to reduce the uncertainty of the certified concentration of the reference standards.

EPA recognized the expertise and scientific stature of NIST by writing traceability requirements into most of their current regulations for stationary source, mobile source, and ambient air monitoring. As a result, NIST's provision of SRMs and certification of NTRMs now represent an important component in the supply chain infrastructure of many U.S. industries and some governmental organizations. In return, the EPA regulations created an unprecedented demand on NIST's laboratory to provide gas mixtures to support end users' needs for traceability.

ES.2 THE COUNTERFACTUAL WORLD WITHOUT THE NTRM PROGRAM

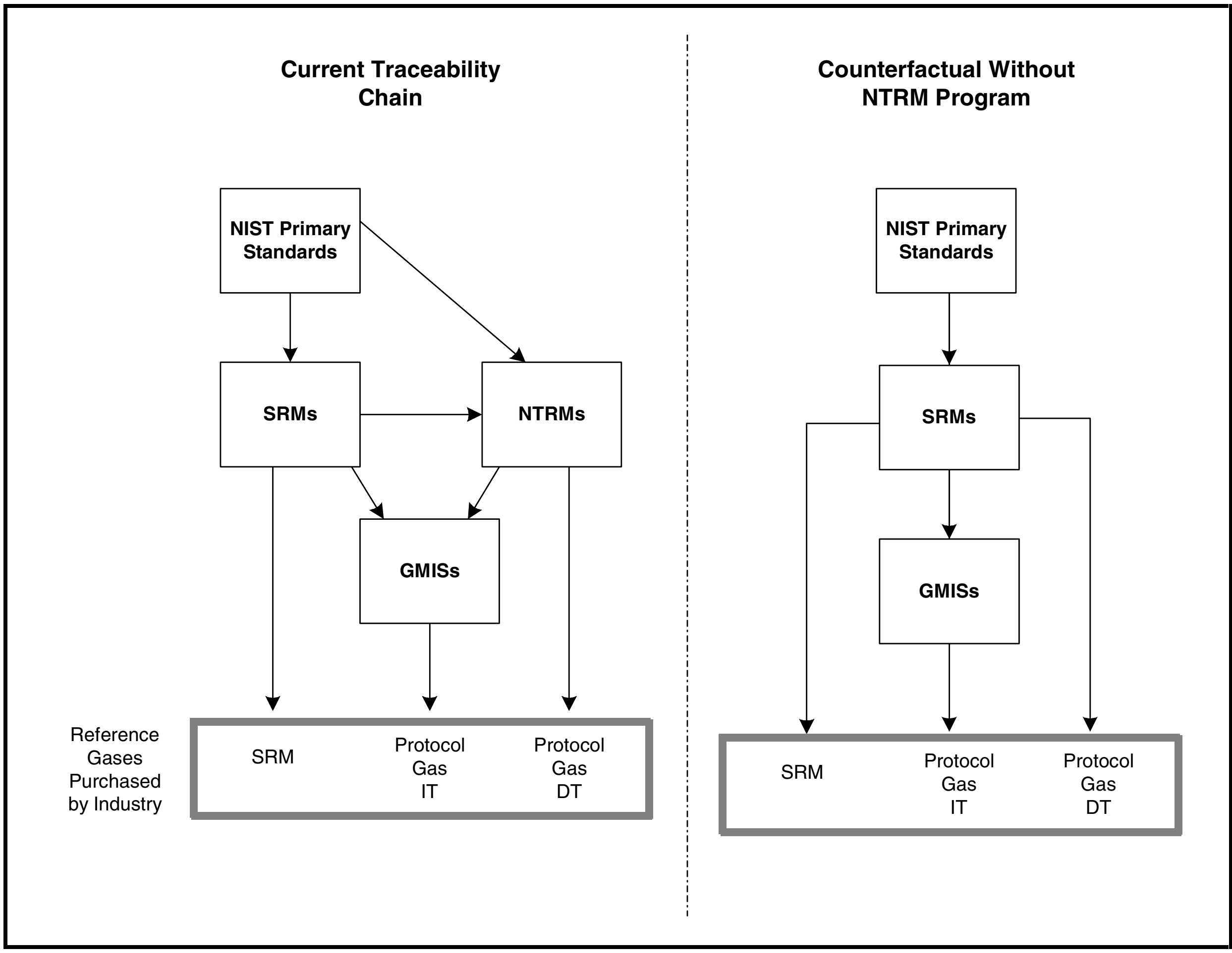
In the absence of the NTRM program, traceability would need to be achieved primarily though the use of SRMs. However, because of NIST's limited capacity to supply SRMs, SGCs would likely increase their reliance on intermediate standards to maintain traceability to NIST.

A conceptual diagram of the current and counterfactual traceability supply chains is shown in Figure ES-1. NIST currently certifies two types of low-uncertainty (approximately 1%) reference materials: SRMs that they characterize and market in-house and NTRMs that are produced and characterized by an SGC, then analyzed and certified by NIST. Either SRMs or NTRMs can be used to certify directly traceable reference gases or gas manufacturers' intermediate standards (GMISs). GMISs are used in the production of indirectly traceable gases that have higher uncertainty than directly traceable gases do because of the additional step in their traceability chain.

In the absence of NTRMs, SRMs would be the only materials certified by and traceable to NIST. Directly traceable gases would need to be certified via an SRM, while indirectly traceable gases could be characterized with reference to a parent SRM. As the diagram illustrates, SRMs would emerge as a major bottleneck in the infrastructure supply chain. In addition, SRM cylinders are substantially more expensive than NTRMs and the volume of gas in an SRM cylinder is one-fifth of that in NTRMs. As a result, whereas the majority of calibration gases currently are directly traceable, under the counterfactual, most reference gases used by industry would be indirectly traceable.

This counterfactual would have three key impacts on SGCs and their customers:

Figure ES-1. Conceptual Approach for Estimating Economic Impacts of the NTRM Program



Note: DT: directly traceable.
IT: indirectly traceable.

1. SGCs' calibration gas production costs would increase due to the constricted supply of SRMs and the need to produce large numbers of GMISs to increase the certification capacity of each SRM.
2. Some end users would be forced to begin consuming indirectly traceable gases. These users would incur higher operations and maintenance expenses because of their lowered confidence in their calibration gas resulting from the increase in uncertainty.
3. These end users' participation in emissions allowance markets would be adversely affected because of the need to ensure the addition of a proportional number of allowances to mitigate that increase in uncertainty and avoid the increased possibility of regulatory penalties.

Elimination of these counterfactual costs are the current benefit of the NTRM program to society. To quantify these benefits, we collected data from end users (i.e., electric utilities, monitoring organizations); SGCs; and several federal and local environmental agencies and coupled them with published statistics.

The NPV of benefits from the NTRM program through 2007 is presented in Table ES-2. Upper and lower bounds of benefits are calculated that reflect the range of incremental uncertainty values provided by SGCs associated with moving from directly traceable gases to indirectly traceable gases. Benefits estimates range from $51.4 million to $65.5 million.

Table ES-2. Economic Impact of NTRM Program from 1990 Estimated through 2007 (NPV $2001)

	Lower Bound	Upper Bound
Costs of NIST NTRM Program	–2,407,897	–2,407,897
Benefits	51,423,874	65,500,883
SGCs	5,398,420	5,398,420
Users	46,025,454	60,102,463
Net Benefits	49,015,977	63,092,986

Notes: Social costs are presented as negative numbers.
The upper and lower bound reflect a range for the increased analytical uncertainty for indirectly traceable gases.

To accurately characterize the net benefit of the program, however, we must also estimate social costs. NIST incurred the initial start-up costs for the program and is reimbursed by SGCs though NTRM certification fees. Through 2007, the total social cost of the program is estimated to be $2.4 million, which reduces the NPV of net benefits of the program to between $49.0 million and $63.1 million.

1 Introduction

Environmental regulation has become increasingly sophisticated over time. A suite of federal, state, and local environmental regulatory initiatives—including the Acid Rain Program, the National Ambient Air Quality Standards, and the Ozone Transport Commission—require air quality monitoring stations, electric utilities, and heavy industrial facilities to supply real-time information on the pollutants they are emitting to the environment or are tasked with monitoring. To meet these regulations' data acquisition and accuracy needs, regulated establishments are required to properly calibrate pollution monitoring equipment with reference standards traceable to the National Institute of Standards and Technology (NIST). However, as these initiatives were being promulgated, the gas-mixture reference standards available directly from NIST, standard reference materials (SRMs), were not available in sufficient quantities to meet the anticipated future demand for highly accurate NIST-traceable reference standards.

The solution was the NIST-Traceable Reference Materials (NTRM) program. The NTRM program was created by NIST in collaboration with the U.S. Environmental Protection Agency (EPA) and specialty gas companies (SGCs) to increase the availability of NIST-certified materials. Under the program, SGCs follow NIST technical guidance to manufacture SRM-equivalent standards and submit these standards to NIST for certification. Once certified, the NTRMs are the functional equivalent of SRMs and are used to assay the large volume of secondary reference standards demanded by consumers to meet their compliance obligations. Since the program's inception in 1992, it has become an integral component of the high-accuracy reference gas supply chain.

The objective of this study is to conduct a microeconomic impact assessment of the NTRM program to estimate its impact on social welfare. Economic impacts are measured relative to a counterfactual scenario that describes the reference material supply chain in the absence of the NTRM program. The counterfactual scenario specifies the behavior changes that SGCs and users of reference materials (referred to as end users) would likely make if NTRMs were not available to produce NIST-Traceable Gases (NTGs).

This section discusses trends in environmental regulation, describes the NTRM program's role in the supply of reference materials, and provides an overview of the analytical approach used to estimate the economic impact of the NTRM program.

1.1 TRENDS IN ENVIRONMENTAL REGULATION

The availability of high-quality reference materials with linkages to well defined national standards is essential for supporting the objectives of U.S. environmental policy. In response to the 1990 Clean Air Act Amendments (CAAA), the EPA developed regulations that require monitoring systems used to measure emissions to be calibrated with standards traceable to NIST. The NTRM program was created to help meet the increasing demand for NTRMs that results from EPA's regulations.

The EPA regulates air emissions from a variety of sources to reduce adverse health and environmental effects. Under the CAAA, EPA developed national emissions standards for 186 hazardous chemicals, including SO_2 and NO_X. National emissions standards for hazardous air pollutants (NESHAP) regulations specify an emissions limit based on what is achievable with a specific control technology and the chemical content of the inputs to the production process.

In addition to these technology-based performance standards, emission sources may also be subject to other local or regional environmental regulations.

- *National Ambient Air Quality Standards (NAAQS)* do not directly affect industry because they are not applied to individual sources. Rather, these standards are applied to the ambient air in a particular area. For example, electricity generators in nonattainment areas may be targeted for more stringent controls implemented through local operating permits.
- The *Acid Rain Program* was authorized by the CAAA to reduce the adverse effects of acidic deposition on natural resources, ecosystems, materials, visibility, and public health. The principal sources of acidic compounds are emissions of SO_2 and NO_x from the combustion of fossil fuels.
- the *South Coast Air Quality Management District's Regional Clean Air Incentives Market (RECLAIM)* and the *Ozone Transport Commission (OTC)* NO_x *Budget* program were implemented by state and local air quality organizations in California and the northeastern states, respectively, to help their respective areas improve compliance with ambient air quality standards and other environmental standards.

The latter two bullet points are programs that include emissions trading. Emissions trading is an innovative approach to environmental regulation that exploits the potential efficiency gain from equating the marginal cost of abatement (pollution reduction) for individual sources within a facility and across companies in a trading region (RFF, 1996). All units are allocated a number of emissions allowances, where each allowance is equivalent to one ton of emissions. Units are allowed to buy, sell, or bank allowances based on their forecasted emissions.

For example, a primary goal of the Acid Rain Program is to reduce annual SO_2 emissions by 10 million tons below 1980 levels. To achieve these reductions, Sec. 401 (b) of the CAAA requires a two-phase tightening of the restrictions placed on fossil-fuel-fired power plants. Phase I began in 1995 and affects 445 units in total at 110 coal-burning electric utility plants located in 21 Eastern and Midwestern states.[1] Emissions data indicate that SO_2 emissions at these units nationwide were reduced by almost 40 percent (5.3 million-ton emissions) below their required level (8.7 million-ton allowable emissions), and by approximately 35 percent (5.4 million-ton emissions) below 1996 allowable levels (8.3 million-ton

[1] The 445 total units include 263 units that were required by law to begin monitoring and reporting actual emissions in 1995 and undergo annual reconciliation processes in 1996. The remaining units are either substitution units or units that opted to begin early participation in the program.

allowable emissions). Phase II, started in 2000, tightens the annual emissions limitation imposed on Phase I plants and also sets restrictions on smaller, cleaner plants fired by coal, oil, and gas. The total number of units participating in the program in 2002 is estimated by RTI to number over 2,300.

Early predictions of the potential annual social benefits associated the SO_2 emissions trading ranged up to $3.1 billion in decreased abatement costs. However, a recent study by Resources for the Future (RFF) estimates annual social benefits of approximately $780 million (RFF, 2000). The RFF authors attribute the reduction in realized benefits to factors such as the deregulation of the railroad industry, which increases the availability of low-sulfur coal and unforeseen advances in abatement technologies. In general, however, most industry experts agree that the SO_2 emissions trading program has made a significant contribution to social welfare by lowering total national abatement costs.

1.2 MEASUREMENT ACCURACY AND NIST TRACEABILITY

Before the CAAA, many stationary-source air regulations required an initial source test, which was followed by other tests only if there was reason to believe the source was no longer in compliance. The CAAA shifted emphasis to continuous monitoring or repeated testing to ensure that sources maintained compliance at all times. The enforcement arm of EPA was given expanded capabilities for obtaining records of all monitoring and testing of products, equipment, and emissions at any regulated facility.

To support the mandated reductions in SO_2 and NO_x, EPA issued regulations requiring affected facilities to install continuous emission monitoring (CEM) systems. To ensure the consistency and accuracy of emissions monitoring, the EPA developed regulations that required the measurement systems used to be calibrated with standards from NIST or standards traceable to NIST and have, at most, ±2 percent measurement accuracy. However, the expanded need for traceability to NIST could not be met solely with the gas-mixture SRMs. In response, EPA issued new rules specifying how SGCs could produce EPA protocol gases that could be used in place of SRMs to perform calibrations on measurement systems used for air pollution monitoring.

The pending SO_2 emissions trading under the Acid Rain Program and other programs (RECLAIM, OTC NO_X Budget) and growth in demand for SRMs and EPA protocol gases would have outstripped the supply of the these standards. To ensure a ready supply of standards, EPA, NIST, and SGCs created the NTRM program between 1990 and 1992.

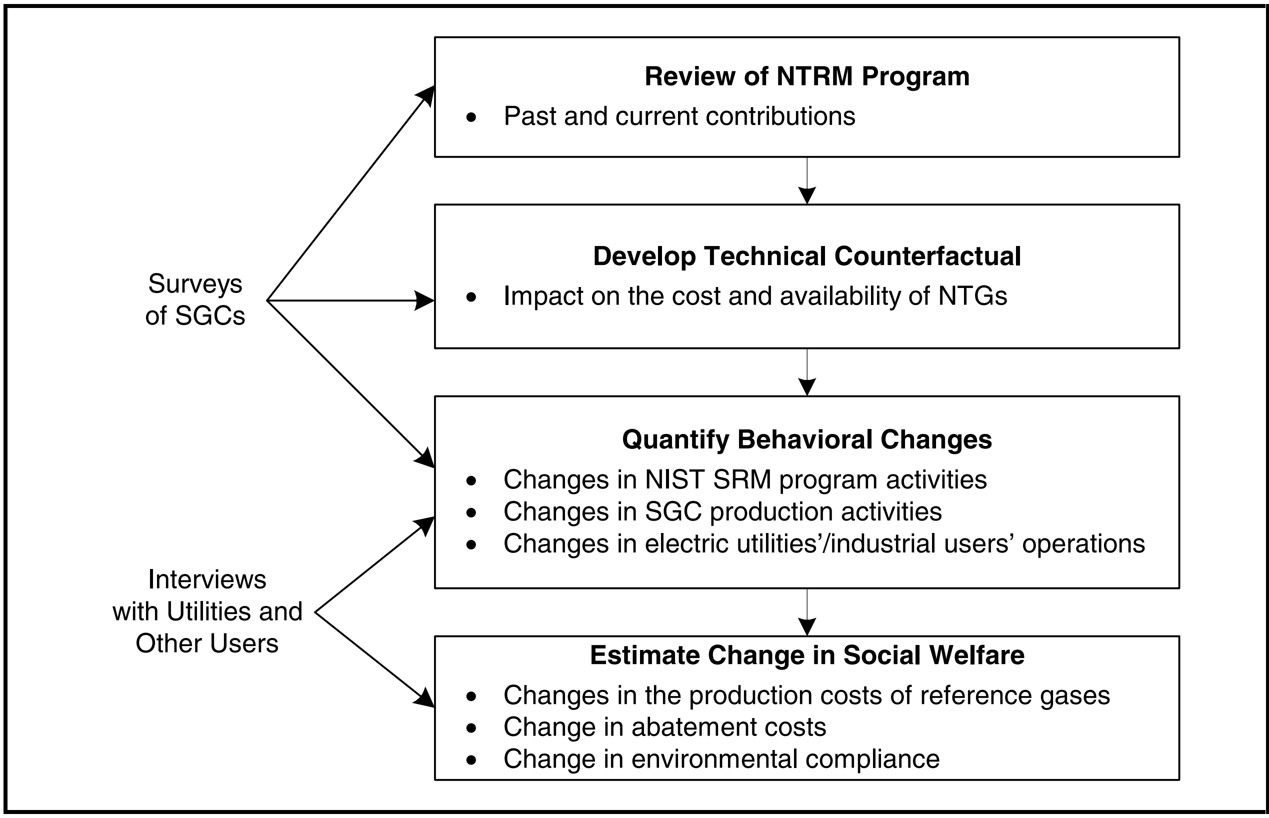
The NTRM program, jointly administered by the NIST Analytical Chemistry Division (a division of the Chemical Science and Technology Laboratory) and the NIST Standard Reference Materials Program, produces gas mixtures (NTRMs) to supplement the supply of existing gaseous SRMs and to be used where SRMs have been used in the past. The NTRM program addressed the issues associated with the increasing demand for high-quality NIST-traceable reference materials. Under this program, NIST works with SGCs to provide the same traceability as SRMs. The NTRM program provides the infrastructure for SGCs to use a gas-mixture NTRM to produce an EPA protocol gas that can then be used to calibrate emissions monitoring instruments. The program has resulted in an increase in the range and number of standards available to end users. In general, they can be acquired faster and at lower cost (NIST, 2000). This study will quantitatively and qualitatively assess the NTRM program's impact on social welfare.

1.3 SUMMARY OF ANALYTICAL APPROACH AND ORGANIZATION

The organization of this report mimics the analytical process through which the economic benefit of the NTRM program is determined. Each section walks the reader through a different stage in the analytical process, from providing background information to determining the economic methodology to data collection and finally to the calculation of economic benefits. Figure 1-1 provides an overview of the steps in the analytical process undertaken in this report and serves as a map for the section-by-section overview of the report provided below.

Whereas the preceding introduction served to introduce the reader to the trends that led to the inception of the NTRM program, Section 2 of this report, "Overview of the Reference Gas Supply Chain," presents background information on the operation and institutional structure of the program itself. This section also

Figure 1-1. Overview of Approach



includes a discussion of the regulatory requirements that stipulate the use of reference standards supported by the program and the companies and entities that both produce and/or consume these gases. The information in Section 2 supports the development of our estimation techniques by providing the context within which vested parties alter their behavior under the counterfactual.

Section 3 explores the technical metrics and the economic methodology that will be used to estimate benefits of the program. A significant portion of this section is devoted to the definition and explanation of the counterfactual scenario through which the economic benefit of the program will be determined. Section 4, "Primary Data Collection," outlines the process through which we collected from stakeholders the data needed to inform our analysis.

Finally, the results section, Section 5, provides a step-by-step walk-through of the quantification of economic benefits, explaining the impact that the counterfactual scenario would have on stakeholders. We evaluate the costs of developing and creating the program and compare them to the benefit the program has had to both reference gas producers and consumers. We also calculate and present three measures of economic return: the net present value of the program, the benefit to cost ratio, and the social rate of return.

2 Overview of the Reference Gas Supply Chain

The NTRM program currently provides the cornerstone for the production of most NIST-Traceable Gases (NTGs) used for environmental compliance and other emission testing activities. Under the program, SGCs manufacture SRM equivalents under NIST's technical guidance. This section provides an overview of the reference gas supply chain, beginning with the history and description of the NTRM program. This is followed by a discussion of traceability issues and an overview of SGCs and users of reference materials.

2.1 INTRODUCTION TO THE NTRM PROGRAM

The NTRM program was created by NIST, in collaboration with EPA and SGCs, to increase the availability of NIST-certified gas-mixture reference materials. The text below discusses the technical and economic history of the NTRM program and the requirements that SGCs must meet to participate.

2.1.1 Technological and Economic History of the NTRM Program

Congress passed the Clean Air Act in 1970, which had the effect of setting maximum allowable pollution levels in many areas. Included in these areas were limits of certain pollutants in the atmosphere and limits of pollutant levels that could be emitted by automobiles and smokestacks. To ensure regulatory compliance, the pollutant levels from these sources had to be monitored. Monitoring was accomplished using measurement instrumentation that had to be calibrated with known gas mixtures to ensure correctness of the indicated pollution level.

"SRMs are materials certified for their chemical composition or physical properties. SRMs help users verify the accuracy of measurement methods or calibrate measurement systems by linking their measurements to NIST…. A NIST-certified SRM carries with it the full weight and authority of NIST and the U.S. Department of Commerce" (Martin, Gallaher, and O'Connor, 2000).

One of the large concerns in the early days of air pollution monitoring was uncertainty regarding the compressed gas calibration standards that were used to calibrate the monitoring instruments. Such standards had been prepared mostly by industrial gas companies and there was no specific procedure to follow for preparing and verifying such standards. Anecdotal stories were frequent about producer-certified standards with concentrations that were inaccurate or standards in which the composition was incorrect (e.g., containing methane when ethane was specified). For example, one paper from the 1970s reported a 25 percent error on a carbon monoxide standard (Mage, 1973). Another paper discussed the cylinder-related concentration instability of up to – 65 percent over 1 year and the need for a central authority to maintain a set of primary standards to which all other standards would be referenced (Wechter and Grieco, 1976). Problems concerning producer-certified standards of uncertain pedigree continued into the early 1980s (Decker et al., 1981).

Before NIST's involvement, anecdotal stories were frequent about producer-certified standards with concentrations that were inaccurate or standards in which the composition was incorrect.

In response to this problem, the National Bureau of Standards (NBS), predecessor to NIST, and EPA began working together in 1972 to develop gaseous SRMs having well-characterized certified concentrations with small uncertainties (e.g., ±1 percent) and little instability (Hughes, 1975; Hughes, 1976; Paulsell, 1976). These SRMs would be available for sale to the public and would have the reputation of NBS standing behind their certified concentrations. They were well received in the monitoring community, and demand for SRMs soon far exceeded the ability of NBS to produce them. Both NBS and EPA viewed the chronic out-of-stock situation that developed as critical.

EPA and specialty gas producers jointly developed an analytical protocol by which the producers could prepare commercially available standards with certified concentrations that are traceable to NBS SRMs (Scott Environmental Technology, Inc., 1977). These EPA protocol gases would be prepared one-by-one by the producers and would be analyzed using SRMs or gas manufacturers' intermediate standards (GMISs) as the analytical reference standards. The GMISs were analyzed using the published protocol, which required analysis using NBS SRMs. These GMIS mixtures were subsequently used as analytical reference standards for analyzing protocol gases or other standards. The protocol's definition of NBS traceability allowed for only one intermediate standard to exist in the calibration chain between the SRMs and the EPA protocol gases. Because an SRM can calibrate an instrument that is used to analyze many more EPA protocol gases, the number of NIST-traceable standards available for the monitoring community increased greatly.

> NBS and EPA jointly developed the CRM program to supply "SRM-quality" gases to specialty gas companies. EPA protocol gases must be NBS- (NIST-) traceable, allowing a maximum of one intermediate standard to exist in the traceability chain.

Although the availability of EPA protocol gases benefited the monitoring community, the continuing lack of SRMs caused problems for the specialty gas producers. To increase the supply of high-accuracy standards that producers could use in the place of SRMs, NBS and EPA jointly developed the Certified Reference Materials (CRMs) Program (Hughes and Mandel, 1981; Hughes, 1982). Producers would prepare these standards in batches of 10 or more cylinders and analyze them using SRMs as reference standards. One characteristic of CRMs is that their certified concentrations are very close (±1 percent) to those for SRMs. After the producer had completed its analyses of the batch and was satisfied that the batch was homogeneous and stable, an EPA-funded third-party auditor would select two cylinders for an independent analysis without knowledge of the producer's results. The producer and the auditor then sent their results to NBS, which made the final determination about whether the batch was stable, homogeneous, and accurately analyzed. If the batch met NBS's requirements, the CRMs were certified. This supply of CRMs could be used for compliance measurements and for the production of EPA protocol gases.

However, by the late 1980s EPA believed that the CRM program was not serving the purpose for which it was implemented and stopped supporting the program. SGC participation was low and it became increasingly difficult to justify the level of financial and technical support needed to maintain the program. Additionally, only one SGC was active in the program at this time and was making CRMs whose gaseous compositions did not address the interests of continuous emissions monitoring.

At this same time, Congress began working on amendments to the Clean Air Act. The effect of the amendments would require much more pollutant monitoring and much more frequent calibration of monitoring equipment. In anticipation of the new legislation, NIST (the successor institution to NBS) and EPA worked on developing a new program to provide more NIST-traceable standards. The program would have to be acceptable not only to NIST and EPA but also to the specialty gas industry and ultimately to the community doing compliance monitoring. The CAAA were passed in 1990 and began to be phased in starting in November 1992. By this time, the newly developed standards program called the NTRM program was in place and operating.

The NTRM program differed from the CRM Program in five significant ways:

- ➤ The concentration of a candidate NTRM would not have to be identical to that of a NIST SRM.
- ➤ The analyst did not have to match an SRM if NIST had primary standards for the analyses.
- ➤ The producer of the candidate NTRM would pay NIST to analyze the candidate NTRM's concentration; EPA funds were not involved.
- ➤ NIST would certify the NTRM's concentration based on its analysis.
- ➤ The NTRM would not have to be sold to third parties because no public funds were used in the certification (Guenther et al., 1996; Mitchell and May, 1993).
- ➤ The uncertainty of the NTRM would be approximately the same as that of an SRM because both are analyzed using NIST primary standards as the analytical reference standards.

By allowing SGCs to manufacture SRM equivalent reference standards, NIST dramatically increases the amount of NIST-certified and analyzed gaseous reference material available. NIST concentrates on its strength to accurately characterize and name standards.

2.1.2 CSTL/NTRM Program Activities

The Standard Reference Materials Program (SRMP) provides over 1,300 internationally accepted SRMs for use in materials production, environmental analysis, health measurement, and basic science and metrology. Its mission is "to provide reference materials that are the definitive physical sources of measurement traceability in the United States" (NIST, 2000). The Chemical Science and Technology Laboratory (CSTL) provides technical leadership for most of the chemical and composition standards produced by NIST.

The Analytical Chemistry Division, part of CSTL, operates the NTRM program that manages the testing and certification of gas mixtures produced by SGCs. Under this program, a specialty gas firm produces a batch of a gas mixture that matches NIST primary standards. The batch is prepared using the same specifications for homogeneity and purity that are used for SRMs. Samples from this batch are selected by NIST and sent to the Analytical Chemistry division for evaluation against primary reference material. Once NIST has approved the batch, it is certified as "NIST-traceable reference material" and is considered equivalent to an SRM for all subsequent uses.

Producers must meet three minimum requirements to participate in the NTRM program (Guenther et al., 1996):

1. The producer must have in place a documented quality system that conforms to international or national guidelines.
2. The producer must have the necessary facilities, equipment, and personnel to produce and analyze the gas mixture in the manner specified by NIST.
3. The producer must agree to one or more of the following requirements: it must make NTRMs available for sale to U.S. customers, it must demonstrate that traceable standards produced from NTRMs will be made available to U.S. customers, or the NTRMs must be used to make EPA protocol gases.

Participants in the NTRM program must meet a set of minimum requirements and follow specific manufacturing procedures to ensure quality.

The following list summarizes the procedures that producers must follow to prepare NTRMs (Guenther et al., 1996):

- Before an NTRM batch is prepared, the producer must submit to NIST for approval a plan describing the analytical procedures to be used.
- Each NTRM batch must consist of a batch of a least 10 cylinders.
- The producer must use NIST-certified standards to determine the concentration relationship among all of the cylinders in the batch (batch homogeneity), to establish the average concentration of the batch, and to establish a baseline from which to compare future analyses performed to evaluate batch stability.
- The initial analysis of the NTRM batch should be performed 2 or more days after the batch preparation, and the second

analysis should be performed 30 or more days after the first analysis.

- The producer must perform a preliminary data analysis to determine the batch characteristics, particularly the stability and homogeneity of the batch.
- The producer must submit to NIST all the data generated from the two analyses.
- After NIST has reviewed these data and has determined that the batch meets their specifications, NIST will select at least two cylinders from the batch for an independent analysis for concentration and impurities using NIST primary standards as the analytical reference standards.
- NIST will assign a certified concentration and uncertainty for the entire batch based on the producer's and NIST's measured concentrations.
- NIST must be compensated directly by the producer for the certification of the batch.

In addition to the financial resources used in preparing a batch of NTRMs, it may take as long as 12 to 18 months to prepare, test, and certify a batch.

2.2 ANALYTICAL TRACEABILTY AND UNCERTAINTY

As described in the previous section, the mission of the NTRM program is to increase the availability of high quality NIST-traceable gas-mixture reference standards. Most of these standards are used in compliance with environmental regulations. This section presents the principal pieces of federal legislation that require the use of these standards. This section also includes a discussion of traceability requirements and a description of the different pathways through which the NIST traceability chain can be established.

2.2.1 Federally Mandated Traceability Requirements

EPA regulates air emissions from a variety of sources to reduce adverse health and environmental effects. Under the CAAA of 1990, EPA developed national emissions standards for 186 hazardous chemicals, including SO_2 and NO_x. Before the CAAA of 1990, many stationary source air regulations required an initial source test followed by other tests only if there was reason to believe that the source was no longer in compliance. The CAAA of 1990 shifted emphasis to continuous monitoring or repeated testing to ensure that sources maintained compliance at all times.

To ensure the consistency and accuracy of emissions monitoring, EPA developed procedures and protocols that specify the frequency, accuracy, and traceability of measurement systems. In many instances, the regulation requires the measurement systems used to be calibrated with standards from NIST or standards traceable to NIST.

All measurements are subject to some uncertainties. The measured value of a variable is a function of both its true value and the measurement system. The measurement system contains a number of elements that contribute to uncertainty in measurement (Taylor, 1997; Bentley, 1983).

The NTRM program supports the traceability of gas-mixture reference standards to NIST to meet regulatory obligations detailed in a myriad of federal statutes. However, different parts of the CAAA of 1990 have different calibration requirements. This section discusses the three major categories of CAAA regulations and highlights their calibration requirements as they relate to the use of NIST-traceable gas mixtures. These categories are as follows:

- technology-based performance standards,
- NAAQS, and
- Acid Rain Program and other emissions trading programs.

Technology-Based Performance Standards

NESHAP regulations specify an emissions limit based on what is achievable with a specific control technology and the chemical content of the inputs to the production process. These regulations are frequently referred to as Maximum Achievable Control Technology (MACT) or Best Available Control Technology (BACT) and are based on a review of the top-performing technologies currently available.

NESHAP regulations specify an emissions limit based on what is achievable with a specific control technology and the chemical content of the inputs to the production process.

Criteria pollutants are also regulated under new source review (NSR) and new source performance standards (NSPSs). NSR requirements are typically conducted by state agencies. This program applies to new facilities or expansion of existing facilities or process modifications and requires facilities to meet Lowest Achievable Emission Rate (LAER) standards as compared to existing (unchanged) facilities. Many criteria pollutants, such as SO_2, also fall under NAAQS and the Acid Rain Program.

Monitoring and calibration requirements can be grouped by source types: existing stationary sources, new stationary sources, and mobile sources.

Existing Stationary Sources. 40CFR Part 63 (NESHAP) specifies continuous monitoring for existing stationary sources associated with selected production processes. Many of the NESHAP regulations require CEM. Examples of the types of facilities for which CEM is required include coke ovens—opacity only; sterilization units—ethylene oxide; phosphoric acid production—stack gas temperature; petroleum and natural gas production—outlet temperature and methane (method 21); pharmaceutical production—HCl (method 25A); and Portland cement kilns—total hydrocarbon. Typically, NTGs are required for bias and Relative Accuracy Test Audits (RATA), which occur at least quarterly. In addition, some daily calibration checks require NIST traceability.

Uncertainties of analytical measurements must be quantified so that decision makers can understand the degree of reliability of the result. ASTM International, formerly known as the American Society for Testing and Materials, defines the sources of variability of a measurement method, each of which belongs to one of the following categories:

- the operator
- the apparatus
- the environment
- the sample
- time

New Stationary Sources. 40CFR Part 60 covers new stationary sources. Part 60 has a number of requirements for allowable pollution levels and the methods used to determine them. Many of the methods specified in Appendix A of Part 60 are also referred to by other parts of 40CFR. For example, the NESHAP required for calibration gas certification are frequently based on new source regulations in Part 60. New sources of all types covered by the regulations in the subparts of Part 60 are required to demonstrate emissions below allowable levels during actual and planned operation. An initial performance test is required and NIST-traceable gas mixtures are specified in most cases. Many of these new sources are also required to perform CEM. In general, this subpart requires NIST-traceable materials for initial testing upon installation, for RATA, and for quarterly accuracy checks of various types.

Mobile Sources. Mobile source testing is covered under a series of parts in 40CFR. The regulations in Part 86 cover new road vehicles, Part 89 covers nonroad compression engines, Part 90 covers nonroad spark engines, Part 91 covers marine engines, and Part 92 covers locomotives. All have essentially the same calibration requirements. Calibration gases must be analyzed to ±1 percent vs. NIST-traceable gas standards, span gases to ±2 percent vs. NIST-traceable gas standards, and blended gases to ±1.5 percent vs. NIST-traceable gas standards. Part 92 indicates that the 1.5 percent can only be obtained if the pure gas components of the blends are "named" ±1 percent to NTRM. In most cases, the exhaust tests are only required during the design stage of the new mobile source.

NAAQS

NAAQS do not "directly" affect industry because they specify regional air quality objectives. However, these standards indirectly affect sources through local regulations targeted at ambient air quality objectives in particular areas. For example, electricity generators in nonattainment areas may be targeted for more stringent controls implemented through local operating permits. In these instances, monitoring and calibration requirements are likely to be similar to NESHAP requirements and hence account for some protocol gas use.

> Ambient air monitoring data is collected by approximately 5,000 samples which make up the SLAM network. "Data collected are used by EPA to aid in planning the Nation's air pollution control strategy and to measure achievement toward meeting NAAQs." (Musick, 1996)

A substantial number of NTGs are used in the calibration of the testing equipment that is used to monitor ambient air quality. 40CFR Part 58 indicates that states are required (through state or local air quality agencies) to ensure the conduct of ambient air quality tests. States may delegate or assign this responsibility to local agencies or State and Local Air Monitoring Stations (SLAMs), National Air Monitoring Stations (NAMs), and Photochemical Air Monitoring Stations (PAMs). Representatives from SGCs indicated that SLAMs and NAMs are nontrivial consumers of protocol gases.

40CFR Part 58 specifies that monitoring requirements should be traceable to NIST: "Gaseous pollutant concentration standards (permeation devices or cylinders…) used to obtain test concentrations of CO, SO_2, NO, and NO_2 must be NIST-traceable." However, 40CFR Part 53, which describes ambient air reference methods, is less stringent and states that state or local organizations should "…use NBS-certified standards whenever possible" for CO_2, CO, C_2H_6, C_2H_4, CH_4, and xylene.[1]

Acid Rain Program and Other Emissions Trading Programs

The Acid Rain Program was authorized by the CAAA of 1990 to reduce the adverse effects of acidic deposition on natural resources, ecosystems, materials, visibility, and public health. The principal sources of acidic compounds are emissions of SO_2 and NO_x from the combustion of fossil fuels. The EPA designed the Acid Rain Program to achieve significant environmental and public health benefits by reducing emissions of SO_2 and NO_x, the primary causes

[1] The National Bureau of Standards (NBS) was the predecessor to the National Institute for Standards and Technology (NIST).

of acid rain. The program employs both traditional and innovative market-based approaches for controlling air pollution. It also encourages energy efficiency and pollution prevention.

The market-based SO_2 emissions trading component allows regulated entities to adopt the most cost-effective strategy to reduce SO_2 emissions at units in their systems.

Allowance trading programs are integral to several environmental regulatory initiatives, including the Acid Rain Program. Allowance trading (also referred to as "emissions trading") is a system included in the CAAA of 1990 intended to reduce the costs of compliance while meeting the same (or improved) environmental objectives. The approach provides a firm with the flexibility to find the most cost-effective way of achieving compliance through the trading of emissions allowances (EPA, 1999).

SO_2 Emissions Trading. The market-based SO_2 emissions trading program began in 1995 and allows utilities to adopt the most cost-effective strategy to reduce SO_2 emissions at units in their systems. Under emissions trading, participants, mostly electric utilities, are allocated a fixed number of allowances and are required to hold one allowance for each ton of SO_2 they emit. Participants may transfer or sell allowances between one another or bank them for use in future years. The system gives participants flexibility in making purchase decisions for pollution control equipment; they may either invest in pollution control or purchase allowances to cover SO_2 emissions. Regardless of the compliance strategy chosen, participants must not exceed EPA-determined emissions ceilings. The market for SO_2 allowances is also open to all other enterprises, groups, and individuals via an "opt-in" component. The primary goal, set by Title IV of the Clean Air Act, is the reduction of annual SO_2 emissions by 10 million tons below 1980 levels.

The Acid Rain Program allows sources to use other methods to create their own compliance strategy. For example, to reduce SO_2, an affected source may repower its units, use cleaner burning fuel, or reassign some of its energy production capacity from dirtier units to cleaner ones. Sources may also decide to reduce electricity generation by adopting conservation or efficiency measures. Some of the options afford the unit special treatment, such as a compliance extension or extra allowances. Most options, like fuel switching, require no special prior approval, allowing the source to respond quickly to market conditions without needing government approval.

Participants are required to install systems that continuously monitor emissions in order to track progress, ensure compliance, and provide credibility to the program's trading component. In any year that compliance is not achieved, excess emissions penalties will apply and sources will either have allowances deducted immediately from their accounts or may submit a plan to EPA that specifies how the excess SO_2 emissions will be offset (EPA, 1997b).

The CEM and trading provisions have dramatically increased the demand for flow and concentration monitors, and thus for the reference gases needed for calibrating these instruments.

EPA regulations require CEM for SO_2, NO_x, and CO_2 at all power-generating facilities over 25MW capacity. During Phase I of the Acid Rain Program, the electric utility sources with the highest SO_2 emissions levels were required to reduce their SO_2 emissions to 5.7 million tons/year. Within this overall cap, facilities are allowed to trade emissions allowances with other affected and nonaffected facilities. The CEM and trading provisions have dramatically increased the demand for flow and concentration monitors, and thus for the reference gases needed for calibrating these instruments. The CAAA of 1990 and the 1993 Acid Rain rules have specifically required these gas mixtures to be NIST-traceable, which led to a large increase in the need for EPA protocol gases. Phase II, which begins in the year 2000, tightens the annual emissions limits imposed on these large, higher-emitting plants and also sets restrictions on smaller, cleaner plants fired by coal, oil, and gas, encompassing over 2,000 units in all (Table 2-1).

Table 2-1. SO_2 Emissions Trading Activity

Year	Number of Allowances (Millions)	Average Price (weighted)	Number of Transactions
1994	9.2	$159	215
1995	16.7	$132	613
1996	8.2	$68	1,074
1997	15.2	$110	1,429
1998	13.5	$117	1,584
1999	18.7	$207	2,832
Total	81.5		7,747

Source: U.S. Environmental Protection Agency (EPA). 2000a. "Cumulative Activity Trading Table." <http://www.epa.gov/acidrain/ats/cumchart.html>. As accessed on December 1, 2000.

The marginal cost of reducing a ton of SO_2 from the utility sector should be reflected in the price of an allowance. The cost of reductions continues to be lower than anticipated when the CAAA were enacted, which is reflected in the price of allowances. The cost of compliance was initially estimated at $400 to $1,000/ton, but declined from over $200 in early 1999 to less than $150 by the end of 1999. The price was $131/ton at the 2000 allowance auction, and prices have remained in the $130 to $140 range since January 2000. Some market observers believe that the lower than expected allowance prices during the first several years of the program were due primarily to lower than expected compliance costs and larger than expected emission reductions, which have increased the supply of allowances and put downward pressure on prices (EPA, 2000b).

Benefits of SO_2 Emissions Trading. The Acid Rain Program is a new method for tackling emerging environmental issues. The allowance trading system leverages market forces to reduce SO_2 emissions in the most cost-effective manner possible. The permitting program allows sources the flexibility to tailor and update their compliance strategy based on individual circumstances. Because firms can transfer allowances among themselves, those operating at high pollution abatement costs have alternatives to installing extensive pollution control equipment. The emissions trading program allows these firms to purchase allowances from firms operating at low marginal abatement costs, lowering their cost of compliance (Burtraw, 1998). These costs savings are directly experienced by electricity generators in terms of capital and operating cost savings. Power consumers also benefit because the pollution control capital and operating costs would otherwise have been passed along to them in the form of higher prices for electricity.

The CEM and reporting systems provide the accurate accounting of emissions necessary to make the program work, and the excess emissions penalties provide strong incentives for self-enforcement. The General Accounting Office recently confirmed the benefits of this approach, projecting that the allowance trading system could save industry as much as $3 billion per year (a 50 percent reduction in abatement costs) compared with a command and control approach typical of previous environmental protection programs (EPA, 2000b).

EPA's NO_x Budget Trading Program. The CAAA of 1990 set a goal of reducing NO_x by 2 million tons from 1980 levels. The Acid Rain Program initially focuses on one set of sources that emit NO_x, coal-fired electric utility boilers. The NO_x program embodies many of the same principles of the SO_2 trading program in its design. The program is results-oriented, flexible in the method used to achieve emission reductions, and maintains stringent emissions measurement requirements. Like the SO_2 emission reduction requirements, the NO_x program is implemented in two phases that began in 1996 and 2000. However, it does not "cap" NO_x emissions as the SO_2 program does, nor does it utilize an allowance trading system (EPA, 1997b). Rather, the program uses NO_x emissions limitations.

Interviews with EPA staff (Nichols, 2000) indicate that the NO_x SIP Call (for 22 states) and the Section 126 Program (for 16 states) will increase the number of CEM systems when they are implemented in 2002.

Emission limitations for the NO_x boilers provide flexibility for utilities by focusing on the emission rate to be achieved (expressed in pounds of NO_x per million Btu of heat input) (EPA, 1997b). Two options for compliance with the emission limitations are provided: compliance with an individual emission rate for a boiler or averaging emission rates over two or more units to meet an overall emission rate limitation. With the latter option, units must have the same owner or operator. These options give utilities flexibility to meet the emission limitations in the most cost-effective way and allow for the further development of technologies to reduce the cost of compliance.

Interviews with EPA staff (Nichols, 2000) indicate that the NO_x SIP Call (for 22 states) and the Section 126 Program (for 16 states) will increase the number of CEM systems when they are implemented in 2002. In October 1998, EPA finalized the "Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group Region for Purposes of Reducing Regional Transport of Ozone" (commonly called the NO_x State Implementation Plan [SIP] Call). The NO_x SIP Call was designed to mitigate significant transport of NO_x, one of the precursors of ozone. For states opting to meet the obligations of the NO_x SIP Call through a cap and trade program, EPA included a model NO_x Budget Trading Program rule (Part 96). This trading program was developed to facilitate cost-effective NO_x emissions reductions from large stationary sources. Part 96 provides sources with a complete trading program, including provisions for applicability, allocations, monitoring, banking, penalties, trading protocols, and program administration. States choosing to participate in the NO_X Budget Trading Program have the flexibility to modify certain provisions within the model rule (see www.epa.gov).

Under Section 126 of the Clean Air Act, states may petition EPA to take action to mitigate the significant transport of NO_X, one of the main precursors of ozone. Eleven states (CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, and VT) and the District of Columbia have petitioned EPA to find that certain major stationary sources in upwind states emit NO_X emissions in violation of the CAAA. They believe that these sources exceed amounts of emissions that contribute significantly to ozone nonattainment or maintenance problems in the petitioning state.

In May 1999, EPA established the Federal NO_X Budget Trading Program as the general control remedy for sources that will be subject to any future finding under Section 126 petitions. On December 17, 1999, EPA finalized findings under the original eight petitions (CT, MA, ME, NH, NY, PA, RI, and VT) and the details of the Federal NO_X Budget Trading Program, including unit allocations, for sources affected by the original eight petitions. EPA also expects to propose action on the petitions from DC, DE, MD, and NJ in the near future.

Other Emissions Trading Programs. In addition to the Acid Rain Program, several other emissions trading systems are in operation around the country or are slated to begin operation within the near term. Functioning in the same manner, these programs are regional rather than national. They include the OTC NO_X Budget program (consisting of the New England and Mid-Atlantic states as well as the District of Colombia and portions of northern Virginia), the South Coast Air Quality Management District's RECLAIM program in greater Los Angeles, and the NO_X SIP Call for the eastern portion of the country, among other programs. Similar to the Acid Rain Program, these regional programs are cap and trade systems where aggregate emissions for the program are capped at some level, polluting sources are provided allowances, and sources are allowed to freely trade those allowances to provide better flexibility in meeting compliance obligations. RECLAIM was the first such system and began operation in 1994 (Coy et al., 2001).

2.2.2 Pathways for Establishing Traceability

EPA's traceability protocol documents dictate the methods and requirements needed to establish NIST traceability.

EPA protocol gases and other NTGs must be linked to NIST primary standards via a traceability chain in which each step is an analysis of a gas mixture that is conducted using an analytical reference standard that was analyzed in the preceding step. Analysts and regulators want to keep the chain as short as possible to reduce the uncertainty of the certified concentration of the reference standards.

As EPA's traceability protocol was being developed, the shortage of SRMs for use as analytical reference standards was a problem for the specialty gas producers. The solution was to allow gas manufacturers' intermediate standards (GIMSs) as reference standards in the analysis of candidate EPA protocol gases. GMISs are intermediate, NIST-traceable reference standards manufactured by SGCs that have themselves been certified by SRMs or NTRMs. GMISs differ from NTRMs in that they are not certified by NIST staff and they are not SRM equivalents. However, once prepared and analyzed, they may be used in the same manner as SRMs and NTRMs. This option, in addition to NIST SRMs and NTRMs, further increases the SGC's flexibility in establishing traceability.

However, the use of GMISs in the traceability chain increases the amount of analysis required because it introduces an additional step. In addition, the analytical procedures for GMISs are more rigorous than those for EPA protocol gases. The current version of the protocol (EPA, 1997a) sets additional requirements for GMISs:

- A candidate GMIS must be analyzed on at least three separate dates that are uniformly spaced over at least a 3-month period.
- For each analysis, the 95-percent uncertainty of the concentration for the candidate must be less than or equal to 1.0 percent of the mean concentration.
- The analyst must calculate the overall mean estimated concentration and the 95-percent uncertainty using the protocol's statistical analysis procedures or equivalent statistical procedures.
- If the 95-percent confidence intervals for the analyses overlap, the candidate GMIS can be considered to be stable.
- A GMIS must be recertified every 2 years.
- Each GMIS candidate cylinder must be certified; unlike NTRMs, they are not assumed to be homogenous as a batch.

The use of GMISs for the analysis of EPA protocol gases was recognized explicitly by EPA's Acid Rain Program (EPA, 1993):

> …The EPA regulations define a 'traceable' standard as one which 'has been compared and certified, either directly or via not more than one intermediate standard, to a primary standard such as a … NBS [gaseous] SRM or… [NTRM]. Certification of a working standard directly to a SRM or [NTRM] primary standard is, of course, preferred and recommended because of the lower error. However, an intermediate reference standard is permitted, if necessary. In particular, a Gas Manufacturer's Intermediate Standard … that has been referenced directly to a SRM or a [NTRM] … is an acceptable intermediate standard and could be used as the reference standard on that basis...

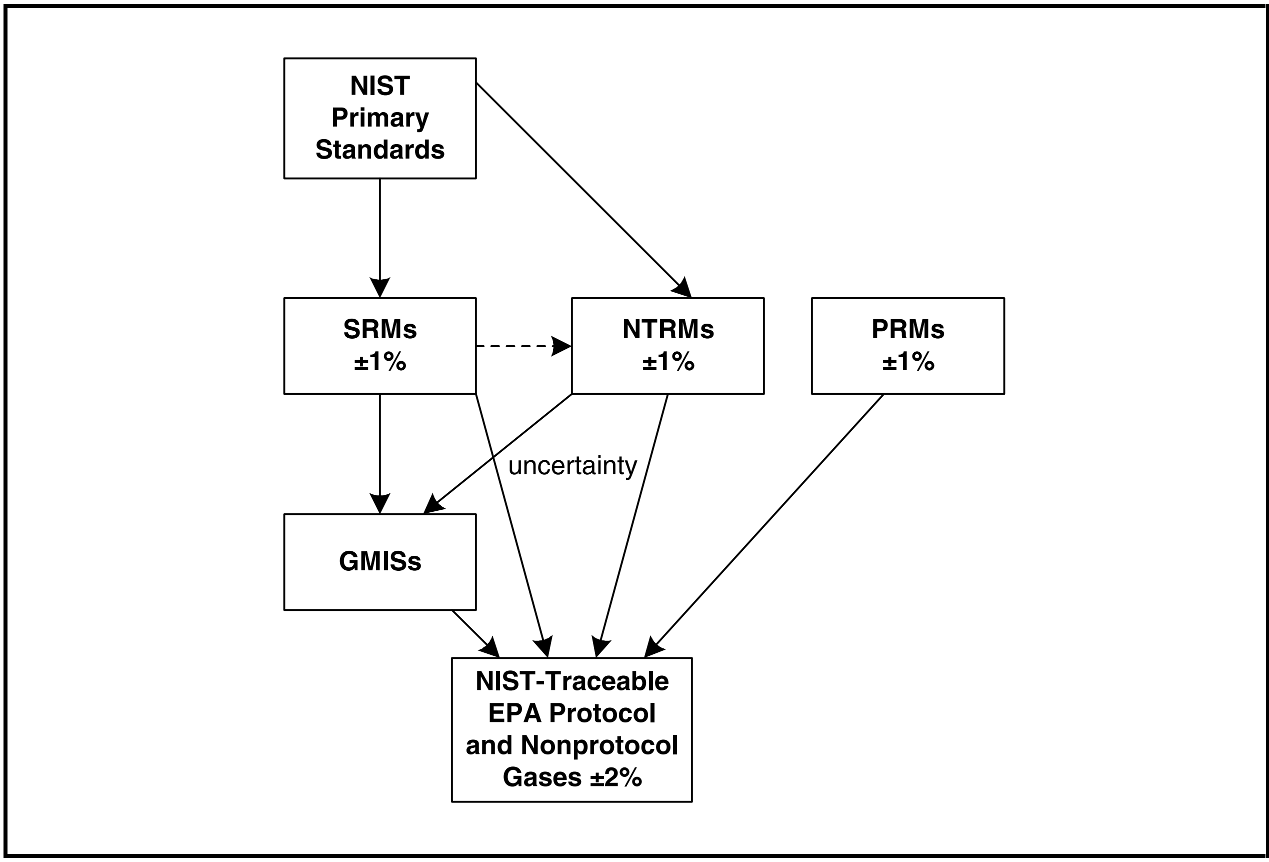
Although specialty gas producers may use GMISs to analyze candidate EPA protocol gases, the use of these standards adds uncertainty to the overall uncertainty of EPA protocol gases.

Although specialty gas producers may use GMISs to analyze candidate standards, the use of these intermediate standards adds to the overall uncertainty of EPA protocol gases. When an SRM, NTRM or, rarely, an SRM-equivalent Nederlands Meetinstituut (NMi) Primary Reference Material (PRM) is used to analyze a candidate, uncertainty arises from the analytical reference standard, from the analyzer's multipoint calibration curve, and from the measurement of the candidate. Figure 2-1 presents a simplified example of establishing traceability. The Acid Rain Program requires EPA protocol gases to have an uncertainty of ±2 percent; SRMs, NTRMs, and PRMs generally have an uncertainty of ±1 percent or less. If a producer elects to use GMISs, it must use much more rigorous analytical procedures to reduce the uncertainty of each of the two analytical steps in the traceability chain from NIST to the candidate gas mixture. However, because of the additional step in the traceability chain, gases certified using GMISs have greater uncertainty as compared to that of gases certified using NTRMs or SRMs.

2.3 THE REFERENCE GAS SUPPLY CHAIN

Figure 2-2 illustrates the NIST-traceable reference gas supply chain implied in the previous two sections of this section. The supply chain includes NIST, SGCs, and a wide variety of governmental and industrial end users. For the discussions in this section, NIST-

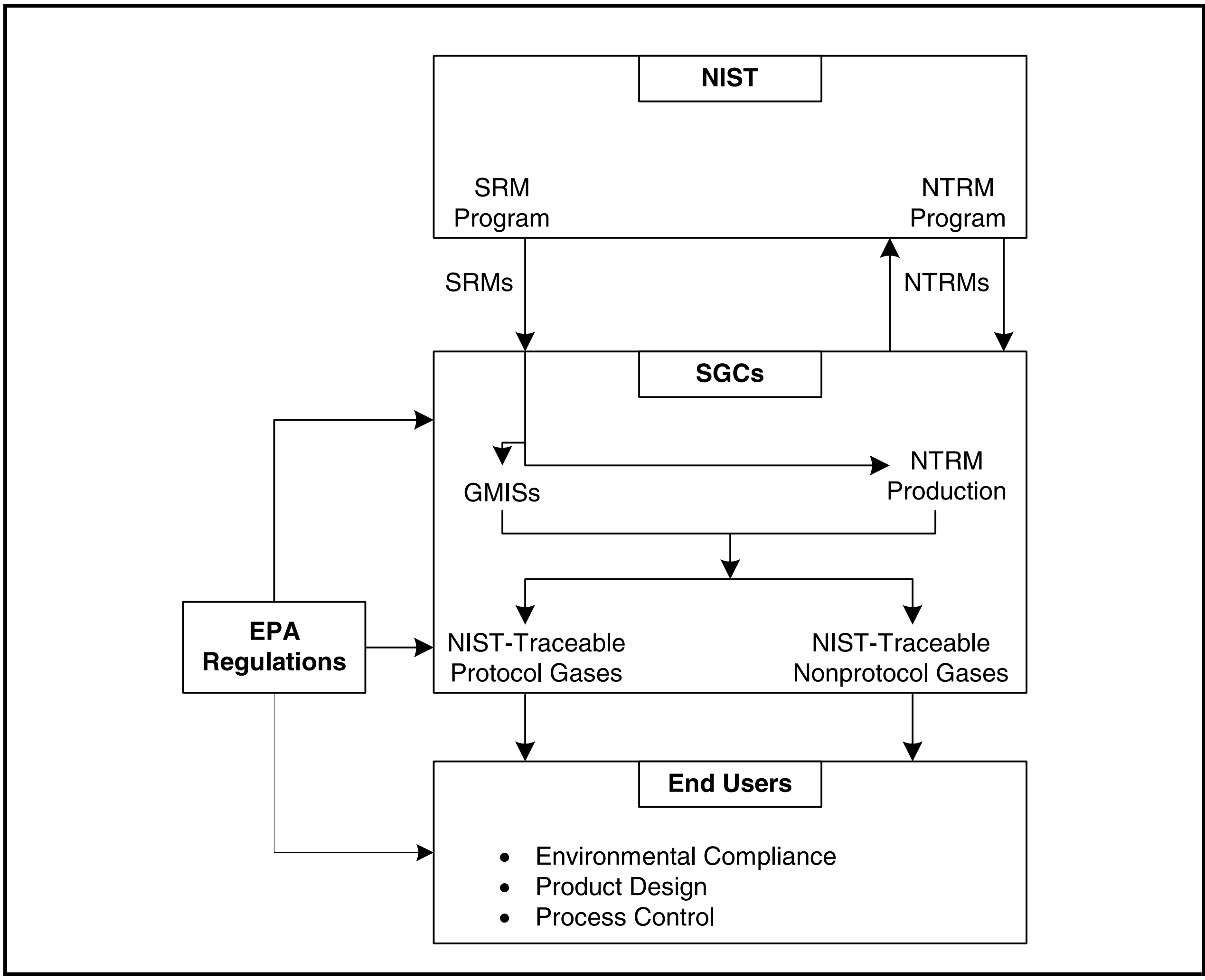
Figure 2-1. Simplified Example of Traceability Chain to NIST Primary Standards
Because NTRMs are compared directly to the NIST primary standards, their accuracy is comparable to that of an SRM. GMISs add an additional step into the production of NTGs.



traceable gas mixtures for consumer end uses are segmented into two general categories: EPA protocol gases that are required to be NIST traceable and nonprotocol gases that are also NIST traceable.

This section completes the overview of the NTRM program by quantitatively investigating how the NTRM program increases the supply of NIST-certified standards and characterizes the demand for NTGs in terms of end-use applications and consumer preferences. The following background information has two purposes. The first is to demonstrate how the NTRM program supports SGC's current NTG production. Second, this information forms much of the foundation used to inform the counterfactual scenario of the absence of the NTRM program to be presented in the next section.

Figure 2-2. NIST-Traceable Gas-Mixture Supply Chain[a]



[a]Not illustrated in Figure 2-2 are the number of SRMs and small number of NTRMs that are sold directly to end users or the sale of NTRMs between SGCs.

2.3.1 SGCs

Gas-mixture reference gases are a segment of the specialty gas market, which is part of the larger industrial gas industry. Specialty gases are distinguished from industrial-grade gases by the more meticulous blending and testing processes used in their production, certification, and analysis. Producers expend resources to verify and certify the raw materials used in producing the gas and to analyze the gas's storage medium. Among specialty gases, gas-mixture NTRMs are considered high-end because of rigorous testing conducted by SGCs on the NTRM both in-house and at NIST. As discussed earlier, once certified by NIST, NTRMs are the functional equivalents of SRMs.

Gas-mixture reference gases are a segment of the specialty gas market, which is part of the larger industrial gas industry. Most industrial gases are produced in large volumes and undergo only the quality assurance needed to ensure compliance with quality specifications and/or legal requirements. Examples of industrial gases include acetylene for welding and medical breathing oxygen.

In this study, the term "SGCs" refers primarily to the nine firms actively participating in NIST's NTRM program. These firms are listed in Table 2-2 along with the total sales and employment figures for each entity. It is important to note that the EPA protocol gases, NIST-traceable nonprotocol gases, or other NTRM-supported products may be a small percentage of the total annual revenues for some of these firms. SGCs also produce a broad spectrum of certified reference gas mixtures that are not NIST-traceable. However, their other specialty-gas operations benefit from the breadth of professional experience and financial resources that accompany being a division of a large corporation. For example, industry experts acknowledge that the technical expertise and strict analytical requirements associated with participation in the NTRM program create knowledge and quality spillovers that enhance SGCs' other gas-mixture product lines.

Table 2-2. SGC Participating in the NTRM Program
Nine SGCs actively participate in the NIST NTRM program.

SGC	Parent Employment	Parent Sales (millions)
AGA Gas, Inc., a unit of Linde AG (Germany)	46,400	$7,900
Air Liquide America Corp., a unit of L'Air Liquide S.A. (France)	30,300	$7,626
Air Products and Chemicals, Inc.	17,800	$5,717
Airgas, Inc.	7,600	$1,629
BOC Gases, Inc., a unit of The BOC Group plc (U.K.)	43,171	$5,556
Praxair, Inc.	24,271	$5,158
Matheson Tri-Gas, Inc., a unit of Nippon Sanso Ltd. (Japan)	1,638	$181
Scott Specialty Gases, Inc.	600	$100
Spectra Gases, Inc.	132	$25

Sources: Hoovers, Inc. 2002. [Online computer file.] Available at <www.hoovers.com>.
American Business Corporation (ABI). 2002. American Business. [Computer file.]

The market for EPA protocol gas mixtures is very competitive because of the stringent analytical requirements all firms must meet to confirm that their products are NIST traceable. Consequently, product differentiation is minimal, and substitutes for one firm's NIST-traceable product are readily available from other SGCs. According to SGCs, end-user consumption decisions are therefore typically based on established business relationships or previous experience with a supplier. Timeliness of delivery and availability are the key product characteristics that distinguish suppliers of NIST-traceable gas mixtures.

2.3.2 NIST-Traceable Reference Gases

For this study, we group gas-mixture reference standards that are supported by the NTRM program into four categories:

- NTRMs,
- GMISs,
- EPA protocol gases, and
- other NTGs.

Table 2-3 compares some general characteristics of the four available types of calibration standards. It is not intended to present all significant differences among the standards. However, it does depict the differences between commercially available standards. In general, standards with lesser uncertainty are more expensive and more difficult to obtain than are standards with greater uncertainty.

Table 2-3. Calibration Standards
In the market for NIST-traceable gas-mixture calibration standards, cost and uncertainty are inversely related.

Characteristics of Calibration Standard	Vendor	Certification by	Traceability to	Batch Size	Uncertainty (%)	Availability	Cost
SRM	NIST	NIST	NIST	50+	±1	Very limited	Highest
NTRM	Producer	NIST	NIST	10+	±1	Limited	High
EPA Protocol Gas	Producer	Producer	NIST	Varies	±1 to 5+	Good	Moderate
Producer-Certified Standard (GMIS, other NIST traceables)	Producer	Producer	Producer	Varies	±1 to 10+	Good	Lowest

NTRM Production Levels

Section 2.1 provided an overview of the NTRM program, including the requirements that SGCs must meet for submitting NTRM batches to NIST and NIST's NTRM certification process. This discussion reviews NTRM use and provides historical production statistics. To illustrate the program's role in increasing the supply of NIST-certified reference material, SRM sales statistics for the same period are also presented.

SGCs primarily use NTRMs in two ways: to produce EPA protocol gases and other NTGs and to generate revenue by offering them for sale on the open market. Although some are sold, about 95 percent of the NTRMs are used in-house to produce EPA protocol gases, GMISs, and other NTGs. The actual "market" for NTRMs is negligible. NTRMs are used to generate the calibration curves that are needed in the naming of EPA protocol gases, GMISs, and other NTGs.

NTRMs are used mostly as a captive supply of reference standards: they are rarely sold on the commercial market but are instead used in-house to produce other products. When NTRMs have been sold, the average price is approximately $3,500. At that price, all the NTRMs that SGCs have produced since 1992 have a commercial value of $32.5 million.

When SGCs do sell NTRMs, it is usually to other SGCs, under very specific terms and usage agreements. Several of the SGCs that are affiliated with the NTRM program do not produce all of the species of NTRMs that they use in their analyses. In those instances where they do not manufacture but wish to obtain one or more NTRMs, they do so via contract with other SGCs. Similarly, some gas companies purchase NTRMs to manufacture their own protocol gases, opting not to directly participate in the NTRM program.

SGCs began submitting candidate NTRM batches for NIST review and certification in 1993. From 1993 through 2001, 402 batches of NTRMs were analyzed and certified by NIST, accounting for a total of 9,277 cylinders (see Tables 2-4 and 2-5). The most popular species were carbon monoxide, carbon dioxide, nitrogen oxide, and sulfur dioxide, species that correspond to testing and monitoring requirements in several EPA regulations.

To illustrate the importance of NIST-certified reference gases made available by the NTRM program, Table 2-6 lists the SRM unit sales for the same period. From 1993 through 2001, NIST's SRM Program sold 2,155 gas-mixture SRM cylinders. Because SRMs contain one-fifth the gaseous volume of NTRMs, NIST would have had to produce approximately 46,000 additional SRMs to meet the demand for NIST reference materials. NIST's capacity, however, is only about 500 gas-mixture SRM cylinders a year, or 4,500 over the 9-year period.

Table 2-4. The Number of NTRM Batches
Since the inception of the NTRM program, SGCs have submitted 402 batches of NTRMs for NIST certification.

NTRM Species	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
C_3H_8	1	1			6	3	10	12	5	**38**
CH_4	2	1			1	1	6		2	**13**
CO	3	2	6	8	14	17	12	11	2	**75**
CO_2	3		6	2	19	4	8	11	3	**56**
EtOH					5					**5**
H_2S							4	3		**7**
Natural gas					1				1	**2**
NO	3	3	23	9	4	13	10	10	9	**84**
NO_2				2						**2**
NO_x								2		**2**
O_2			6	2		20	5	5	2	**40**
SO_2	7	1	18	11	11	13	2	8	7	**78**
Total	**19**	**8**	**59**	**34**	**61**	**71**	**57**	**62**	**31**	**402**

Source: NIST NTRM program.

Table 2-5. The Number of NTRM Cylinders Certified
Between 1993 and 2001, 9,277 NTRM cylinders were certified.

NTRM Species	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
C_3H_8	15	19			122	44	184	246	105	**735**
CH_4	50	30			23	16	134		49	**302**
CO	71	60	94	137	296	395	432	262	52	**1,799**
CO_2	75		210	35	380	48	181	280	84	**1,293**
EtOH					69					**69**
H_2S							57	33		**90**
Natural gas					12				21	**33**
NO	77	77	588	229	129	245	464	170	211	**2,190**
NO_2				79						**79**
NO_x								35		**35**
O_2			134	20		363	114	84	40	**755**
SO_2	163	35	371	300	262	277	94	260	135	**1,897**
Total	**451**	**221**	**1,397**	**800**	**1,293**	**1,388**	**1,660**	**1,370**	**697**	**9,277**

Source: NIST NTRM program.

Table 2-6. Number of SRM Cylinders Sold
During the NTRM programs operation, the SRM program sold 2,155 SRM cylinders.

SRM Species	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
C_3H_8	22	23	5		22	11	13	1	13	**110**
CH_4	20	9		1	11	14	5	6	6	**72**
CO	27		1	36	13			15	7	**99**
CO_2	31	42	18		9	14	11	14	6	**145**
H_2S			25	24		28	17	14	26	**134**
NO	136	165	93	122	83	90	63	148	175	**1,075**
NO_x	5	18	2					7	8	**40**
SO_2	85	36	94	49	76	21	37	40	42	**480**
Total	**326**	**293**	**238**	**232**	**214**	**178**	**146**	**245**	**283**	**2,155**

Source: NIST NTRM program.

GMISs

By using GMISs, the number of protocol gases produced from a single NTRM can be increased by a factor of about 100. However, the additional GMIS step increases the uncertainty of the protocol gas.

GMISs are used as an in-house standard to increase the number of NIST-traceable standards that can be produced using one NTRM. By certifying a batch of GMISs against an NTRM, the SGC significantly increases the number of protocol gases it can produce while lowering its costs. For example, suppose an SGC can certify 150 EPA protocol gases using one NTRM cylinder, and it can get half as many GMISs using that same cylinder because of different analytical requirements. Because the cylinder sizes and analytical requirements for producing protocols from NTRMs and GMISs are the same, the SGC can produce the same number of EPA protocol gas cylinders (150) from the GMIS as from the NTRM. Thus, by introducing the GMIS method into the traceability chain, the SGC can reap as many as 11,250 protocol gas cylinders from one NTRM, as opposed to 150 if the protocol gases were analyzed directly using NTRMs.

However, the GMIS method increases the uncertainty of the EPA protocol gases and increases the end-users' "distance" from the NIST primary standard. Also, because NTRMs are assumed to be homogenous as a batch, and GMISs are not, protocol gases certified by GMISs are subject to the disparate data issues that accompany each cylinder. Exact production data on the number of GMIS cylinders produced annually are unavailable.

EPA Protocol Gases

Directly traceable gases are one step away from the NIST primary standard and are typically assayed using NTRMs.

This analysis refers to two classes of EPA protocol gases. The first class consists of those EPA protocol gases that have been certified directly against an NTRM or another NIST-certified standard following a written EPA protocol method. These gases are called "directly traceable" EPA protocol gases. They are one step away from the primary standard. In some instances, SRMs may be used to assay these gases should NTRMs not be available; however, it is rare. Directly traceable EPA protocol gases often have analytical uncertainty of about ±1 percent.

Indirectly traceable gases are two steps away from the NIST primary standard and are typically assayed using GMISs.

The second class is "indirectly traceable" EPA protocol gases that are traceable to NIST; however, they have been assayed via GMISs. They are, therefore, two steps away from the primary standard. As described during the discussion of GMISs, these gases are often less costly and are of higher analytical uncertainty because of the insertion of the GMIS intermediate step in the gas analysis chain. Indirectly traceable EPA protocol gases often have analytical uncertainty of ±2 percent, but it is possible that they may be categorized as ±1 percent if the SGC minimizes the uncertainty from the GMIS using rigorous analysis techniques.

Other NTGs

SGCs also produce nonprotocol but NIST-traceable calibration gases for the automotive emissions testing, ambient air quality, and other specialty markets. Although these gases are not assayed using the EPA protocol, they still meet performance standards and specifications defined by their end use. Examples include standards for automotive emissions testing, air quality testing, and custom applications.

2.4 REFERENCE GAS END USE

Specialty gas applications fall into one of four general areas: environmental, process control, manufacturing, and analytical laboratory (Gittler and Denyszyn, 2000). Some of these applications do not require NIST traceability. Users generally do not use NTGs unless legally required to do so, because the additional analytical certification increases their price. However, there are certain process and laboratory applications in which the increased accuracy of NTGs is desirable and economical.

The calibration of environmental monitoring equipment is currently the primary application for reference gases. Equipment used to assess the chemical composition of air, water, soil, and other samples must be properly calibrated using materials of known or certified values. In some cases, regulations stipulate the type, use, and quality of the reference gas and the method by which the gas is used and the machine is calibrated. Calibration ensures that the equipment is functioning properly, providing users with readings that are as accurate as possible, given an amount of uncertainty. Applications in this category include mobile source testing (i.e., cars, planes); stationary source testing (e.g., utilities, combustion boilers and turbines, chemical processes); and ambient monitoring (e.g., soil, water, and air analysis).

Specialty gas applications generally fall into the following areas:

- environmental,
- process control,
- manufacturing, and
- analytical laboratory (Gittler and Denyszyn, 2000).

Process control applications to calibrate sensitive production equipment are also a major use of reference and other specialty gases. Petroleum refineries and chemical plants use expensive and sensitive catalysts during the production process. These facilities use specialty gases to calibrate the equipment, which tracks input and end products as well as the level of impurities in the production streams. Monitoring helps protect end products' chemical composition and ensures that expensive inputs are handled properly and not needlessly wasted. A process control example is industrial boilers at oil refineries. Oxygen and carbon monoxide sensors are used to check the quality of the steam used as process heat during the manufacturing process.

In manufacturing applications, specialty gases are used during the production process as catalysts or protectants, or they may become part of the final product. In semiconductor manufacturing, gases are used to build the layers and circuitry contained on a microchip. The food and beverage industry uses specialty gases to prolong the shelf life of processed foods, and specially designed gas mixtures are used to inhibit bacterial growth and improve product appearance.

Finally, specialty gases are used at analytical laboratories as support and calibration gases for scientific experiments, research, and analysis. In this context, they serve as support gases (such as carriers and fuel) for gas chromatography, optical spectrometry, spectroscopy, and other instruments and techniques (Gittler and Denyszyn, 2000). Calibration gases are used for quality control and quality assurance. The type of gas used is not generally mandated by law but by the requirements of the end user.

NIST-Traceable Applications. NTGs supported by the NTRM program are most frequently used in environmental monitoring and analytical laboratory applications. Of these, industry experts estimate that at least 70 percent are used for environmental applications. Manufacturing and process control applications tend to incorporate producer-certified gases because the acceptable range of uncertainty may be wider. They are also not required by law to use more expensive NTGs. Environmental and analytical laboratory applications, on the other hand, often follow regulatory guidelines established by federal, state, and local agencies.

Decisions about which gases to use in process control and manufacturing applications are independent business decisions. Where there is no legal mandate, plants and laboratories must balance economic, scientific, and quality motives (quality/grade vs. price) when selecting the appropriate gas (Gittler and Denyszyn, 2000).

2.4.1 End Use by Industry

End users of NTGs fall into four major consumer groups: electric utilities, petrochemical firms, transportation equipment firms, and government agencies and independent organizations. Although firms that do not fit into these groups may purchase NTGs from time to time, the members of these consumer groups are the principal buyers. Table 2-7 provides an overview of the various applications that NTGs are used for by different consumer groups.

Table 2-7. Principal End-Use Markets for NTGs

	Electric Utilities	Petrochemical Firms	Transportation Equipment Firms	Other Firms	Government Agencies and Independent Organizations
Stationary source monitoring					
CEMS calibration (regulated)	X				
CEMS calibration (voluntary)		X	X	X	
Ambient monitoring					
Ambient air, soil, and/or water monitoring	X	X			X
Mobile source monitoring					
Emissions testing equipment calibration (autos)			X		X
Product development and testing					
Product design and development		X	X		
Product testing		X	X		X
Process control					
Production monitoring		X	X		
Equipment monitoring		X	X		
Verify accuracy of third-party standards	X	X	X	X	X
Verify equipment calibration	X	X	X	X	X

Electric Utilities

End users of NTGs fall into four major user groups:
- electric utilities,
- petrochemical firms,
- transportation equipment firms, and
- government agencies and independent organizations.

The electric utility industry is one of the largest consumers of EPA protocol gases and other NTGs. Pursuant to regulations laid out under the EPA's Acid Rain Program, electric utilities conduct daily calibrations of their CEM systems using EPA protocol gases.

CEM systems are used to monitor the chemical composition of exhaust gases and other waste streams that are emitted to the environment during electricity generation. Nearly all electricity in the U.S. is generated through the combustion of fossil fuels, which release nitrogen oxides, sulfur oxides, and other pollutants when burned. These pollutants are the catalysts for acid rain and other forms of environmental degradation. The electric utility industry accounts for a large portion of sulfur oxides released into the environment.

Calibrating CEM systems allows utilities to accurately compile data and to monitor emissions. Accurate measurements facilitate regulatory compliance and participation in the emissions trading program. Preliminary discussions with SGCs suggest that more accurate measurements allow utilities to sell more emissions credits on the open market than they would otherwise sell, all else held the same.

The calibration materials and methods are explicitly detailed in the laws governing emissions monitoring at electricity generation plants. Many laws dictate the use of EPA protocol gases. Furthermore, if the plant is required by local or state agencies to conduct ambient air, soil, or water monitoring, it may be required to do so using NTGs. The following sections in this report present further discussion of electric utilities' and other firms' obligations under the Acid Rain Program and other environmental programs and the role NTGs play in those programs.

Petrochemical Firms

Like the electric utility industry, petrochemical firms use NTGs to calibrate CEM and ambient monitoring systems; they also use them to monitor delicate production processes and equipment. Oil refineries and chemical plants must comply with a suite of environmental regulations, many of which require measurements that are traceable to NIST. Furthermore, research and development divisions conduct sensitive analyses during product development, and enhanced measurement accuracy aids in the analysis of product testing. Online analyzers monitoring input streams may be calibrated with NTGs to more effectively track impurities and verify product quality. Petrochemical firms use both EPA protocol gases and nonprotocol gases. They may also purchase NTGs to verify the quality of third-party standards.

Transportation Equipment Firms

Transportation equipment firms use NTGs in the engine design and development process. Original equipment manufacturers (e.g., Ford, General Motors, DaimlerChrysler) and suppliers (e.g., Dana, Johnson Controls, Delphi, TRW) use these gases to verify that the engines they are designing meet both product and environmental emissions standards. These firms are not required to use EPA protocol gases, but commonly use both SRMs and NTRMs to verify engine functions.

Government Agencies and Independent Organizations

Government agencies and independent organizations, such as auditors and nonprofit research organizations, purchase NTGs to calibrate environmental monitoring equipment, to verify calibration, and to check the quality of third-party standards.

State, local, and federal agencies maintain ambient air, soil, and water or emissions monitoring systems, among others, to protect the public health and the environment. Independent organizations may operate monitoring systems in a watchdog capacity or as part of an environmental audit or research. As with utility and petrochemical monitoring systems, these systems must be properly calibrated for readings to be credible. In particular, NIST traceability may be required if monitoring is used to identify environmental law violations and support litigation.

Calibration of automotive emissions testing equipment is another example of government applications. Many regulatory authorities require automobile emissions testing, both during the mobile source design phase and during post-consumer operation, such as IM240 and BAR90 (see Table 2-8). In the post-consumer area, auditors may use NTGs to verify that the emissions testers are functioning properly. They also may be using those gases to verify that a third-party gas they are using for calibration is sufficiently accurate.

Table 2-8. Examples of Metropolitan Areas Conducting Post-Consumer Emissions Testing
This list was produced as of 2000 and is not intended to be exhaustive.

State	Metropolitan Areas
Alaska	Anchorage and Fairbanks
Arizona	Phoenix and Tucson
California	Statewide
Colorado	Denver-Boulder and Ft. Collins-Colorado Springs
Connecticut	Statewide
Delaware	Statewide
District of Columbia	Citywide
Georgia	Atlanta
Idaho	Boise
Illinois	Chicago and East Saint Louis
Indiana	Chicago and Louisville
Kentucky	Louisville
Maryland	Baltimore and D.C. area
Massachusetts	Statewide
Missouri	Saint Louis
Nevada	Reno and Las Vegas
New Jersey	Statewide
New Mexico	Albuquerque
New York	Statewide
North Carolina	Charlotte, Raleigh-Durham, and Greensboro-Winston-Salem
Ohio	Cleveland-Akron and Dayton-Springfield
Oregon	Portland
Pennsylvania	Philadelphia and Pittsburgh
Rhode Island	Statewide
Tennessee	Memphis and Nashville
Texas	Dallas-Ft. Worth, El Paso, and Houston
Utah	Salt Lake City, Provo, and Ogden
Vermont	Statewide
Virginia	D.C. area
Washington	Seattle, Tacoma, Spokane, and Vancouver
Wisconsin	Milwaukee and Sheboygan

2.4.2 End Use by Analytical Accuracy Demanded

A second important dimension of the market for reference gases is the level of compositional uncertainty, which is reflected in the stated or guaranteed certification accuracy. This section describes the demand for NIST-traceable standards by the level of accuracy demanded and NIST traceability.

Current SRM Users (Ultrahigh Accuracy Demanders)

Users currently purchasing SRMs for design activities would continue to purchase them in the absence of the NTRM program.

The customers with the highest need for calibration accuracy in reference gases typically purchase gas and gas-mixture SRMs directly from NIST to ensure that they are obtaining the best possible accuracy. These organizations benefit indirectly from the current NTRM system because of faster turnaround and easier availability of SRM cylinders due to decreased demand for SRMs.

In addition to SGCs, important examples of this type of purchaser are the Big-Three automakers, whose automobile and light truck designs must meet EPA tailpipe emission standards. A failure of an engine to meet the required standards could force a redesign that would cost hundreds of millions of dollars. Likewise, design allowances to cover avoidable uncertainties in the concentration of reference standards would create cost and performance penalties in the vehicle, which would also be prohibitively costly.

In the absence of the NTRM program, the automotive industry would continue to demand SRMs, and their high willingness to pay (WTP) means that they would likely obtain SRMs in any likely allocation scheme, either by entering the queue quickly and repeatedly or by repurchasing SRMs bought by those at the front of the queue. From a methodological standpoint, we therefore consider all end users now purchasing SRMs directly from NIST to be these high demanders. We will net out their purchases from the total capacity in determining counterfactual market equilibrium (as described in Section 3).

Purchasers of High-Accuracy Gases

In the current NTRM program, SGCs produce a large number of gases and gas mixtures that they certify to have ±1 percent relative accuracy. These are produced primarily from NTRMs. Included in this category are most of the products sold as “EPA Protocol” and “EPA Methods” gases. As the names suggest, the purchasers of these products are primarily firms that are required to show NIST traceability for emissions monitoring. They may demand the high accuracy to support emissions trading, to allow operation as close as possible to optimal conditions, or to inspire maximum confidence in their calibration results. For the remainder of this study, we will refer to high-precision, low uncertainty gases produced by SGCs using NTRMs as **directly traceable gases**.

Users of directly traceable gases would be most affected in the absence of the NTRM program. As we explain in Section 3, the reduced supply of these gases would mean that they would have to switch to indirectly traceable gases; their counterfactual behavior is of the most interest for this study.

Lower-Accuracy Gas Users

A third class of reference gas users, less demanding than the first two, requires a lower level of certified compositional accuracy. The SGCs make a variety of products for these users, certified to have no more than 2 percent relative uncertainty; we call these **indirectly traceable gases**. For example, BOC sells a line of this type of gas that they call "CEM Calibration Standards" (BOC, 2000). In most cases, these products are certified with reference to GMISs rather than from NTRMs; if the GMIS is named to an SRM or NTRM, the gases are still NIST traceable.

Examples of these users include petrochemical firms as well as electric utilities that are not trading SO_2 allowances. As detailed below in the counterfactual scenario described in Section 3, the supply of these calibration gases would be relatively unaffected in the absence of the NTRM program.

3 Methodology

This section presents the economic and analytical methodology for determining the benefits of the NIST Gas-Mixture NTRM program. This document provides the conceptual foundation and identifies the data needs for surveys of SGCs and selected end users.

Section 3.1 details the economic rationale for the NTRM program, focusing on economic benefits generated by government involvement. In Section 3.2, the counterfactual is specified that represents the likely state of the market for high-accuracy calibration gases in the absence of NIST involvement. This counterfactual forms the basis for technical and economic impact metrics that are presented in Section 3.3. Details of our estimation approach are presented in the last section.

3.1 ECONOMIC RATIONALE FOR NIST INVOLVEMENT

In many ways, the use of SRMs and NTRMs in the reference gas supply chain is essential in that it provides a well defined traceability to existing primary standards for chemical measurements. EPA recognized the expertise and scientific stature of NIST by writing traceability requirements into most of their current regulations for stationary source, mobile source, and ambient air monitoring. As a result, NIST's provision of SRMs and certification of NTRMs now represents an important component in the supply chain infrastructure of many U.S. industries and some governmental organizations. In return, the EPA regulations created an unprecedented demand on NIST's laboratory to produce gas mixtures to support end users' needs for traceability.

This produces a fundamental difference between the NTRM program and many other NIST activities, which are aimed at providing standards infrastructures and other public goods. The value of these initiatives lies primarily in eliminating market failures or increasing spillovers and other positive externalities. In the NTRM case, however, the benefits provided by NIST's activities are subsumed in the supply chains of the purchasing organizations.

If the NIST program that certifies traceable standards was a private enterprise, it would set prices sufficiently high to maximize profits given the development and production costs. A great deal of end users' WTP could be appropriated by the producer of the SRMs. An economic analysis of the NTRM program would not be necessary to establish its social value (although such a study could capture spillovers not appropriated by NIST). The mere existence of each reference gas product would be a strong indication that private (and thus social) benefits exceed the costs. If this were not the case, the reference gas in question would not be offered for sale.

This study undertakes the task of valuing the contribution of one step in a supply chain, albeit one of unusual importance in affecting the quality of the final products.

But NIST is not a profit-maximizing firm and sets prices to cover only its development and operating costs. Thus, this study undertakes the task of valuing the contribution of one step in a supply chain, albeit one of unusual importance in affecting the quality of the final products. The use of a counterfactual will allow us to isolate these evident and quantifiable benefits by comparing the current state of the world to a hypothetical one in which the NTRM program does not exist. In this counterfactual world, we would observe higher costs and excess demands that would appear to be market failures.

3.1.1 Effect of Constraints

EPA regulations are the most important factor driving the demand for NTGs. The analysis supporting EPA's requirements for NIST traceability are not available to us, but we must assume that they show a net benefit for social welfare in the U.S. By implication, we also assume that these benefits outweigh any negative consequences from the large increase in the demand for NIST-traceable reference gases created by the regulations. We therefore consider the regulatory demand as an exogenous, binding *constraint* on the markets for calibration gases. Given this exogenous demand, NIST's actions can help avoid market failures by reducing equilibrium costs in this constrained system and allowing markets to clear by providing for expanded supply.

For this analysis, market failures are viewed as factors leading to the inefficient allocation of resources within a fixed set of constraints. In this context, constraints are exogenous factors over which market participants have no influence, at least in the short run. The main constraints influencing the market for EPA protocol gases and other NTGs are categorized as follows:

- resource constraints (availability of SRMs)
- production technology constraints (technology determining the process for converting SRMs into EPA protocol gases)
- regulatory constraints influencing demand (EPA mandates traceability to NIST primary standards)

The resource constraints are primarily those within NIST itself. The Gas Metrology and Classical Methods group in the CSTL has extensive expertise in measurement technology and analytical methods, but it is not a manufacturing operation. Their primary mission to advance the science of metrology becomes strained by the need to certify SRMs for industry use. Increasing demands on their capacity, such as those created by the emissions trading provisions of the Acid Rain program, would threaten their ability to perform their core function. As a result, the gas metrology group has indicated to RTI that their supply would be limited to 500 SRM cylinders per year without the NTRM program.

Production technology constraints relate to the process by which SGCs produce directly traceable EPA protocol gases. To certify the composition and relative accuracy of a batch of gas-mixture cylinders, the producing firms must analyze samples of candidate cylinders alongside an SRM or NTRM of known uncertainty. Because this consumes a portion of the standard mixture, the number of cylinders that can be certified in this way is limited. One of the objectives of the SGC interviews will be to determine the severity of this production constraint, which will be an important factor in our estimate of counterfactual supply.

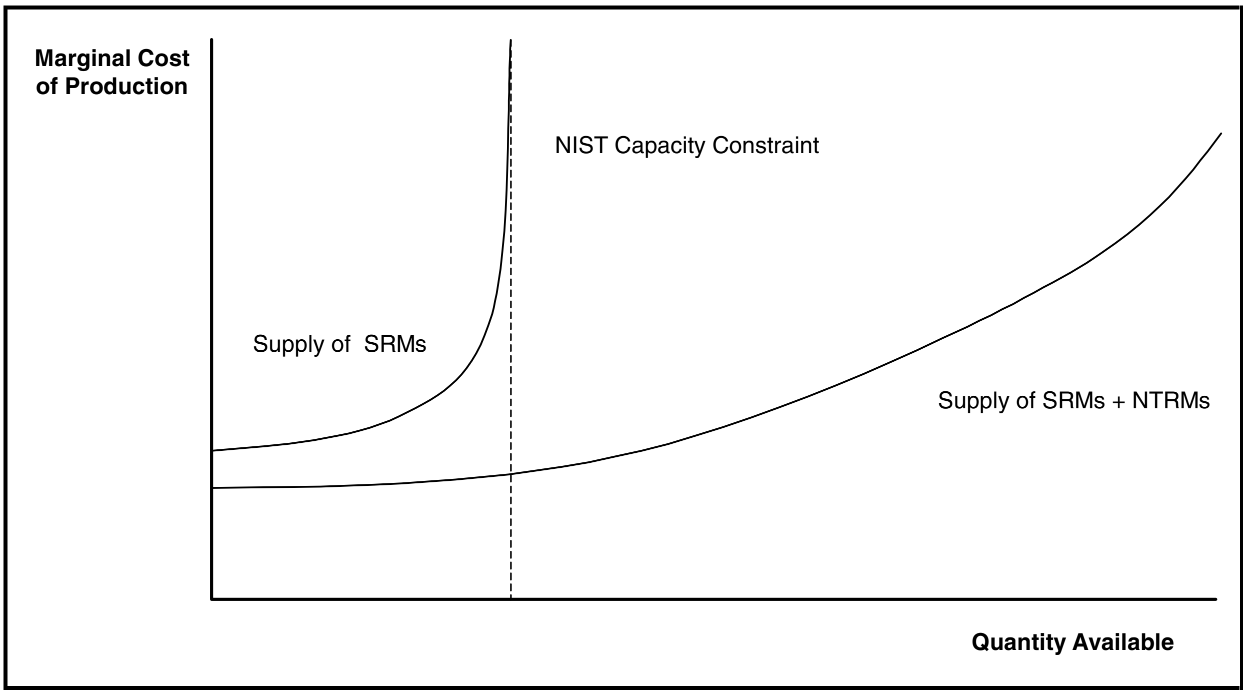
Regulatory-demand constraints established by the EPA and other government agencies have been discussed above and are incorporated into our economic analysis in several different ways, particularly in determining the demand for the various reference gases. As mentioned before, we will maintain the assumption that the requirements by EPA for NIST traceability would not be relaxed in the absence of the NTRM program.

3.1.2 Role of the NTRM Program

It is assumed that the requirements by EPA for NIST traceability would not be relaxed in the absence of the NTRM program.

In light of the constraints discussed above, the primary role of the NTRM program is to facilitate the supply of directly traceable EPA protocol gases, given fixed SRM production and EPA regulations. The NTRM program does this by working with SGCs to create the infrastructure needed to lower the cost and increase the production capacity of NIST-traceable reference materials. As shown in Figure 3-1, the NTRM program shifts out the supply curve representing the technology production function for NTGs.

Figure 3-1. Illustration of Potential Supply Impact of NTRM Program



3.1.3 Potential Market Failures

The potential market failures being addressed by the NTRM program are directly associated with the production of EPA protocol gases from SRMs. Table 3-1 lists the three major market failures addressed by the NTRM program.

Table 3-1. Three Major Market Failures Addressed by the NTRM Program

Potential Market Failure	Role of NTRM Program
Supply limitations on NIST-traceable reference gases force demanders of high-accuracy calibration gases (directly traceable gases) to accept lower accuracy products (indirectly traceable gases)	NTRM program allows SGCs to produce high volumes of directly traceable gas from certified NTRM batches
R&D needed to develop new EPA protocol gas production technology exceeds resources of individual SGCs and returns may not be appropriated by individual firm	NIST's unique position to provide low-cost, highly technical solutions to the problem of mass production of directly traceable gases
A small group of companies monopolizes a scarce resource (SRMs) and becomes the oligopolistic suppliers of EPA protocol gases	NTRM program counterbalances SRM resource constraints by increasing production capacity and flattening marginal cost curves, thus eliminating market power for individual firms

1. Capacity constraints within NIST limit the number of SRM batches that can be prepared and certified within a given period of time. By allowing SGCs to produce batches of the gas mixtures and restricting NIST's necessary role to that of interpreting analytical results and testing a small number of cylinders, the NTRM program significantly expands supply of high quality (accuracy $< \pm 1$ percent relative) reference gases. These, in turn, can be used to meet end users' demand for directly traceable calibration gases.
2. The private sector may not have the resources or incentives to provide the infrastructure or technologies needed to enhance the production process linking SRMs to EPA protocol gases. Through NIST's unique expertise and certification capabilities, the cost of providing directly traceable materials is greatly reduced. Whereas enhancements to other production processes (such as improving the quality of indirectly traceable gases) are the potential alternative to the NTRM program, it is unlikely that an individual SGC would have the resources to develop alternative technologies. In addition, technology spillovers may affect their returns to innovation, further limiting the probability of investment in these areas. Similarly, several experts have expressed reservations about whether new processes for significantly expanding the number of directly traceable gases that can be produced from a single SRM are technically feasible in the near future. Thus, this may be an area in which the public sector has a technological advantage leading to a lower production cost.
3. The market for EPA protocol gases and its competitive structure have also been changed by the NTRM program. The absence of the NTRM program would increase the potential for imperfect markets where SGCs could exploit

the limited supply of SRMs. Given the constraints, there is a strong potential that a small group of companies monopolizing the scarce resource (SRMs) could become oligopolistic suppliers of EPA protocol gases. This could result in substantial economic inefficiencies in a market characterized by highly inelastic demand due to regulatory mandates.

3.1.4 Additional Economic Benefits from the NTRM Program

We anticipate that a large part of the economic benefit of the NTRM program will come from preventing market failure and eliminating negative market impacts from the constraints discussed above. However, we also qualitatively examine in our surveys additional benefits conferred by NIST. These are a result of the valuable technical skills possessed by the scientists in the Gas Metrology and Classical Methods laboratory of NIST's CSTL and the freedom to apply these skills brought about by the NTRM program's "outsourcing" of reference material production and characterization. Two of these potential benefits are briefly discussed below.

Timely Development of New Methods and Products

The scientists in the gas metrology group at NIST stay at the forefront of research into gas metrology, analytical methods development, storage stability, and a number of other critical technology areas. They also maintain strong working relationships with regulators at EPA and other government agencies whose rule making and compliance assessment depend on the accuracy of calibration and reference gases. As a result, these NIST resources often develop knowledge about reference gas products that will be needed by end users in the future. They are therefore able to lead the process to develop new SRMs or NTRMs in a timely manner.

An example is the low-level NO standards soon to be required in large volumes by utilities and other regulated end users. The reactivity of NO with a wide variety of metals creates instability in storage and thus degradation over time. NIST scientists have been working with SGCs to develop a robust system of formulation and storage that will allow the necessary uncertainty levels to be certified by the producers. These complications have added to the already considerable lead times required to create a new NTRM (or SRM); without the early involvement of NIST, it is unlikely that suitable reference materials would have been created on the timeline required by EPA's regulations.

Provision of Low-Demand Species of Reference Gases

As a not-for-profit organization within NIST, the gas metrology group is free to develop and produce products that they consider important, even if there is low current demand. These products would not be requested by the SGCs in the absence of the NTRM program and could not be developed if the NIST group were forced to produce SRMs at maximum capacity. Nonetheless, these species are important in supporting other work within NIST, research requests from outside laboratories, and anticipated future metrology needs. Whereas it is beyond the scope of this study to quantify benefits from this type of work, these low-demand species supporting basic research may yield significant economic benefits in the future.

3.2 COUNTERFACTUAL WORLD WITHOUT NTRMS

To quantify the economic benefit of the gas-mixture NTRM program, we will compare the *actual* situation of producers and customers of NTGs to a *hypothetical* scenario in which the NTRM program does not exist. In the absence of the NTRM program, SRMs would be the only reference gases produced in coordination with and certified by NIST. Any SGC that wished to produce NIST-traceable calibration gases would need to certify them against SRMs purchased from NIST. This section develops this detailed counterfactual world and describes supply, demand, and equilibrium conditions that would arise.

Admittedly, the construction of a counterfactual scenario is a synthetic exercise; it is difficult or impossible to fully describe a situation that does not exist with a high degree of confidence. Nevertheless, with the large amount of data that we will collect and by using sound economic theory and logic, we can assemble a hypothetical scenario that should seem reasonable to most observers. The issue of the usefulness of counterfactual analysis, although debated extensively throughout the 1960s and 1970s following Robert Fogel's (1979) work on railroads, was largely settled following Fogel's 1979 address to the Economic History Association.

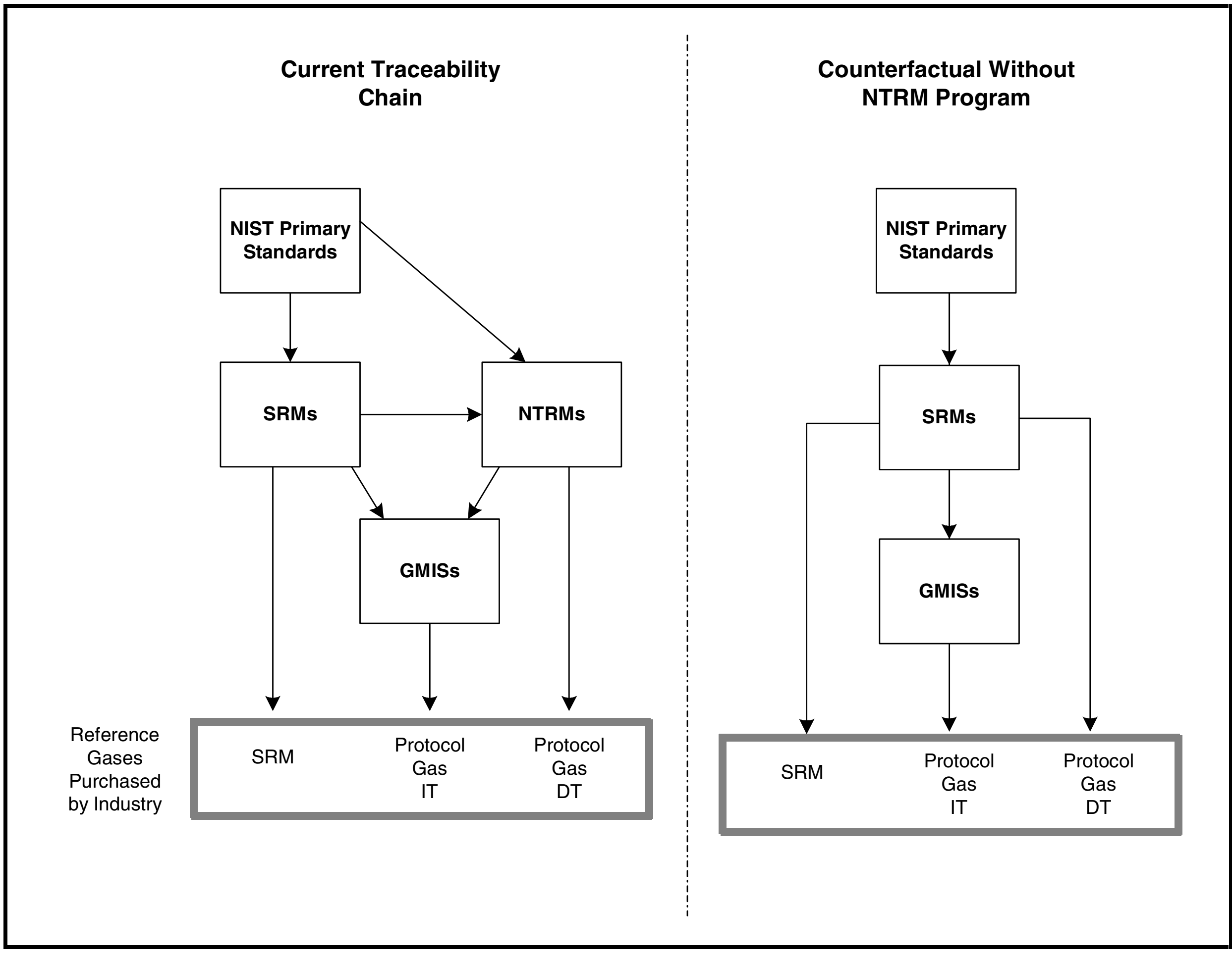
3.2.1 Specifying the Counterfactual

Specifying the counterfactual scenario is essential to determining the information that will be needed to estimate the social benefits of the NTRM program. We will need to characterize the supply and demand of all the major categories of reference gases, propose market structures and mechanisms, and examine changes over time.

A key part of this characterization is an understanding of changes to the supply chain that would occur in the absence of the NIST program. A conceptual diagram of the current and counterfactual supply chains is shown in Figure 3-2. Since the inception of the gas-mixture NTRM program, NIST has certified two types of low-uncertainty reference materials: SRMs that they characterize and market in-house and NTRMs that are produced and characterized by an SGC, then analyzed and certified by NIST. Either SRMs or NTRMs can be used to certify GMISs for use in the production of indirectly traceable gases, while NTRMs are used to directly characterize gases.

In the absence of NTRMs, SRMs would be the only materials certified by and traceable to NIST. To meet the low-uncertainty requirements, directly traceable gases would need to be certified directly to an SRM, while indirectly traceable gases could be made from a GMIS as before. The GMIS, in turn, would have to be characterized with reference to a parent SRM. As the diagram illustrates, SRMs would emerge as a major bottleneck in the infrastructure supply chain. This general proposition was shared with SGC representatives at the 2001 Pittcon meetings in New Orleans, and it was agreed that this was a fair assessment of the situation that would emerge without the NTRM program. The remainder of this section sets out the economic implications of this counterfactual supply chain modification.

Figure 3-2. Conceptual Approach for Estimating Economic Impacts of the NTRM Program



Note: DT: directly traceable.
IT: indirectly traceable.

3.2.2 Supply-Side Considerations

Supply of SRMs

NIST representatives have told us that they could produce and certify up to 500 gas-mixture SRM cylinders per year, a quantity in excess of current and historical totals but within their current total certification capacity.

The analysis does not consider the substitution of equivalent standard materials from other countries. The activities required in establishing such a linked certification would likely require an amount of effort similar to that invested in the NTRM program, and the available certification capacity would not likely be greatly different from that of NIST.

Also, the method of selling and distributing SRMs should have no impact on the resulting equilibrium. After a period of adjustment, the resulting production of reference gas standards would be sequenced in decreasing order of end users' WTP, whether priority was established by a queuing system such as that used now or by some type of market mechanism. High demanders with the highest WTP would most likely saturate the queue with requests for SRMs to ensure that they receive them.

Supply of Indirectly Traceable Reference Gases

In the absence of the NTRM program, the supply function for indirectly traceable gases would be minimally affected. GMISs would still be used as the reference standards to produce indirectly traceable gases; the only difference would be that GMISs would be assayed using SRMs rather than NTRMs. As discussed in Section 5, the use of SRMs in the production of GMISs slightly increases the cost of indirectly traceable gases.

Based on discussion with SGCs, the supply of indirectly traceable gases with or without the NTRM program is "virtually unlimited." Thus, under the counterfactual, there would be no shortage of indirectly traceable EPA protocol gases available for compliance with environmental regulations. This is because the number of indirectly traceable cylinders that can be certified from each GMIS is large enough that the entire market could be served with a small number of SRMs.

In order to verify/quantify the economic impacts of the counterfactual scenario for the production of indirectly traceable gases, the SGC surveys are used to

- Confirm that GMISs can be certified against SRMs as easily as they can against NTRMs and that distributional issues would not hinder production of indirectly traceable gases.
- Determine how many cylinders of indirectly traceable gas can be made from one GMIS and investigate the related question of how many GMISs can be made from an SRM.

Supply of Directly Traceable Reference Gases

Because our conceptual approach and preliminary interviews suggest that the directly traceable gases would be most affected by the absence of the NTRM program, the surveys with SGCs and end users concentrate on these products. The total supply quantity of all species of directly traceable gases under the counterfactual is determined by the production constraints imposed by the limited availability of SRMs. The quantities of each specific species of reference gas available would be determined by demand from end users, based on their WTP for each product. This demand-side rationing of the market is described below in Section 3.2.3.

We have assumed throughout this conceptual process that directly traceable gases could only be made from SRMs in the absence of the NTRM program. We have no evidence that an overseas organization or technological breakthrough could or would provide comparable SRMs within this time frame.

In addition, specialty gas producers said that there is little they could do to adjust their operations in order to increase the productivity of a single SRM. They said that, at least in the near future, it was not possible to modify their production processes to allow more cylinders of calibration gas to be produced with a single SRM cylinder.

Several options for increasing the productivity of SRMs were investigated. For example,

- Currently, computer-operated gas analysis systems can be implemented for the sequential analysis of up to 20 candidate standards and 1 reference standard (Hughes and Suddueth, no date). It is not impossible, on a technical basis, that this technology could be extended to the sequential analysis of larger numbers of candidate standards.
- The volumetric quantity of EPA protocol gases and SRMs could also be increased by increasing the volume of the compressed gas cylinders. The most common cylinder size for EPA protocol gases is the Luxfer N155 aluminum cylinder, which holds 142 cubic feet of nitrogen. Gaseous SRMs come in aluminum cylinders that contain approximately 26 cubic feet of useable mixture. Luxfer also sells a N265 aluminum cylinder, which holds 244 cubic feet of nitrogen. If the larger Luxfer aluminum cylinders were used for both EPA protocol gas production and SRM production, the volume of available EPA protocol gas using only SRMs as reference standards could be increased by a factor of approximately 16 times more than the current cylinder capacities.
- The volumetric quantity of reference standard needed to analyze candidate standards could be reduced by redesigning the sampling and analytical apparatus. If the volumetric flow rate demands and dead-space volumes of the analytical instrumentation could be reduced, then the

quantity of gas needed for an analysis could be reduced. A similar redesign could be used for the field instruments that use the EPA protocol gases for calibration purposes. NIST's Bill Dorko points out that current instrumentation is designed for high volumetric throughput and fast response times and that the redesign effort would require considerable research and development resources.

However, SGCs indicated that none of these alternatives were feasible in the foreseeable future and that, in the absence of the NTRM program, they would most likely increase the use of GMISs to meet the demand for NTGs.

3.2.3 Demand-Side Considerations

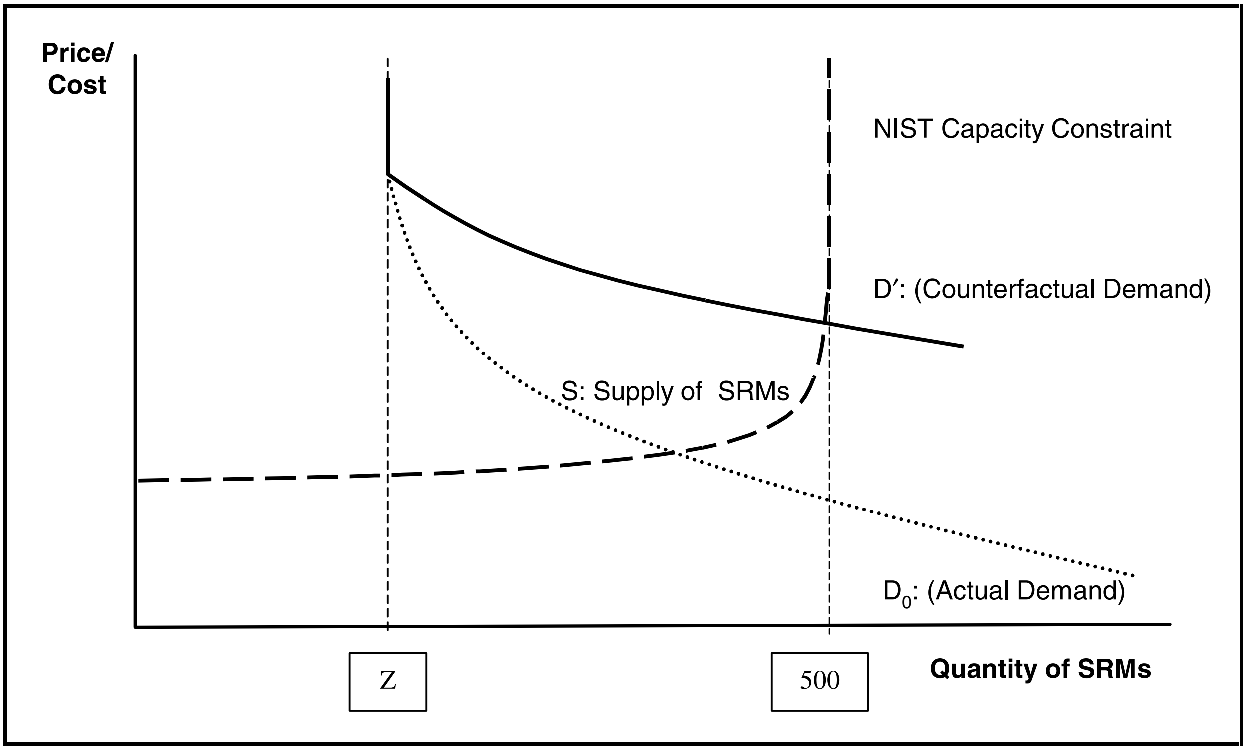
Demand for SRMs

The elimination of NTRMs for producing EPA protocol gases would induce a significant increase in the demand for SRMs in comparison to the current state. In addition to the mostly inelastic requirements from automobile firms, SGCs would want to procure more SRMs for their internal use. As we discuss above, very little of this demand could be accommodated because of the production constraints at NIST. We anticipate that there would be increases in requests for all species of reference gas mixtures for which NTRMs are currently produced.

Figure 3-3 illustrates this demand shift, along with the supply situation described earlier. Current demand is shown with a minimum quantity of **Z**, the quantity required by those end users with a near-infinite WTP. At higher quantities, there is a progressive increase in elasticity, representing the presence of substitutes for most end uses. Counterfactual demand is shown with higher WTP for each quantity, as the availability of directly traceable substitutes is eliminated for many end uses. NIST's supply curve is depicted as following a near-constant average cost, perhaps with an increase as the capacity limit is approached. The SRM supply curve is unaffected by the absence of the NTRM program; the NTRM program only affects the demand because it supports the production of substitutes for SRMs.

Note that in the absence of the NTRM program, the WTP for SRMs increases and, if NIST was a profit-maximizing organization, it would be able to significantly increase the price of SRMs under the counterfactual scenario. However, changes in price reflect only

Figure 3-3. Supply and Demand for SRM Production by NIST



transfer payments between entities and do not affect the total economic impact on society. For this reason, changes in the price of SRMs (as well as directly and indirectly traceable gases) are not modeled as part of the analysis. In addition, because NIST sets its prices for reference gases based on a cost recovery formula, the price NIST charges for NTRMs would not change.

Our analysis assumes that some other mechanism (nonprice) would allocate SRMs to their highest value use. For example, firms with the highest WTP for SRMs would be willing to bear the highest transaction costs to obtain SRMs. Note that if available SRMs do not go to firms with the highest WTP, this creates an additional market inefficiency (failure) and would increase the economic impact of removing the NTRM program.

Demand for Directly and Indirectly Traceable Calibration Gases

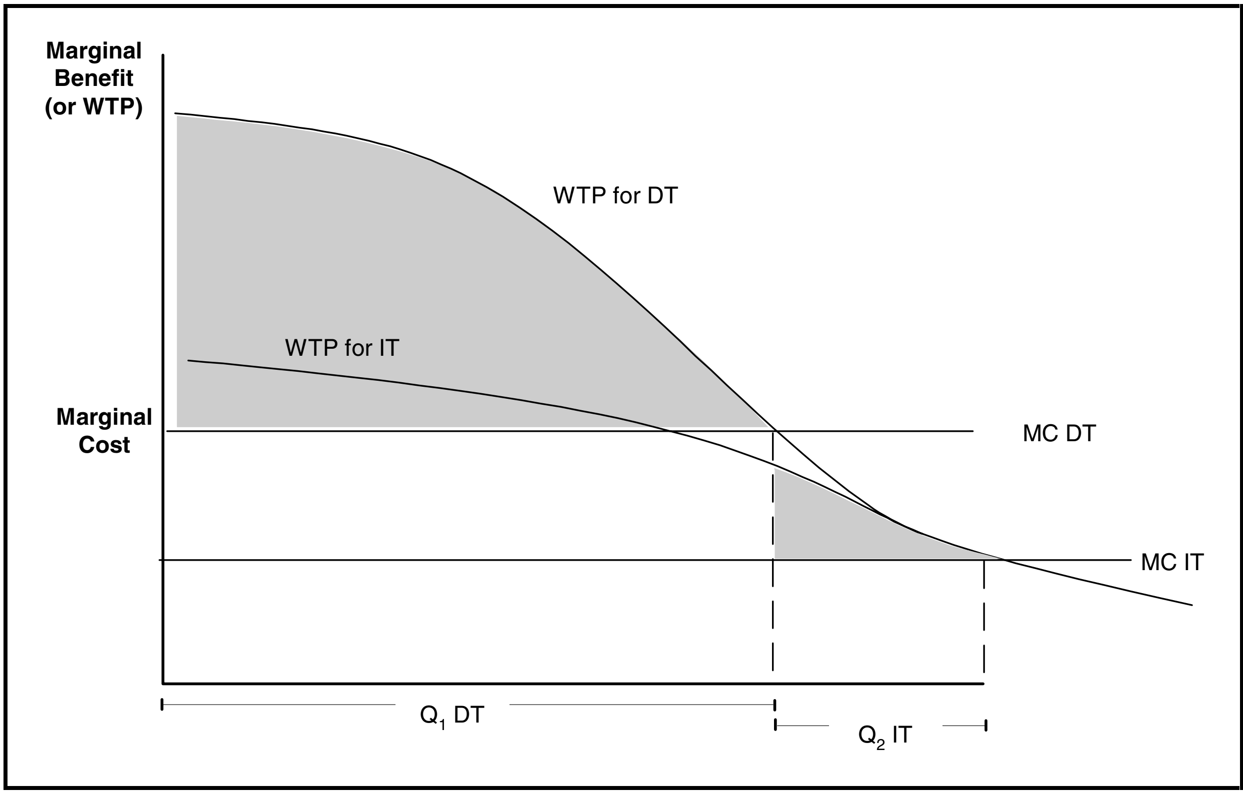
Our analysis makes the important distinction between directly traceable and indirectly traceable calibration gases. Under the counterfactual, directly traceable gases would need to be calibrated against SRMs and indirectly traceable gases would be calibrated against GMISs. To quantify the impact of the NTRM program, we need a description of the demand for these gases for the major classes of end users. One of the principal goals of the SGC surveys was to identify specific end users' current consumption of these gases and then use the end-user surveys to estimate the WTP for directly and indirectly traceable gases that underlies the industry demand curves.

Figure 3-4 is a simplified diagram of demand for these two products. The end users are aggregated and positioned based on their WTP for the two types of protocol gases. For clarity of exposition, the marginal cost of production is used in place of selling price; this implicitly assumes that the SGCs lack market power and that fixed costs are negligible. Those whose WTP for the directly traceable gas exceeds the marginal cost purchase the higher accuracy products; the volume demanded equals Q_1. The less demanding end users purchase Q_2 units of the indirectly traceable reference gases. Those whose WTP falls below the marginal production cost of the lower accuracy product do not enter the market.

The main impact of the counterfactual scenario is depicted in Figure 3-5. The marginal cost (supply) curve for directly traceable gas is now shown as vertical beyond quantity Q_1', resulting from the binding constraints on SRM production. This situation allows only those end users with the highest valuation to purchase directly traceable reference gases. A large number of customers are forced to accept the lower relative accuracy of indirectly traceable products. Their reduction in consumer surplus, represented by the difference between their WTP for the two product classes, is the largest component of the social benefit lost in the counterfactual scenario and thus an approximation of the value of the NTRM program for these demanders.[3]

[3]The other major economic impact component quantified as part of the study is the increased cost of producing directly and indirectly traceable gases due to the elimination of NTRMs. However, as will be shown in Section 5, the impact on end users is between 11 and 15 times greater than the impact from increased NTG production costs.

Figure 3-4. Current Market for Directly Traceable and Indirectly Traceable Protocol Gases



Note: DT: directly traceable.
IT: indirectly traceable.

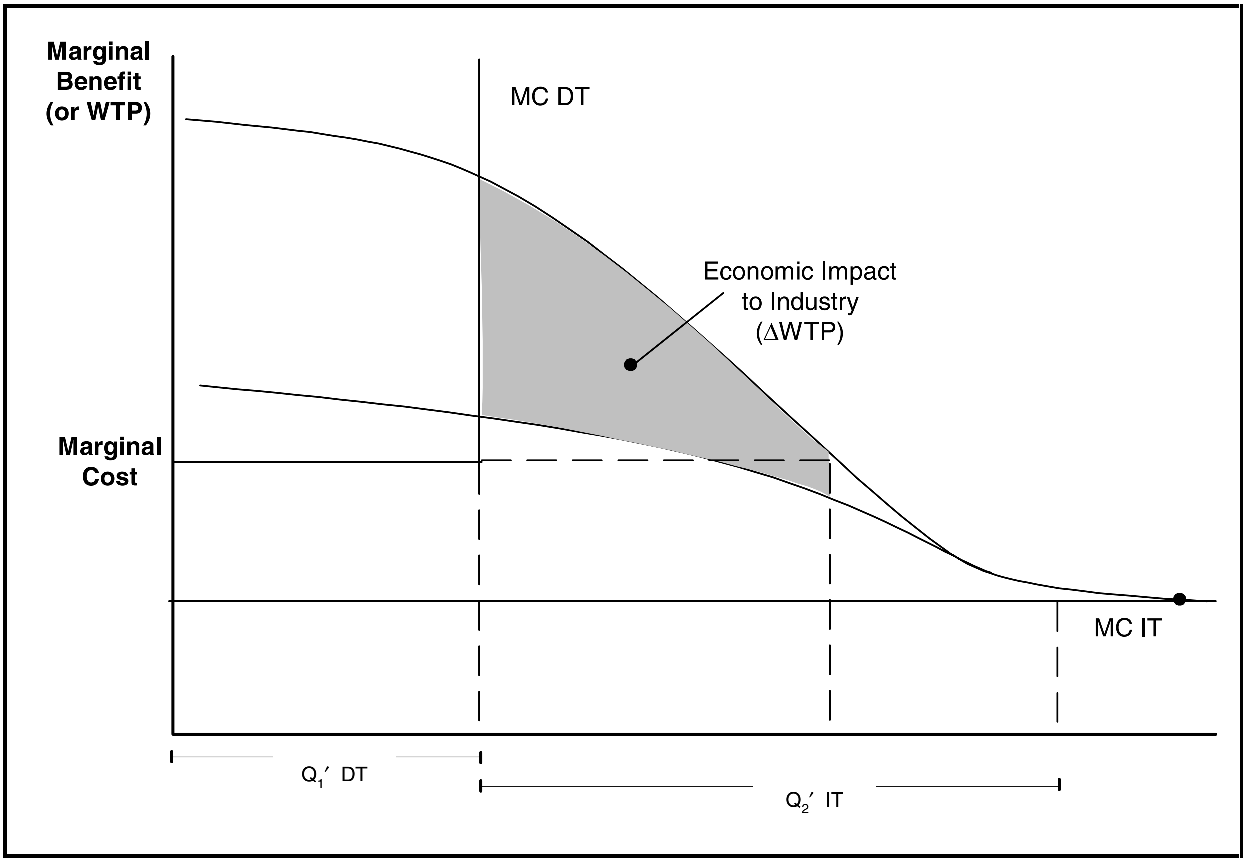
3.2.4 Dynamic Issues

Up to this point, the counterfactual scenario has been described in a static sense, without consideration of changes over time. However, one of the objectives of the study is to estimate a time series of economic impacts beginning at the inception of the NTRM program and projected through the year 2007. For this reason, several dynamic issues will be important and are discussed below.

Changes in Regulatory Requirements

The requirements for using NIST-traceable materials have changed considerably over the 10+ years since the passage of the CAAA (see Section 2). Some of these changes were written into the legislation itself, while many more emerged as EPA issued rules designed to carry out the law's mandates. These evolving requirements led, in turn, to changes in demand for EPA protocol gases and NTRMs.

Figure 3-5. Counterfactual Without NTRM Program



Note: DT: directly traceable.
IT: indirectly traceable.

For example, the first phase of the Acid Rain Program required the 263 "dirtiest" electric utility operations to continuously monitor, report, and reduce their emissions of NO_X and SO_2. Between 1994 and 2000, other facilities were permitted to opt in to the Acid Rain Program to buy or sell SO_2 credits, in which case they would be subject to the same monitoring requirements. In 2000, Phase II brought all remaining power generators into the program and further reduced allowable SO_2 emissions. The cap and trade provisions of the NO_X SIP Call will increase demand for NO reference standards when it becomes effective in 2002. The demands for SO_2 and NO standards will continue to change (most likely to grow) at least until the final limits become effective in 2010.

The same sort of progression has occurred in stationary source, mobile source, and ambient air regulations. Over the past 5 years, there has been a steady release of rules covering various categories of new and existing stationary sources, almost all of which require calibration with NIST-traceable reference gases. This has affected requirements for monitoring all acid rain and criteria pollutants, including SO_2, NO_2, NO_x, CO, hydrocarbons, and other species. Although most of the national emissions standards for hazardous air pollutants (NESHAPs) have now been written, demand will continue to evolve as new sources come online and others are shut down. In the mobile source arena, Tier-2 automobile tailpipe standards will be implemented beginning in 2003, and many nonautomotive and off-road regulations have been completed and are in the process of being adopted.

The effect that these changes have on our counterfactual analysis is straightforward. Because we are treating the EPA regulations as exogenous constraints, the derived demand for reference gases in each year will be assumed to be the same in the actual and counterfactual cases. Thus, historical changes in regulatory requirements will be captured through past consumption of EPA protocol gases. Knowledge of upcoming regulations will allow us to project future demand.

Development of New NIST-Traceable Species

A second time-dependent consideration is that of the types of reference gas products available in the market in each year. To ensure the quality and stability of new standards materials, NIST must be involved in the initial release of SRMs and NTRMs, either by producing them in-house or by testing and characterizing them. It appears that the NTRM program, in freeing up resources in the gas metrology group, has significantly accelerated its release of new mixtures and different concentration ranges of existing mixtures.

The "production pressure" on NIST under the counterfactual would likely prevent the creation of most new SRMs and slow the development of difficult species, such as the low-level NO standards. The variety of EPA protocol gases could be reduced substantially and lead times for additional products from the SGCs would increase. It is even possible that major EPA initiatives, such as NO_x regulations, CO_2 reporting, and Tier-2 tailpipe standards could be negatively affected.

3.3 TECHNICAL AND ECONOMIC IMPACT METRICS

The detailed counterfactual scenario above provides several hypotheses about how affected agents would change their behavior in the absence of the NTRM program. In this section, we discuss these hypotheses and present related technical and economic impact metrics, which are used to inform the data collection surveys of SGCs and end users. Data collection activities are described in Section 4 and the survey findings are presented in Section 5.

3.3.1 Impact Hypotheses

We hypothesize that all of the agents in the reference gas supply chain receive benefits from the NTRM program and thus would be affected negatively by its absence. As discussed in the counterfactual, the absence of NTRMs would lead to the following:

- Manufacturing companies currently purchasing SRMs would continue to do so, paying any higher costs passed on by NIST.
- SGCs' production costs would moderately increase because of the increased use of SRMs to produce directly traceable gases and GMISs.
- End users currently purchasing directly traceable reference materials would be the most seriously affected by limited production capacity for these products; some species might not be available as directly traceable gases, while others would be costly and difficult to find.
- Many end users would be forced to change their operations to allow the use of indirectly traceable gases, with attendant economic costs. These costs could include more complicated compliance procedures, greater allowances in operating conditions to prevent out-of-compliance operations, and reduced trading of emissions permits.
- The development of new species of reference gases would be slowed, and future regulatory or operating benefits would be delayed.

3.3.2 Impact Metrics

The impact hypotheses listed above lead naturally to a set of impact metrics, which are summarized in Table 3-2. The technical impact metrics describe the changes in production and business operations under the counterfactual, and the economic impact metrics describe the method for valuing these changes. For example, the main technical impact for end users is that they are forced to increase

Table 3-2. Technical and Economic Impact Metrics

Segment Affected	Technical Impact Metrics	Economic Impact Metrics
End users	Decreased supply of directly traceable gases leads to increased use of indirectly traceable gases and an increase in reference gases' uncertainty	Increased labor and material cost associated with calibration activities And Market value of additional emissions allowances retired
SGCs	Increased use of SRMs to replace NTRMs Changes in production process to "stretch" supply of SRMs	Increased production cost
NIST	Increased production of SRMs	Changes in production costs Lost opportunity costs
EPA	Delays in new rule making due to increased time required to develop new reference materials	Postponing attainment of social benefits from new regulations

their use of indirectly traceable reference gases. This in turn leads to changes in business operation, such as more frequent calibrations and changes in the number of emission credits they choose to retire. The economic impact of these changes in business operations is quantified in terms of the increased labor and materials for calibration and the value of additional emission credits that the firm may need to purchase due to the increased uncertainty of the indirectly traceable gases as compared to that of the directly traceable gases.

Information to quantify these impacts is gathered during the SGC and end-user surveys for the first three categories. Valuing the fourth category, the social cost from postponing environmental regulations, is a complex and controversial task and is beyond the scope of this project.

3.4 BENEFITS AND COSTS ESTIMATION

The information to support the benefits and cost calculations are collected from NIST, the SGCs, and representative end users. The benefits from the NTRM program are equivalent to the negative economic impacts quantified by the metrics described in Section 3.3.2, because the prevention of these impacts constitutes the benefits delivered. Dollar benefits in each year will be summed, as will the annual development and operating costs for the NTRM program. We will then calculate a series of measures of net social benefits, including benefit-to-cost ratio (B/C), internal rate of return (IRR), and net present value (NPV). In this section, we summarize data-collection needs, outline the process for determining annual benefits, and conclude with a description of the net benefits measures.

3.4.1 Data Requirements

Specific information collected from NIST include

- their annual expenditures for developing the NTRM program;
- a confirmation of their SRM-producing capacity (we have been told it is 500 cylinders per year);
- the number and species of SRMs purchased each year directly by end users and the identity of these purchasers, if available;
- current per-unit cost incurred for producing SRMs; and
- an estimate of any changes (if any) in per-unit costs for SRMs if production was increased to the maximum level.

From the SGCs, the following information is needed:

- their annual production of NTRMs, GMISs, and directly traceable and indirectly traceable gases;
- description of their most important customer types, including the end use of NTGs and an estimate of how these customers' choices and costs would change if they were forced to accept lower-accuracy calibration gases;
- expandability information about their standards (i.e., how many cylinders can they certify with each GMIS, NTRM, and SRM cylinder);
- an assessment of the possibility of "stretching" the use of SRM material in the absence of the NTRM program, and the additional unit costs the SGCs would incur; and
- their developmental costs for supporting the NTRM program by year.

Our end-user interviews will gather the following data:

- actions that would be taken if directly traceable gases now purchased were to become unavailable;
- changes in operating costs that would be incurred if indirectly traceable gases were substituted for the 1-percent products now used; and

- for firms participating in emissions trading programs, the likely or potential changes in trading activities and the retirement of allowances due to the increased use of indirectly traceable gases.

3.4.2 Determination of Annual Economic Benefits

Based on the information from the data-collection effort, dollar benefits estimates are generated for the various impact areas described above. This includes a complete time series of net expenditures by NIST to develop and operate the NTRM program, as well as the benefits of the NTRM program to SGCs and end users in terms of avoided costs. For each time period (t), the benefits and costs can be depicted as follows:

$$\begin{aligned} \text{benefits}_t &= \Delta\ \text{end-user operating costs}_t + \\ &\quad \Delta\ \text{end-user emission allotment costs}_t + \\ &\quad \Delta\ \text{SGC operating costs}_t \\ \text{costs}_t &= \text{NIST program development costs}_t + \\ &\quad \Sigma\ \text{NIST net operating costs}_t \quad . \end{aligned} \tag{3.1}$$

3.4.3 Calculating Measures of Net Social Benefits

A time series of benefits and costs for the NTRM program is estimated from its inception in 1992 to the present using historical data and from 2002 to 2007 using projected demand for NTGs. The time series of benefits and costs will be used to develop three summary measures of the net benefits from NIST's contributions: the benefit-cost ratio, the NPV, and the internal rate of return. If B_t is the incremental net benefits accrued to all beneficiaries (net of any non-NIST development and adoption costs) in year t, and C_t is the cost to NIST of the program in year t, then the benefit-cost ratio for the program is given by

$$(B/C) = \frac{\sum_{i=0}^{n} \frac{B_{(t+i)}}{(1+r)^i}}{\sum_{i=0}^{n} \frac{C_{(t+i)}}{(1+r)^i}} \tag{3.2}$$

where t is the first year in which benefits or NIST costs occur, n is the number of years in which the benefits or costs occur, and r is the social rate of discount. Because benefits and program costs may occur at different time periods, both are expressed in present-value terms before the ratio is calculated.

The NPV of NIST's contributions through the NTRM program is

$$NPV = \sum_{i=0}^{n} \left[\frac{B(t+i)}{(1+r)^i} - \frac{C_{t+i}}{(1+r)^i} \right] \quad . \qquad (3.3)$$

The internal rate of return is the value of r that sets NPV equal to 0 in Eq. (3.3).

4 Primary Data Collection

To estimate the net benefits of the NTRM program hypothesized in Section 3, we collected primary and secondary data throughout the gas-mixture reference material supply chain. The data-collection activities focused on SGCs and their customers, gas-mixture reference material end users. Figure 4-1 provides a conceptual overview of the primary and secondary data-collection activities undertaken to support this study.

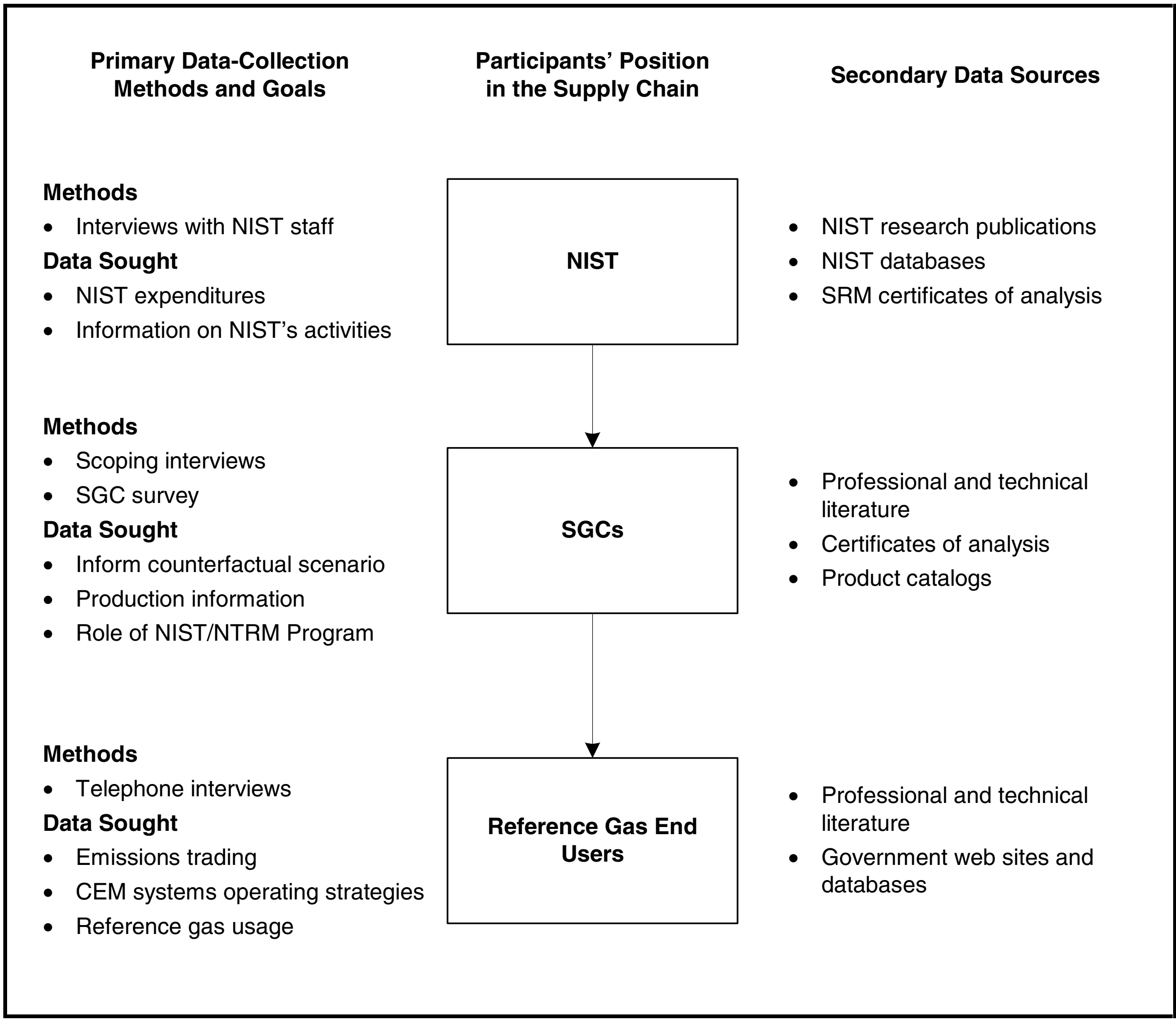
This section discusses the primary data-collection methods and goals for SGCs and end users of NIST-traceable reference materials.

4.1 SPECIALTY GAS COMPANIES

The SGC interviews served several purposes. The first goal was to learn how the NTRM program supports the supply of NIST-traceable reference gases used to meet the environmental compliance obligations of end users. The second goal was to learn how those operations would differ in the absence of the program; specifically, what processes SGCs would use to maintain the supply of NIST-traceable reference materials if NTRMs were not available.

RTI conducted two rounds of interviews with the SGCs' representatives. The first round of discussions consisted of informal scoping interviews to learn about the market for NIST-traceable reference gases, their applications, and the extent to which NTRMs are involved in their production. This was followed by a second round of more formal interviews aimed at understanding how SGCs' operations would change in the absence of the NTRM program and collecting the data needed to quantify these impacts.

Figure 4-1. Overview of Data Collection
All the major parties involved in the NIST-traceable reference gas supply chain participated in this study, including NIST, SGCs, and end users (e.g., electric utilities and automotive emissions testers).



The SGC interviews were also used to obtain information about the characteristics of NIST-traceable reference gas end users. SGCs explained in detail who the consumers of NIST-traceable reference gases were and the applications in which these reference gases were used. This information was then used to prepare and conduct the end-user survey.

RTI also made a presentation at a NTRM/SGC meeting held at the PITTCON 2001 meetings, an annual conference on analytical chemistry and spectroscopy held in New Orleans. This presentation provided an overview of the counterfactual scenario (described in

Section 3) to SGCs to confirm that the GMIS method of production would be the most likely scenario in the absence of the NTRM program.

4.1.1 SGC Scoping Interviews

Early in the project, we conducted a series of informal scoping interviews with four of the nine SGCs active in the NTRM program. Each of the four scoping interviews consisted of one to two 30- to 45-minute telephone conversations.

The purpose of the scoping interviews was to understand the SGCs' operations (and the role that NTRMs play within them) early in the project to help develop the impact metrics that we used to estimate economic impacts. SGCs provided early insights into how NTRMs were used, the NIST traceability chain, and the end users of gases certified against NTRMs. These insights were later explored more formally through the SGC survey and the end-user survey.

4.1.2 SGC Survey

Using the list of NTRM program participants as the survey population, RTI conducted a confidential survey of the specialty gas industry. Seven of the nine SGCs that regularly submit NTRM batches to NIST for certification and testing participated in the survey, yielding an overall response rate of 78 percent. These seven companies represented 95 percent of NTRM production in 2000.

Survey Method

> Seven of the nine SGCs that regularly submit NTRM batches to NIST for certification and testing participated in the survey, yielding an overall response rate of 78 percent. These seven companies represented 95 percent of NTRM production in 2000.

The SGC interviews were conducted over a 4-week period, as participants' schedules permitted. Before the actual conversation took place, participants were provided with a copy of the interview guide and a memorandum outlining the project's goals. In most instances, participants chose to first complete the survey instrument and then discuss their responses on the telephone. Following each initial interview, respondents were recontacted for further clarification about any particular comment or issue raised.

Although not all the SGCs chose to participate in the survey effort, the firms that appear to be most active in the program did. The combined market share for protocol gases of survey participants is estimated to exceed the survey response rate. In the empirical analysis, the average participants' responses were used to approximate those of nonparticipants.

RTI asked SGCs to reflect on the role that the NTRM program plays in their production processes and how those processes may change in its absence.

Survey Topics

RTI asked SGCs to reflect on the role that the NTRM program plays in their production processes and how those processes may change in its absence. The survey consisted of four sections, each containing a series of short answer and table-format questions. Appendix A contains a copy of the survey. The first section asked for some background information from the responding employee concerning his or her function within the SGC. The remaining sections asked the following:

- Production of NTGs. The questionnaire asked basic questions about SGCs' production of EPA protocol gases and other gases supported by the NTRM program. This section also asked about NTRM program-related expenses.
- Counterfactual scenario. This section asked SGCs how their operations would change in the absence of the NTRM program. Questions focused on bottlenecks, investment decisions, and changes in their cost structure.
- End users. The final section asked SGCs to characterize gas end users by industry and by species.

The survey instrument contained in Appendix A was used primarily as a discussion guide. It was shared with respondents prior to the interviews and served as the general structure for the discussion. However, in many cases it was the unanticipated information and comments obtained during the interviews that proved most insightful.

The individual surveys completed by the SGCs contain confidential, business proprietary information. The main condition under which the SGCs agreed to participate was that individually identifiable information be excluded from the final report. As such, only aggregate impacts or comments are presented throughout this report. At no time is any comment attributable to a particular SGC.

4.2 END-USER SURVEY

The second component of the primary data collection effort was a survey of end users. The end-user survey was designed to gather information about how end users used the NTGs supported by the NTRM program. They were also asked about the importance of the traceability chain in their consumption decisions and what effect increased analytical uncertainty of reference gases would have on their business operations.

4.2.1 End-User Population

The SGC survey was used to investigate the impact of the analytical uncertainty of EPA protocol gases on end users. To evaluate how the counterfactual scenario would affect end users of NTGs, RTI spoke with four electric utilities and four regulatory agencies about how an increase in the analytical uncertainty of the reference gases they consume would affect their operations and costs. As shown in Table 4-1, respondents' backgrounds ranged from environmental engineering to laboratory management.

Table 4-1. Interviewed End Users' Backgrounds

End User	Industry	Background
End User 1	Electric utility	Environmental engineers
End User 2	Electric utility	Emissions testing group
End User 3	Electric utility	CEM systems supervisor
End User 4	Electric utility	Environmental engineer
End User 5	Ambient air monitoring organization	Standards laboratory
End User 6	Mobile source emissions testing organization	Testing laboratory manager
End User 7	Mobile source emissions testing organization	Technical manager
End User 8	Air quality policy commission	Technical manager

The electric utilities were used to represent the CEM systems calibration market, and the regulatory agencies provided information for the automotive emissions testing market. SGCs identified these two market segments as the ones that benefited the most from the NTRM program. End users were contacted by telephone and asked to participate in a 30-minute telephone conversation.

4.2.2 End-User Survey Topics

The end-user survey asked respondents to reflect on their current use of EPA protocol gases and other NTRM gases and the role that these gases play in their operations. They were also asked how their business operations and costs would change under the counterfactual scenario.

End users were asked how their business operations and costs would change under the counterfactual scenario.

Appendix A contains a copy of the survey instrument. The first section asked for some background information about the respondent and the company's background. Other sections asked the following:

- Current NTG use. End users were asked to describe the applications in which they use NTGs and how many cylinders of these gases they consume annually.
- NTG use under the counterfactual scenario. End users were asked how their operations would change if the gases they typically use had higher analytical uncertainty or if some gases were unavailable for purchase.
- Comments. This last section was open-ended and provided end users with the opportunity to discuss issues relating to their NTG consumption that were not specifically identified in the survey instrument.

As with the SGC survey, the instrument supplied in Appendix A was used primarily as a discussion guide. It was shared with respondents prior to the interviews and served as the general structure for the discussion. All company-specific information collected through the interviews remained confidential.

5 Results

This section quantifies the economic benefits and costs associated with the NTRM program and presents the flow of net benefits over time. Benefits include the increased labor and capital expenditures that SGCs and reference material users would insure in the absence of the NTRM program. Costs are the NTRM certification expenditures by NIST and SGCs.

Table 5-1 presents an overview of the economic impacts of the NTRM program from 1990 to 2007. The projected NPV through 2007 was calculated for the NTRM program; the time series was extended into the future because the benefits of the NTRM program are projected to increase significantly as participation in emission trading programs increases and credits are retired under advanced phases of cap and trade programs. The NPV through 2007 is estimated to be between \$49.0 million and \$63.0 million. The benefit-cost ratio was between 21.4 and 27.2.

Table 5-1. Economic Impact of NTRM Program from 1990 Estimated through 2007 (NPV \$2001)

	Lower Bound	Upper Bound
Costs of NIST NTRM Program	–2,407,897	–2,407,897
Benefits	51,423,874	63,092,986
SGCs	5,398,420	5,398,420
Users	46,025,454	60,102,463
Net Benefits	49,015,977	63,092,986

Note: Social costs are presented as negative numbers.

Note: The upper and lower bound reflect a range for the increased analytical uncertainty for indirectly traceable gases.

Reference material users are the primary benefactors of the NTRM program, accounting for between 92 and 94 percent of the benefit, which represents avoided operations and maintenance costs and emissions credit expenditures.

This section begins with a discussion of SRM production and consumption under the counterfactual scenario (in the absence of the NTRM program). This is followed by several sections that describe the impact of SGCs' and users' reference materials. The section concludes with a summary of NIST's expenditures to support the NTRM program and the calculation of measures of economic return from the NTRM program.

5.1 SRM PRODUCTION AND CONSUMPTION UNDER THE COUNTERFACTUAL SCENARIO

In the counterfactual scenario, the NTRM program would not be available to support the production of directly traceable gases. As a result, we hypothesize that the demand for SRMs would greatly exceed NIST's capacity to certify them. (Candidate SRMs are produced under contract to NIST and, once prepared, are certified by NIST CSTL's Analytical Chemistry Division.) Even if contract producers were in a position to increase SRM production, NIST's resource constraints for certification would limit the number of SRMs that would be available each year for SGCs and other industries.

5.1.1 Maximum SRM Production

> For this analysis, the maximum supply of SRMs is assumed to be 500 per year.

According to NIST technical representatives, the Analytical Chemistry Division has a total annual certification capacity of approximately 500 gas-mixture SRMs. Without significant increases in current funding levels, there are no process changes that could feasibly increase certification capacity. Therefore, for this analysis, the maximum supply of SRMs is assumed to be 500 per year. This implies that the supply curve in a standard supply and demand curve graph becomes vertical at a quantity of 500; for any given price, the supply of SRMs can not exceed 500.

5.1.2 NIST-Certified Reference Material Consumption

The primary impact of the NTRM program is that it increases the availability of NIST-certified reference material. In the absence of the program, the only NIST-certified material would be SRMs. SGCs have produced over 9,000 NTRM cylinders over the past nine years, or approximately 1,000 cylinders a year. Because each NTRM cylinder contains five times as much gas as an SRM cylinder (29.5 L vs. 5.9 L), the 1,000 NTRMs are equivalent to 5,000 SRMs. This illustrates that the current annual consumption of NIST-certified materials far exceeds the feasible supply that could be provided by SRMs.

Applications/uses with lower WTP will be forced to switch to alterative production methods and/or reference materials under the counterfactual scenario.

As a result, under the counterfactual, there will be a shortage of NIST-certified reference materials, which will lead to changes in SGCs' and other industries' behavior. Applications/users with the highest WTP will likely still obtain SRMs. However, other applications/users with lower WTP will be forced to switch to alterative production methods and/or reference materials under the counterfactual scenario.

SRM demanders include SGCs and other domestic consumers.[1] Table 5-2 shows the distribution of consumption of SRMs from 1993 to 2001. Under the counterfactual scenario, it is assumed that current non-SGC consumers of SRMs, such as government research laboratories and automobile design divisions, have the highest WTP for SRMs and hence will continue to consume them in the absence of the NTRM. These non-SGC consumers indicated during interviews that their operations are extremely sensitive to uncertainty in calibration reference materials and that the use of SRMs is essential to their operations. This is reinforced by the fact that they are currently using SRMs when less expensive NTRMs are available.

As a result, SRMs available for purchase by SGCs under the counterfactual scenario would be equal to NIST's certification capacity (500) less the quantity purchased by non-SGC consumers.

[1]We assume that increasing the use of Primary Reference Materials (PRMs) from Nederlands Meetinstituut (NMi) would not be an option to alleviate the supply shortage for SRMs. Currently, some domestic SGCs purchase SRM-equivalent PRMs from NMi in the Netherlands, and some foreign consumers purchase NIST SRMs to establish NIST traceability. This analysis assumes that, in the counterfactual scenario, current foreign SRM consumers would switch to PRMs from NMi or other national standards laboratories because of the unavailability of NIST SRMs, and that foreign consumers will completely consume foreign supply so that SGCs cannot import foreign standards. As a result, foreign producers and consumers of NIST-certified (or equivalent) reference materials have no net impact on the SRM market and are excluded from the analysis.

Table 5-2. Current and Counterfactual Demand for SRMs

	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Current										
Domestic Consumption	249	248	188	202	186	159	121	212	248	1,813
SGCs	172	179	132	151	127	106	66	150	175	1,258
Regulatory agencies and independent testing, monitoring, and research organizations	44	37	38	32	27	34	44	39	61	356
Transportation equipment manufacturers	23	22	13	13	26	8	8	12	6	131
Electric utilities and nonutilities	2									2
Other consumers	10	8	5	6	6	11	3	11	6	66
Foreign consumption	77	45	50	30	28	19	25	33	35	342
Total	326	293	238	232	214	178	146	245	283	2,155
Counterfactual										
NIST maximum certification	500	500	500	500	500	500	500	500	500	4,500
SGCs	423	431	444	449	441	447	445	438	427	3,945
All other consumers	77	69	56	51	59	53	55	62	73	555

Source: NIST's Standards Reference Materials Program and RTI estimates.

Table 5-2 presents the distribution of counterfactual SRM consumption from 1993 to 2001. As an example, in 2000 NIST sold 245 SRMs, of which 33 were to foreign consumers and 150 were to SGCs. That means that 60 SRMs were sold to domestic non-SGC consumers. Under the counterfactual scenario, those same non-SGC consumers would still have access to the 60 SRMs and SGCs would purchase all remaining units. Thus in 2000, SGCs would have had 438 NIST-certified reference materials available to them without the NTRM program. We use this method to estimate the counterfactual sale of SRMs from the introduction of the NTRM program to the present.

SGCs would then use their available supply of SRMs to produce either directly traceable reference materials or GMISs to produce indirectly traceable reference materials. The limited availability of SRMs and its implication for the production processes used by SGCs to make available NTGs is discussed in the following sections.

5.2 SPECIALTY GAS COMPANIES

The previous section discussed the impact that the absence of the NTRM program would have on the availability of NIST-certified materials and the number of SRMs available to SGCs to certify NIST traceability for their products. The limited availability of SRMs has implications for the production processes used by SGCs to produce and certify NTGs, such as EPA protocol gases.[2]

SGCs will still supply the same number of NTGs to users—what will change is that there will be fewer directly traceable reference materials available and many users will be forced to switch from directly traceable to indirectly traceable reference materials.

A key assumption is that SGCs will still supply the same number of NTGs to users—what will change is that there will be fewer directly traceable reference materials available and many users will be forced to switch from directly traceable to indirectly traceable reference materials. Table 5-3 shows the calculated distribution of directly and indirectly traceable NTGs under the counterfactual scenario.

As shown in Table 5-3, most NTGs produced from 1993 to 2001 were directly traceable. However, it is estimated that the limited availability of SRMs would shift the majority of NTG production from directly traceable gases to indirectly traceable gases under the counterfactual scenario.

The data used to estimate the shift in production from directly to indirectly traceable gases were developed from responses to the SGC survey. Responses from all participating SGCs were aggregated to model the market as a single product and thereby gauge industry response to the counterfactual as opposed to an individual company's response by species.

[2]Note that when the term NIST-traceable gas (NTG) is used, we are referring to a commercially-available NIST-traceable gas-mixture reference standard produced by SGCs that has been assayed using NIST-certified material and is stored in the industry standard cylinder, a 29.5-L aluminum cylinder. We do not use NTG to refer to NIST SRMs, NTRMs, or in-house GMISs.

Table 5-3. Current and Counterfactual NIST-Traceable Gas-Mixture Standards Production (cylinders)

	1993	1994	1995	1996	1997	1998	1999	2000	2001
Current production									
Directly traceable NTGs	53,782	55,282	84,394	84,374	83,914	85,895	85,795	91,517	92,557
Indirectly traceable NTGs	9,166	9,421	14,383	14,379	14,301	14,638	14,621	15,597	15,774
Total NTGs	62,947	64,704	98,777	98,753	98,215	100,533	100,416	107,114	108,331
Counterfactual production									
Available SRMs	423	431	444	449	441	447	445	438	427
Directly traceable NTGs	11,571	11,783	11,756	11,902	11,675	11,822	11,766	11,482	11,147
SRMs used	402	409	408	414	406	411	409	399	387
Indirectly traceable NTGs	51,376	52,921	87,021	86,851	86,539	88,711	88,650	95,632	97,183
SRM used[a]	21	22	36	35	35	36	36	39	40
GMISs used	357	368	605	603	601	616	616	664	675
Total NTGs	62,947	64,704	98,777	98,753	98,215	100,533	100,416	107,114	108,331

[a]For production of GMISs.

Source: Confidential SGC questionnaires and RTI estimates.

The market demand for NIST-traceable products is assumed to be fixed in this analysis; in large part it is driven by regulated environmental compliance calibration activities. This means that regardless of the standards used to certify NTGs, there are customers that will need to buy them. For example, under the counterfactual scenario, it is assumed that the Acid Rain Program would still be in effect and electric utilities would still need to calibrate their monitoring equipment with NIST-traceable EPA protocol gases to ensure conformity with environmental regulations. Therefore, in the counterfactual environment, SGCs would maintain their current production levels to meet market demand.

The issue then becomes how SGCs would meet market demand for NTGs when the availability of NIST-certified material was significantly smaller. All the SGCs indicated during their interviews that they would significantly increase use of GMISs in their production of NTGs.

5.2.1 Cost Impact of the Counterfactual Scenario on the Traceability Chain

> The use of GMISs to establish the traceability chain would result in a slightly lower per-unit costs compared to the use of NTRMs, but would increase uncertainty.

Whereas the majority of NTGs are currently directly traceable, SGCs indicate that in the absence of the NTRM program, they would be forced to certify a large percentage of their NTG products via GMISs. Most gases would therefore shift from being directly traceable to indirectly traceable.[3] The use of GMISs to establish the traceability chain would result in a slightly lower per-unit costs but would increase uncertainty compared to currently available NTGs certified using NTRMs. An additional impact under the counterfactual scenario is that any directly traceable gases would need to be certified using SRMs. This would increase their cost, while not affecting the level of uncertainty. This section estimates the change in per-unit SGC production costs.

To introduce the calculation of SGC production cost impacts, we discuss the current cost structure of producing NTGs from SRMs, NTRMs, and GMISs. The main impact on NTG production costs is related to the use of SRMs, NTRMs, and GMISs in the certification process. Labor, equipment, and materials costs for producing NTGs are the same regardless of whether SRMs, NTRMs, or GMISs are used. The impact comes from the cost difference between certifying NTGs using SRMs, NTRMs, and GMISs.

> The use of SRMs for certification of directly traceable gases is close to 10 times more costly compared to the use of NTRMs.

Table 5-4 summarizes these cost differences. It costs approximately $57 per cylinder to certify an NTG using an SRM. The cost of certification using NTRMs or GMISs is significantly lower. Certification using a NTRM costs $6; certification using a GMIS costs $5.50. However, an important difference is that certification using a GMIS yields indirectly traceable gas with higher uncertainty compared to a directly traceable gas certified with an SRM or an NTRM. The supporting data and methodology for calculating the costs shown in Table 5-4 is discussed below.

[3]SGCs indicate that end users would alter their behavior if they used indirectly traceable gas instead of directly traceable gas. This response is not discussed here, but rather in the sections devoted to the impact of the counterfactual scenario on end users.

Table 5-4. Cost of Certifying NTGs Using Different Methods

	SRM (5.9 L)	NTRM (29.5 L)	GMIS (29.5 L)
Cost per cylinder	$1,645.00	$550.00	$797.00
NTGs per cylinder[a]	29	144	144
Certification costs Cost Per NTG	$56.72	$3.82	$5.53
SRM cost component[b]	—	$27	$97

[a]Assumes that same volume of gas is needed to certify NTG. Difference in the number of NTGs per cylinder is due to the size of the cylinder (5.9 L for SRM and 29.5 L for NTRM and GMIS).

[b]The SRM cost component is the dollar value of the quantity of SRM consumed to certify one NTRM and GMIS cylinder.

Cost of Certifying Using an SRM

The weighted average cost of the various gas-mixture SRMs sold by NIST is about $1,645 per cylinder. According to SGCs, each SRM cylinder is capable of certifying an average of 29 NTGs. Each NTG cylinder therefore consumes about $57 worth of SRM during the certification process.

Cost of Certifying Using an NTRM

The average batch of NTRMs produced by an SGC consists of 22 cylinders and has a total production cost of $12,100, yielding an average cost of $550 per NTRM. The production cost includes labor and materials expenses as well as transportation costs to and from NIST for NIST-selected candidate cylinders (usually two or three cylinders). The $550 also includes the cost of SRMs consumed during the preparation of the NTRM batch, approximately 5 percent ($27) of the cost.[4]

As part of the survey process, we also asked SGCs how many NTGs they can produce using one NTRM. This piece of information is important because it is needed to estimate the NTRM costs per NTG. Responses to this question ranged from 75 to 300 cylinders. However, by weighting individual responses by the number of cylinders the SGC is producing relative to industry cylinder production, we estimated that the weighted average number of NTG cylinders produced from one NTRM (or by default, one GMIS) is about 144.

[4]An SRM can certify on average 60 NTRMs, resulting in an SRM cost per NTRM of approximately $27 ($1,645/60).

Based on the above information, with SGCs producing 144 NTGs from one NTRM, the NTRM cost per NTG is about $3.82 ($550/144).

Cost of Certifying Using a GMIS

GMISs are more costly to certify than NTRMs because the testing requirements outlined in the EPA protocol require that each GMIS be certified individually. NTRMs are tested on two separate occasions for homogeneity and stability, and not all NTRMs in a batch must be tested.[5] In contrast, GMISs must be tested individually on three separate occasions (EPA, 1997a). This certification process represents the primary cost difference between the two standards because the production apparatus, quantity and quality of materials, and cylinder sizes are the same for producing NTRMs and GMISs.

SGCs estimate that it costs on average $700 to produce a GMIS, excluding the cost of the SRM. The $700 per GMIS accounts for the labor costs incurred for setting up the production apparatus, connecting candidate GMIS cylinders, analyzing the cylinders, and accomplishing record keeping requirements. It also accounts for having to test all of the GMIS cylinders up to three times as outlined in the EPA protocol.

> NTG production costs differ depending on whether SRMs, NTRMs, or GMISs are used in the certification process. The total cost per cylinder using
> - SRMs is $1,645;
> - NTRMs is $550; and
> - GMISs is $797.

According to SGCs, one SRM yields about 17 GMISs.[6] Using the weighted average cost of SRMs of $1,645, the SRM cost per GMIS cylinder is about $97 (1,645/17). This yields a total cost of a GMIS of about $797.

Once certified, a GMIS may be used in the same fashion as an NTRM. Using a GMIS increases the number of steps away from NIST, and thereby the uncertainty of the final reference standard, but it allows the SGC to manufacture as many NTGs as it can with one NTRM.

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[5]Although SGCs are not required to conduct testing of each NTRM cylinder because the batch is assumed to be homogenous, most SGCs admit that they do test most if not all cylinders. Because NIST selects which cylinders will be tested, SGCs test more cylinders than required to ensure that the batch will pass NIST's certification process. Testing a larger number of cylinders provides SGCs with increased confidence that the batch is in fact homogenous.

[6]By comparison, SGCs estimated that they can prepare about 60 NTRMs from one SRM because of the different testing requirements.

Per-Unit Cost Implication of the Counterfactual Scenario

In summary, under the counterfactual scenario there are two primary per-unit cost impacts:

1. Directly traceable gases are certified with SRMs instead of NTRMs. This results in an increase of $52.90 ($56.72 – $3.82) per unit for directly traceable gases.
2. Many users that currently purchase directly traceable gases will be forced to switch to indirectly traceable gases due to limited SRM availability. The indirectly traceable gases will have a slightly higher per-unit cost and have higher uncertainty.[7] The per-unit cost decrease of NTGs produced using GMISs versus NTRMs is $1.71 ($3.82 – $5.53)

5.2.2 Impact of the Counterfactual on NTG Production

NTG production shifts from mostly directly traceable to mostly indirectly traceable gases when the NTRM program is removed from the traceability chain and SGCs are left with only NIST SRMs to certify NTGs. SGCs react by producing GMISs in sufficient quantity to maintain current NTG output levels.

Determining the Counterfactual Production Mix Between Directly and Indirectly Traceable NTGs

Directly traceable NTGs would still be produced under the counterfactual scenario; however, these numbers would be significantly smaller than current or historical production. For example, if SGCs were to use all of the SRMs available to them to manufacture NTGs, the supply of directly traceable gases would not be sufficient to meet NTG demand. Conversely, If SGCs were to use all of their allotment of SRMs solely to produce GMISs, and in turn use those GMISs to produce NTGs, the supply of indirectly traceable gases would exceed NTG demand. As a result, under the counterfactual, some combination of directly traceable gases certified by SRMs and some indirectly traceable gases certified by GMISs would be produced.

The approach to calculating the counterfactual production mix between directly and indirectly traceable gases is described below. A key assumption is that the total production of NTGs remains unchanged because total demand is exogenously driven by

[7]The cost to end users due to the increased uncertainty of indirectly versus directly traceable gases is discussed in Section 5.3.

compliance with environmental regulation. To maximize profits, SGCs will want to produce as many directly traceable gases as possible while still meeting the constraint of supplying end users with all the NTGs (directly + indirectly traceable) needed to comply with environmental regulations.[8]

Based on survey results discussed in Section 5.2.2, one SRM can be used to directly assay about 29 NTGs. Alternatively, one SRM can be used to assay 17 GMISs, which in turn would be used to produce 144 NTGs, yielding a total of 2,477 NTGs per SRM (17 GMISs/SRM x 144 NTGs/GMIS).

To mathematically solve for the equilibrium mix between directly traceable and indirectly traceable NTGs, let

SRM = the number of SRMs available to SGCs (exogenous),

NTG = the number of directly and indirectly traceable NTGs needed by users to comply with environmental regulations (exogenous),

DSRM = the number of SRMs used to certify directly traceable gases in the counterfactual (endogenous), and

ISRM = the number of SRMs used to produce GMISs, which in turn are used to certify indirectly traceable gases in the counterfactual (endogenous).

The two unknowns can be solved for by the following system of equations:

$$NTG = (29 * DSRM) + (2477 * ISRM)$$

$$SRM = DSRM + ISRM \quad .$$

For example, if 400 SRMs are available to SGCs and 100,000 NTGs are needed by end users, under the counterfactual scenario, 11,600 and 88,400 directly and indirectly traceable gases would be produced.

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[8]We do not explicitly model end users' demand for directly traceable and indirectly traceable gases. However, as will be shown in the following sections, users' incremental WTP for directly traceable gases far exceeds the incremental cost of producing them. Hence, to maximize profits, SGCs would produce as many directly traceable gases as possible given the constraints of (a) the number of SRMs available and (b) the total number of NTGs needed to meet environmental regulations.

Current and Counterfactual NTG Production Estimates

SGCs produced approximately 108,000 NTGs in 2001, nearly 85 percent of which were directly traceable to an NTRM. This estimate was derived from data collected by the SGC survey instrument as well as historical NTRM production data. Historical production levels to 1993 were then estimated by relating participation in the Acid Rain Program as well as NTRM production and SRM sales to the current production level to estimate growth over time. Table 5-3 presents the NTG production statistics estimated for the period 1993 to 2001, the first full years since the inception of the NTRM program. Table 5-3 also compares these production values with our estimated counterfactual production estimates. (Table 5-3 is located on page 5-6.)

Without NTRMs, the available supply of directly traceable NTGs in 2001 would have decreased from 92,500 to 11,000.

In 2001, if SGCs only had 427 SRMs available to them under the counterfactual, they would manufacture about 11,200 directly traceable NTGs instead of the more than 92,500 that they actually did produce. The balance of the production needed to equate the current and counterfactual scenarios was produced using the GMIS method discussed at several points in this report. The number of directly traceable NTGs produced was significantly smaller under the counterfactual scenario. Directly traceable production ranges between approximately 12 and 13 percent of all NTGs throughout most of the years of the NTRM program.

5.2.3 Impact of the Counterfactual on SGC Production Costs

The incremental change in the SGC production cost from production with the NTRM program to production without the program is the difference in costs from producing NTGs with NTRMs and producing NTGs with SRMs and GMISs. Using the unit cost estimates and the traceability chain developed earlier in this chapter, we calculate the change in the SGC costs. This incremental change is the economic benefit of the NTRM program to SGCs.

SRMs are the most costly reference standard in the traceability chain at a weighted average cost of approximately $1,645 per 5.9-L cylinder. NTRMs cost approximately $550 for a 29.5-L cylinder, including all SGC inputs and NIST certification fees. GMISs cost

$797 for a 29.5-L cylinder, including the cost of the SRM used in its certification. These cost estimates reflect the total cost to society and include all labor, equipment, materials, and administrative expenses used to produce the SRM, NTRM, or GMIS.

Cost impacts due to the hypothetical removal of the NTRM program are estimated by comparing current resources expended to certify NTGs to resources required under the counterfactual to certify the same number of NTGs. The resulting increase in certification costs under the counterfactual scenario is the cost component of the economic impact of the NTRM program. However, this cost component does not capture the economic impact of the change in quality (increased uncertainty) on end users as large numbers of indirectly traceable gases are consumed under the counterfactual; this is quantified in Section 5.3.

Table 5-5 shows the cost impact under the counterfactual scenario from 1993 to 2001 and estimated through 2007. Since 1993, the NTRM program has yielded between $687,000 and $753,000 in production benefit annually for society. The aggregate benefit for the years included in Table 5-5 is $10.9 million.

5.3 IMPACT ON PARTICIPANTS IN EMISSIONS TRADING PROGRAMS

The previous section calculated the benefits that the NTRM program provides to the production of NTGs. The following three sections complete our analysis of the economic impact by quantifying (to the extent possible) the impact that the NTRM program has on end users of gas-mixture reference gases. Specifically we focus on the impact of increased uncertainty resulting from the increased use of indirectly traceable reference materials in the absence of the NTRM program.

This analysis assumes that because of their greater WTP, automotive end users who perform emissions testing during the testing and design phases of their products would be furnished with all of the estimated directly traceable NTGs. This topic will be further explored in the subsequent section; however, it is important to preface the discussion in this section because the analysis assumes that entities performing CEM calibration to support emissions trading would be switching to indirectly traceable NTGs.

Table 5-5. Difference in Certification Costs Under the Counterfactual Scenario

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Historical and Projected Production of NTGs															
Directly Traceable NTGs	53,782	55,282	84,394	84,374	83,914	85,895	85,795	91,517	92,557	93,974	95,434	96,939	98,490	100,089	101,736
Certification Cost Using NTRMs	$205,416	$211,148	$322,338	$322,262	$320,504	$328,070	$327,688	$349,544	$353,518	$358,929	$364,506	$370,254	$376,178	$382,283	$388,575
Indirectly Traceable NTGs	9,166	9,421	14,383	14,379	14,301	14,638	14,621	15,597	15,774	16,015	16,264	16,521	16,785	17,057	17,338
Certification Cost Using GMISs	$41,640	$42,802	$65,342	$65,327	$64,970	$66,504	$66,426	$70,857	$71,662	$72,759	$73,890	$75,055	$76,256	$77,494	$78,769
Total NTGs	62,947	64,704	98,777	98,753	98,215	100,533	100,416	107,114	108,331	109,990	111,699	113,460	115,275	117,146	119,074
Total Cost	$247,057	$253,950	$387,680	$387,588	$385,474	$394,574	$394,114	$420,401	$425,180	$431,688	$438,396	$445,309	$452,434	$459,777	$467,344
Counterfactual and Projected Production of NTGs															
Directly Traceable NTGs	11,571	11,783	11,756	11,902	11,675	11,822	11,766	11,482	11,147	11,457	11,437	11,416	11,394	11,372	11,349
Certification Cost Using SRMs	$661,472	$673,597	$672,054	$680,395	$667,441	$675,853	$672,603	$656,389	$637,246	$654,987	$653,824	$652,626	$651,390	$650,117	$648,805
Indirectly Traceable NTGs	51,376	52,921	87,021	86,851	86,539	88,711	88,650	95,632	97,183	98,533	100,262	102,044	103,880	105,774	107,725
Certification Cost Using GMISs	$266,593	$274,613	$451,558	$450,676	$449,061	$460,327	$460,013	$496,242	$504,294	$511,297	$520,266	$529,515	$539,044	$548,870	$558,993
Total NTGs	62,947	64,704	98,777	98,753	98,215	100,533	100,416	107,114	108,331	109,990	111,699	113,460	115,275	117,146	119,074
Total Cost	$928,065	$948,209	$1,123,612	$1,131,071	$1,116,502	$1,136,180	$1,132,616	$1,152,632	$1,141,540	$1,166,283	$1,174,090	$1,182,140	$1,190,434	$1,198,987	$1,207,798
Difference	$681,009	$694,259	$735,931	$743,483	$731,027	$741,607	$738,502	$732,231	$716,360	$734,595	$735,694	$736,831	$738,000	$739,210	$740,454

Source: Confidential end-user questionnaires and RTI estimates.

As a result, the absence of the NTRM program would increase the analytical uncertainty of the EPA protocol gases that electric utilities and other facilities use to calibrate CEM systems as required by federal, state, and local regulatory programs. The increased analytical uncertainty would have several potential effects on firms regulated under programs that include emissions trading.[9] End users that currently use directly traceable EPA protocol gases indicated that an increase in the analytical uncertainty could result in the following impacts on their operations:

- over- or under-reporting of emissions for SO_2 and NO_x;
- over- or under-reporting of unit operating data for CO_2 and heat input;
- increased calibration costs and checks;
- cost of annual review of calibration gases;
- operational status of marginal units;
- economic dispatch of units; and
- fuel mix.

Upon further reflection, end users believed that the majority of the economic impact would be associated with the first four items listed above. These four items are combined into two categories:

- increases in operations and maintenance costs; and
- over-reporting of emissions.

5.3.1 Impact of the Counterfactual on End Users' Operations and Maintenance Costs

> According to the electric utilities and other firms interviewed for this analysis, shifting to indirectly traceable gas would cause an increase in operation and maintenance costs; these costs primarily include annual reevaluation of calibration gases and more frequent calibration and calibration checks.

This section calculates the incremental operation and maintenance costs associated with the counterfactual. The per-unit costs are then applied to the population of units participating in emissions trading programs that currently use directly traceable EPA protocol gases and would be forced to switch to indirectly traceable gases.

Description of Operations and Maintenance Costs

End users who purchase directly traceable NTGs do so because they value not having an intermediate step between the standards they are using to calibrate their CEM systems and NIST-certified standards. According to the electric utilities and other firms interviewed for this analysis, shifting to indirectly traceable gas

[9]Programs include the South Coast Air Quality Management District's RECLAIM, U.S. EPA's Acid Rain Program, and OTC's NO_X Budget.

would cause an increase in operation and maintenance costs; these costs primarily include the annual reevaluation of calibration gases and more frequent calibration and calibration checks.

Uncertainty refers to the variability in a the certified value of a gas. Uncertainty in EPA protocol gases impacts the confidence that environmental engineers have in the quality of CEM systems calibration. Under the protocol, the GMISs are analyzed individually and the uncertainty of their certified concentrations do not accrue the statistical benefit derived from the analysis of multiple, homogenous cylinders. Additionally, the increased uncertainty is passed along the traceability chain to EPA protocol gases certified using this method. End users are also simply more confident in standards that have been assayed directly against NIST-certified standards. End users said that the additional step used in the GMIS method reduces their confidence in the standard.

End users are also simply more confident in standards that have been assayed directly against NIST-certified standards.

The economic consequence of failing a RATA or a linearity check is significant. Failures could cause a plant to incur penalties, declare a unit out of control, and/or shut down a unit. By using EPA protocol gases that are directly traceable to NIST, the plant is more certain that the certified values are those that are printed on the accompanying certificates.

It should be noted that some end users currently using indirectly traceable standards believe that the EPA protocol gases certified via the GMIS method are equivalent in data quality to that of directly traceable gases. These end users believe that the quality control and assurance programs implemented by SGCs ensure that the EPA protocol gases they purchase are well characterized. They also believe that the incremental uncertainty associated with these standards is incidental and not large enough to have any economic impact on their operations. Therefore, in this analysis below, the units currently using indirectly traceable gases are not impacted by the counterfactual and therefore are subtracted from the affected population.[10]

[10]These units might be indirectly affected through the increased price of indirectly traceable gases. However, to avoid double counting, this component of the economic impact is captured in the changes in production costs and not quantified for users.

Quantifying Operations and Maintenance Costs

Under the counterfactual scenario, end users said that they would conduct more frequent calibration checks or calibrations as a precautionary measure and would annually reevaluate the EPA protocol gases they use to ensure that the information included on the certificates is accurate. Most electric utilities and large industrial establishments have on-staff environmental compliance teams that perform these activities. These teams may consist of one or more individuals and either be located on site or, as is the case with many utilities, based at a central location and travel among plants.

Users estimate that under the counterfactual scenario of using indirectly traceable reference gases, the incremental operations and maintenance costs associated with monitoring an individual unit would be approximately $2,940 a year.

In addition to more frequent calibrations and calibration checks, under the counterfactual scenario of using indirectly traceable gases, the EPA protocol gases would annually be subjected to internal round-robin testing by the compliance team. This process would entail testing standards against more rigorous standards, standards from other SGCs, or would use more advanced techniques. The team would undertake this process every year to maintain their confidence in the standards that they are purchasing from the vendor.

Users estimate that under the counterfactual scenario of using indirectly traceable reference gases, the incremental operations and maintenance costs associated with monitoring an individual unit would be approximately $2,940 a year.[11] The estimate is calculated on a per-unit basis to facilitate extrapolation to the total number of units that participate in emissions trading programs and are estimated to currently use directly traceable EPA protocol gases.[12] End users interviewed indicated that the level of effort involved in that process would be directly related to the number of units under management. The per-unit estimate covers all operations and maintenance costs, including annual reevaluation of indirectly traceable gases.

[11]The operations and maintenance cost estimate of $2,941 was developed using information from an internal study conducted by an electric utility. The utility's estimated annual savings from using directly traceable EPA protocol gas was divided by the number of units located with the fleet involved in the analysis. These calculations are not disclosed herein to maintain the utility's confidentiality.

[12]Although it is possible for more than one unit to share a stack, and therefore a CEM system, these instances are negligible.

Estimated Unit Population

The population of affected electric utility and industrial units, such as large utility and industrial boilers, was gathered from annual compliance reports for the three emissions trading systems included in this analysis: Acid Rain Program, OTC NO_x Budget, and RECLAIM. These unit populations were projected through 2007 using the average annual growth rate of the period for which data was available (see Table 5-6). The total unit population for 2001 was 2,795; for the year 2007, the population is projected to be 3,301, an increase of 19 percent.[13] All of these units are required to maintain CEM systems that must be calibrated using EPA protocol gases. To avoid double counting units, we subtracted from the unit population total instances in which a unit participated in more than one program.

As stated earlier, not all units are currently using directly traceable EPA protocol gases. These "unaffected" units are subtracted from the population because they would experience no change in operations and maintenance costs. Using confidential sales data obtained during the SGC interviews, we estimate that approximately 419 of the 2,313 estimated units involved in the SO_2 allowance trading program of the Acid Rain Program in 2001 used EPA protocols certified via the GMIS method. This represents approximately 18 percent of the utility and industrial units. Based on this information, 18 percent of the units were removed from the entire time series. The same estimation methodology was applied to units involved in other programs to remove the number that already purchase indirectly traceable EPA protocol gases.

Table 5-7 shows the total estimated operations and maintenance cost for the population of units. To calculate the annual impacts, the number of units in each year was multiplied by the $2,940 estimated operations and maintenance cost estimate. The operations and maintenance cost savings for units in these programs is estimated to be $6.7 million for 2001 and will increase to $7.9 million in 2007.

[13]Data for RECLAIM is collected by facility, not by unit. As such, we use the number of facilities participating in RECLAIM as an estimate of the number of units.

Table 5-6. Number of Units Participating in Emissions Trading Programs

Year	Acid Rain Program	OTC NO_x Budget	RECLAIM[a]	Total
Total population				
1993				
1994	263		394	657
1995	1,905		386	2,291
1996	1,904		378	2,282
1997	1,881		370	2,251
1998	1,980		362	2,342
1999	1,975	135	354	2,464
2000	2,261	139	335	2,735
2001	2,313	144	338	2,795
2002	2,384	149	341	2,873
2003	2,457	153	344	2,954
2004	2,532	158	347	3,037
2005	2,610	163	350	3,122
2006	2,689	168	353	3,210
2007	2,772	173	356	3,301
Number using directly traceable NTGs				
1994	263		323	586
1995	1,552		316	1,868
1996	1,551		309	1,860
1997	1,528		303	1,831
1998	1,631		296	1,927
1999	1,608	111	290	2,008
2000	1,895	114	274	2,283
2001	1,894	118	277	2,288
2002	1,952	122	279	2,352
2003	2,011	125	282	2,418
2004	2,073	129	284	2,486
2005	2,136	133	287	2,556
2006	2,202	138	289	2,628
2007	2,269	142	291	2,703

[a]Data is collected by facility in RECLAIM, not by unit. As unit data was unavailable, facilities counts are used as estimates.

Sources: U.S. Environmental Protection Agency. 2002b. "EPA's Clean Air Market Programs: Compliance Reports [various years]." <http://www.epa.gov/airmarkets/cmprpt/>. As obtained on May 9, 2002.
South Coast Air Quality Management District. 2002. "Annual RECLAIM Audit Report for 2000 Compliance Year." Diamond Bar, California: South Coast Air Quality Management Board. March 1.

Table 5-7. Estimated Operations and Maintenance Costs Under the Counterfactual Scenario ($)

Year	Acid Rain Program	OTC NO_x Budget	RECLAIM	Total
1994	773,529		948,728	1,722,257
1995	4,563,761		929,464	5,493,225
1996	4,560,820		910,201	5,471,021
1997	4,493,718		890,937	5,384,656
1998	4,797,441		871,674	5,669,115
1999	4,728,731	326,010	852,410	5,907,151
2000	5,572,635	334,947	806,659	6,714,241
2001	5,569,562	346,743	813,883	6,730,189
2002	5,740,074	357,602	821,107	6,918,783
2003	5,915,807	368,800	828,331	7,112,938
2004	6,096,919	380,349	835,555	7,312,823
2005	6,283,576	392,260	842,779	7,518,615
2006	6,475,948	404,544	850,002	7,730,494
2007	6,674,209	417,212	857,226	7,948,648

Source: Confidential end-user questionnaires and RTI estimates.

5.3.2 Impact of the Counterfactual on Retirement of Emissions Allowances

Units undergo an annual reconciliation process during which emissions allowances are retired in sufficient quantities to cover the actual volume of emissions from the preceding year. As such, the accuracy with which the data are reported impacts the number of allowances retired.

The increase in analytical uncertainty associated with switching from directly to indirectly traceable EPA protocol gases certified via the GMIS method would increase the number of emissions allowances retired by trading program participants each year. To maintain compliance with environmental regulations, affected units must submit monitoring data to regulatory bodies and perform accuracy assessments. Units undergo an annual reconciliation process during which emissions allowances are retired in sufficient quantities to cover the actual volume of emissions from the preceding year. As such, the accuracy with which the data are reported impacts the number of allowances retired.

Estimating the Increase in Analytical Uncertainty

> Because uncertainty is cumulative, an NTG will carry the uncertainty of the standards that precede it in the traceability chain in addition to its own.

In Sections 2 and 3, we discussed how and why the certification of EPA protocol gases and other NTGs via the GMIS method results in larger analytical uncertainty. During the interviews, several SGCs said that some gases that currently have ±1 percent uncertainty would have ±2 percent, but not all. Other SGCs said that the distribution of their products between ±1 percent and ±2 percent uncertainty would not change. And still more SGCs indicated that all their products would have ±2 percent uncertainty under the counterfactual scenario.

The differences in responses are largely attributed to a marketing technique used by SGCs that rounds off the actual uncertainty to the nearest whole number to differentiate products. Generally, gases labeled ±1 percent are directly traceable to NIST and gases labeled ±2 percent are indirectly traceable. However, all SGCs said that the average actual difference was significantly less than ±1 percent: i.e., ±1 percent gases have typically been rounded down and ±2 percent gasses have typically been rounded up.

When an NTG is consumed, however, the actual uncertainty printed on the cylinder's accompanying certificate of analysis is input into the continuous emission monitoring (CEM) systems' data acquisition systems. Although SGCs may classify NTGs as "1 percent" or "2 percent" for marketing purposes, consumers ultimately input the actual uncertainty value from the certificate into their data systems.

> Because we received a mixture of qualitative and quantitative responses from about half of the SGCs and no measurable responses from the others, the increase in uncertainty is expressed as a range over which the average increase is likely to exist. This range reflects an upper and lower bound of economic impacts.

SGCs disagreed over what the average incremental uncertainty from the insertion of the GMIS step is. The GMISs' uncertainty will vary among SGCs depending on the equipment used, manufacturing tolerances, time, number of tests, and quality control techniques, among other factors. One SGC may add relatively little uncertainty whereas another may add a more significant amount.

Because we received a mixture of qualitative and quantitative responses from about half of the SGCs and no measurable responses from the others, we decided to express the increase in uncertainty as a range over which the average increase is likely to exist. This range reflects an upper and lower bound of economic impacts.

The impact calculations assume an incremental increase of between 0.1 and 0.3 percent uncertainty. As an example, a directly traceable NTG currently having an uncertainty of 1 percent would become an indirectly traceable gas under the counterfactual with an uncertainty between 1.1 and 1.3 percent. The remainder of this section used the lower bound of 0.1 to present the analysis approach for calculating impacts associated with increasing the number of emissions allowances retired each year.

Any increase in uncertainty will increase the number of allowances that need to be retired by a firm to cover its emissions. As discussed in Section 3, an increase in uncertainty widens the 95 percent confidence interval of the calibration value. The increase in analytical uncertainty would increase the number of allowances retired each year by emissions trading program participants by the incremental uncertainty multiplied by the actual number of allowances retired. If 100 allowances were originally retired and then uncertainty increased 1 percentage point, then without the NTRM program, 101 allowances would have been retired.

Estimating the Additional Allowances Retired due to Higher Analytical Uncertainty

Economic benefits are expected to increase with the commencement of the Section 126 Federal NO_X Budget Program and the NO_X SIP Call, which will add hundreds of units to the total number of units participating in emissions trading programs.

To estimate the value that the NTRM program has on reducing unnecessary or early retirement of allowances, we quantify the number of allowances that units avoided retiring early, net of firms currently using indirectly traceable EPA protocol gases. We then multiply the number of allowances associated with that increase by the market price for that vintage, or allowance year.

Table 5-8 shows the number of allowances retired under the Acid Rain Program, OTC NO_X Budget, and RECLAIM from the inception of those programs to present and estimates through 2007.[14] Each allowance is equal to one ton of SO_2 or NO_X emissions. These are the baseline emissions from which the impact of increased uncertainty for end users is valued. To account for allowances retired by current indirectly traceable gas users, we take the average number of allowances per unit multiplied by the number of units using indirectly traceable gases and subtract these from the total

[14]The Acid Rain Program and OTC NO_X Budget Program denominate allowances in tons. RECLAIM denominates allowances in pounds. However, to facilitate comparison, RECLAIM data is presented in tons.

Table 5-8. Allowances Retired Under Existing Emissions Trading Systems

Year	Acid Rain Program (SO_2)	OTC NO_x Program (NO_x)	RECLAIM (SO_2)	RECLAIM (NO_x)
For all units				
1994			7,232	25,314
1995	5,298,429		8,064	25,764
1996	5,433,351		6,484	24,796
1997	5,474,440		6,464	21,786
1998	5,298,498		6,793	20,892
1999	4,944,676	174,843	6,378	20,775
2000	11,201,999	174,492	6,009	20,491
2001	11,017,475	183,283	5,412	15,403
2002	10,835,990	177,539	4,796	13,731
2003	10,657,495	135,000	4,184	12,228
2004	10,481,940	135,000	4,184	12,228
2005	10,309,277	135,000	4,184	12,228
2006	10,139,459	135,000	4,184	12,228
2007	9,972,437	135,000	4,184	12,228
For units currently using directly traceable standards				
1993				
1994			5,921	20,725
1995	4,337,820		6,602	21,093
1996	4,448,280		5,308	20,300
1997	4,481,920		5,292	17,836
1998	4,337,876		5,561	17,104
1999	4,048,202	143,144	5,222	17,008
2000	9,171,067	142,856	4,920	16,776
2001	9,019,998	150,054	4,430	12,610
2002	8,871,416	145,351	3,926	11,242
2003	8,725,283	110,524	3,426	10,011
2004	8,581,556	110,524	3,426	10,011
2005	8,440,197	110,524	3,426	10,011
2006	8,301,167	110,524	3,426	10,011
2007	8,164,426	110,524	3,426	10,011

Sources: U.S. Environmental Protection Agency. 2002b. "EPA's Clean Air Market Programs: Compliance Reports [various years]." <http://www.epa.gov/airmarkets/cmprpt/>. As obtained on May 9, 2002.
RTI estimates.
South Coast Air Quality Management District. 2002. "Annual RECLAIM Audit Report for 2000 Compliance Year." Diamond Bar, California: South Coast Air Quality Management Board. March 1.

number of allowances. The resulting number of allowances is the estimate of the number retired by directly traceable gas users.

Table 5-9 shows the incremental impact on the number of allowances retired for each program for the upper and lower bound ranges of incremental uncertainty. These are the allowances that directly traceable gas users avoided retiring early by not using indirectly traceable gas. These credits are therefore equivalent to those they would have retired in the absence of the NTRM program. We next calculate the value of these credits.

The market value of allowances established through the emissions trading programs is used to quantify the economic impact of the need to retire more allowances. The market value, in theory, reflects the marginal cost of emissions abatement. For, example, if Utility A needs to purchase 1 percent more allowances, then somewhere a similar Utility B will need to reduce its emissions 1 percent. The cost of Utility B reducing emissions by 1 percent is the marginal cost of abatement and determines the market price.

Table 5-10 includes the average market price for each vintage of allowance for the cap and trade programs. The price data included in Table 5-10 are determined by EPA auctions, from Cantor Fitzgerald's Environmental Brokerage Services, or as reported by the South Coast Air Quality Management District. As is shown in Table 5-10, the allowance prices fluctuate widely. Prices depend on market conditions, the economic dispatch of units in operation, and the operating levels of units participating in the program. Prices have been as low as \$68 per ton of SO_2 in the Acid Rain Program and as high as \$41,152 for NO_x in RECLAIM.

Multiplying the price data by the number of allowances yields the value of the credits (see Table 5-11). In 2001, the total value of the lost credits ranges between \$2.2 million and \$6.8 million for our estimated incremental uncertainty range.[15] This reflects the cost to the user from having to retire additional allowances in order to meet compliance obligations due to switching from directly traceable to indirectly traceable.

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[15]The future value of the credits has been estimated using forward prices for credits as set by early auctions by EPA and market demand for credits usable in future compliance years.

Table 5-9. Avoided Early Retirement of Allowances by Units in Existing Emissions Trading Programs

Vintage	Acid Rain Program (SO_2)	OTC NO_x Program (NO_x)	RECLAIM (SO_2)	RECLAIM (NO_x)
Assuming a 0.1 increase in uncertainty				
1994			6	21
1995	4,338		7	21
1996	4,448		5	20
1997	4,482		5	18
1998	4,338		6	17
1999	4,048	143	5	17
2000	9,171	143	5	17
2001	9,020	150	4	13
2002	8,871	145	4	11
2003	8,725	111	3	10
2004	8,582	111	3	10
2005	8,440	111	3	10
2006	8,301	111	3	10
2007	8,164	111	3	10
Assuming a 0.3 increase in uncertainty				
1994			18	62
1995	13,013		20	63
1996	13,345		16	61
1997	13,446		16	54
1998	13,014		17	51
1999	12,145	525	16	51
2000	27,513	523	15	50
2001	27,060	550	13	38
2002	26,614	533	12	34
2003	26,176	405	10	30
2004	25,745	405	10	30
2005	25,321	405	10	30
2006	24,903	405	10	30
2007	24,493	405	10	30

Source: RTI estimates.

Table 5-10. Market Prices for Emissions Allowances for Existing Emissions Trading Programs

Vintage	Acid Rain Program (SO_2)	OTC NO_x Program (NO_x)	RECLAIM (SO_2)	RECLAIM (NO_x)
1994			$2,000.00	$678.73
1995	$132.00		$524.25	$710.56
1996	$68.14		$1,063.42	$786.42
1997	$110.36		$2,304.51	$1,024.41
1998	$116.96		$617.98	$1,372.92
1999	$207.03	$710.00	$839.79	$2,556.91
2000	$130.69	$676.00	$2,108.29	$21,308.32
2001	$174.97	$712.00	$5,756.32	$41,151.74
2002	$167.74	$827.00	$3,000.00	$4,000.00
2003	$105.15	$4,662.00	$3,000.00	$4,000.00
2004	$102.15	$4,817.00	$3,000.00	$4,000.00
2005	$111.15	$3,944.00	$3,000.00	$4,000.00
2006	$179.79	$3,944.00	$3,000.00	$4,000.00
2007	$68.32	$3,944.00	$3,000.00	$4,000.00

Sources: U.S. Environmental Protection Agency. 2002a. "Acid Rain Program: Allowance Auctions [Various Years]." <http://www.epa.gov/airmarkets/auctions/index.html>. As obtained on May 9, 2002.
Cantor Fitzgerald Environmental Brokerage Services. 2002. "Market Prices Index [As of May 2002]." <http://www.emissionstrading.com/marketp.htm>. As obtained on May 9, 2002.
South Coast Air Quality Management District. 2002. "Annual RECLAIM Audit Report for 2000 Compliance Year." Diamond Bar, California: South Coast Air Quality Management Board. March 1.

> We estimate the total benefit since the inception of the NTRM program, including the administrative and allowances costs, to range between $9.0 million and $13.5 million for emissions trading program participants in 2001.

To summarize, we estimate the total benefit since the inception of the NTRM program, including the operations and maintenance costs and allowances costs, to range between $9.0 million and $13.5 million for emissions trading program participants in 2001 (see Table 5-12). These economic benefits are expected to increase as cap and trade programs become more popular; in particular, the commencement of the Section 126 Federal NO_x Budget Program and the NO_x SIP Call, which will add hundreds of units to the total number of units participating in emissions trading programs.

Table 5-11. Value of Avoided Early Retirement of Allowances ($)

Vintage	Acid Rain Program (SO_2)	OTC NO_x Program (NO_x)	RECLAIM (SO_2)	RECLAIM (NO_x)	Total
Assuming a 0.1 increase in uncertainty					
1994			11,800	14,100	25,900
1995	572,600		3,500	15,000	591,000
1996	303,100		5,600	16,000	324,700
1997	494,600		12,200	18,300	525,100
1998	507,400		3,400	23,500	534,300
1999	838,100	101,600	4,400	43,500	987,600
2000	1,198,600	96,600	10,400	357,500	1,663,000
2001	1,578,200	106,800	25,500	518,900	2,229,500
2002	1,488,100	120,200	11,800	45,000	1,665,000
2003	917,500	515,300	10,300	40,000	1,483,000
2004	876,600	532,400	10,300	40,000	1,459,300
2005	938,100	435,900	10,300	40,000	1,424,400
2006	1,492,500	435,900	10,300	40,000	1,978,700
2007	557,800	435,900	10,300	40,000	1,044,000
Assuming a 0.3 increase in uncertainty					
1994			35,500	42,200	77,700
1995	1,717,800		10,400	45,000	1,773,100
1996	909,300		16,900	47,900	974,100
1997	1,483,900		36,600	54,800	1,575,300
1998	1,522,100		10,300	70,400	1,602,800
1999	2,514,300	372,400	13,200	130,500	3,030,300
2000	3,595,700	353,900	31,100	1,072,400	5,053,100
2001	4,734,700	391,500	76,500	1,556,800	6,759,500
2002	4,464,300	440,500	35,300	134,900	5,075,000
2003	2,752,400	1,888,100	30,800	120,100	4,791,500
2004	2,629,800	1,950,900	30,800	120,100	4,731,700
2005	2,814,400	1,597,300	30,800	120,100	4,562,700
2006	4,477,400	1,597,300	30,800	120,100	6,225,700
2007	1,673,400	1,597,300	30,800	120,100	3,421,700

Source: RTI estimates.

Table 5-12. Summary of Economic Benefits to Participants in Existing Emissions Trading Programs ($)

Vintage	Acid Rain Program (SO_2)	OTC NO_x Program (NO_x)	RECLAIM (SO_2)	RECLAIM (NO_x)
Assuming a 0.1 increase in uncertainty				
1994	773,500		974,600	1,748,200
1995	5,136,400		947,900	6,084,300
1996	4,863,900		931,800	5,795,700
1997	4,988,300		921,400	5,909,700
1998	5,304,800		898,600	6,203,400
1999	5,566,800	427,600	900,300	6,894,800
2000	6,771,200	431,500	1,174,500	8,377,200
2001	7,147,800	453,600	1,358,300	8,959,700
2002	7,228,200	477,800	877,900	8,583,800
2003	6,833,300	884,100	878,700	8,596,000
2004	6,973,500	912,700	885,900	8,772,100
2005	7,221,700	828,200	893,100	8,943,000
2006	7,968,400	840,500	900,300	9,709,200
2007	7,232,000	853,100	907,500	8,992,700
Assuming a 0.3 increase in uncertainty				
1994	773,500		1,026,500	1,800,000
1995	6,281,500		984,800	7,266,300
1996	5,470,100		975,000	6,445,200
1997	5,977,600		982,300	6,959,900
1998	6,319,500		952,400	7,271,900
1999	7,243,000	698,400	996,000	8,937,500
2000	9,168,300	688,800	1,910,200	11,767,300
2001	10,304,200	738,200	2,447,200	13,489,700
2002	10,204,300	798,100	991,300	11,993,800
2003	8,668,200	2,256,900	979,300	11,904,400
2004	8,726,700	2,331,200	986,500	12,044,500
2005	9,098,000	1,989,600	993,700	12,081,300
2006	10,953,300	2,001,900	1,001,000	13,956,200
2007	8,347,600	2,014,500	1,008,200	11,370,300

Source: RTI estimates.

5.4 IMPACT ON AUTOMOTIVE EMISSIONS TESTING

There are essentially two groups conducting emissions testing: (1) groups performing engine and automotive component design and testing and (2) groups performing post-consumer emissions tests for motor vehicles. Both groups consume NIST-traceable gas mixtures; however, their current consumption patterns are very different and are estimated to remain unchanged under the counterfactual scenario.

5.4.1 Post-Consumer Emissions Testing

Based on nonattainment of federal air quality standards, locally mandated post-consumer emissions testing using BAR90, IM240, and other methods requires audit organizations and testing facilities to use NTGs to calibrate analyzers. In most instances the materials used to assay candidate standards are certified using specially prepared NIST reference gas mixtures (RGMs) in cooperation with state-level environmental agencies and specialty gas manufacturers. However, in some instances, NTRMs and SRMs are used in the traceability chain. But, as the candidate standards are also certified via the GMIS method, the counterfactual scenario would have no incremental uncertainty effect similar to that discussed in the previous section concerning indirectly traceable EPA protocol gases for CEM systems calibration.

5.4.2 Automotive Design Emissions Testing

Automotive equipment manufacturers are adverse to high uncertainty of reference standards and therefore have a higher WTP for directly traceable NTGs.

Emissions testing conducted by automotive equipment manufacturers during the design phase and by their environmental regulatory bodies under compliance verification programs rely primarily on the use of directly traceable gases and SRMs themselves. As shown in Table 5-2, automotive equipment firms purchase SRMs to be used directly in the testing of engine designs or subsystem designs or to certify internally prepared standards to be used for the same purpose. In addition, they will use NTRMs or directly traceable NTGs purchased from SGCs.

According to interviewees, the economic consequences of failing to meet federal and state-mandated technical performance specifications are considerable. Automotive original equipment manufacturers (OEMs) and part manufacturers expend resources to verify that their products are in compliance with federally mandated specifications and averages. Failure to comply would invoke penalties and delay product development and consequently, product introduction, among other consequences.

These consumers are adverse to high uncertainty of reference standards and therefore have a higher WTP for directly traceable NTGs. Several major domestic and foreign OEMs minimize risk by purchasing SRMs directly from NIST or, if research and development facilities are located outside the U.S., PRMs from NMi in The Netherlands, or other national standards bodies. In instances where manufacturers purchase NTGs from SGCs, those NTGs are directly traceable to SRMs and NTRMs.

The volume of NTGs currently purchased from SGCs is approximately equal to the estimated number of directly traceable NTGs manufactured under the counterfactual scenario according to confidential SGC estimates. Based on discussion with industry experts, we believe that the automotive design firms have the highest WTP for directly traceable gases and would purchase virtually all of the NTGs certified against SRMs. As a result, they would not be affected by an incremental increase in uncertainty and would be only indirectly affected under the counterfactual due to the higher cost of directly traceable gases (which is captured in the NTG production cost analysis).

Automotive OEMs and regulatory agencies that currently purchase SRMs would continue to do so under the counterfactual scenario. Earlier in this chapter, we discussed the number of SRMs that would be available to SGCs. The SRMs currently purchased by these consumer groups were netted out of NIST's SRM capacity. We assume, therefore, that these current SRM customers would still be able to purchase SRMs.

5.5 OTHER IMPACTED PARTIES

There are several other categories of potentially impacted end users besides those performing CEM and automotive emissions tests. These end users include ambient air quality monitoring organizations, petrochemical facilities, and independent testing organizations and laboratories, including universities. These organizations purchase some combination of directly and indirectly traceable NTGs, and under the counterfactual they would be purchasing only indirectly traceable ones.

With the exception of ambient air quality monitoring organizations, it is not known for which non-CEM-related activities these organizations are using NTGs. Therefore, it is not possible to develop any impact metrics or quantify any benefits for these groups. The specific applications for which these end users are using NTGs are as disparate as their markets and industries. The exclusion of these potentially affected firms leads to an underestimate of the benefits of the NTRM program.

Regarding ambient air quality monitors, "in assessing the accuracy of an air pollution monitoring agency, measurements are made through the implementation of independent audits in which the measurements are challenged with standards… have traceability as directly as possible to NIST standards" (Musick, 1996). However, the window of accuracy for the approximately 5,000 air samplers around the country is ±20 percent. According to governmental organizations, the calibration and audit gases must be NIST traceable, but organizations are allotted a degree of flexibility in determining which "types" of NIST-traceable mixtures they use. Some may use directly or indirectly traceable EPA protocol gases. Others may use samples prepared from NTRMs, SRMs, or GMISs. In any event, as the accuracy is not as critical to their operation as it is to other end users, it is likely that increased uncertainty in the range of 0.1 to 0.3 would have no significant economic impacts.

5.6 SOCIAL COSTS OF THE NTRM PROGRAM

> NIST spent approximately $185,000 between 1990 and 1992 to develop and begin operating the NTRM program. From 1992 forward, SGCs supported the program by paying NIST fees to have candidate NTRM batches certified.

The costs of operating the NTRM program consists of the initial program development costs incurred in the early 1990s and ongoing NTRM certification expenses. Although NTRM program start-up costs were borne by NIST, the day-to-day operations costs for the program are borne by SGCs. Thus, the operation of the NTRM program consists of both NIST and industry costs. The sum of these two cost categories represents the NTRM program's social costs.

NIST spent approximately $185,000 between 1990 and 1992 to develop and begin operating the NTRM program. NIST's expenditures included $35,000 in 1990 and $75,000 in both 1991 and 1992 to design, test, evaluate, and place into operation the NTRM program.

As discussed in Section 2, SGCs are required to pay NIST to certify batches of NTRMs. The fees paid constitute the actual labor, materials, and depreciation costs, among other costs, incurred by NIST. The actual amount that SGCs pay per batch is a function of the number of cylinders in the batch (see Table 5-13). For example, SGCs pay on average $12,000 to certify between 61- and 80-cylinder batches.

Table 5-13. NIST Certification Fees ($)

Batch Size	Fee
Up to 20 Cylinders	6,000
21 to 40 cylinders	8,000
41 to 60 cylinders	10,000
61 to 80 cylinders	12,000

Source: NIST's NTRM program.

Table 5-14 summarizes both NIST's development costs and the certification fees for 1990 to 2001 and projected through 2007. Because no reasonable guidance was available on the future number of NTRM batches, the fees projections for 2002 through 2007 are the average of the annual fees paid during the historical period. Thus, over the life of the program presented in this analysis, NIST's fees totaled $185,000 and industry's $4.7 million. The combined social cost of the program is therefore about $4.9 million.

5.7 CALCULATING MEASURES OF SOCIAL RETURN

To determine the returns from NIST's investment in the development of the NTRM program, we compared the net benefits to SGCs and end users with the expenses NIST incurred in the early 1990s to develop the program. In this final section of the report, we summarize the quantified impacts of the NTRM program and calculate three summary measures of the net benefits of the program: the benefit-cost ratio, the NPV, and the social rate of return.

Table 5-14. NIST and Industry Certification Costs ($)

Year	NIST	SGC Certification Costs
1990	35,000	
1991	75,000	
1992	75,000	
1993		142,000
1994		60,000
1995		408,000
1996		242,000
1997		410,000
1998		462,000
1999		444,000
2000		428,000
2001		214,000
2002		312,222
2003		312,222
2004		312,222
2005		312,222
2006		312,222
2007		312,222
Total	185,000	4,683,332

5.7.1 Time Series of Aggregate Costs and Benefits of the NTRM Program

Table 5-15 assembles the time series of the costs and benefits of the NTRM program into one table. The SGC production benefits and the end-user administrative benefits form the base of the total benefits, about $7.5 million in 2001. The remaining benefit, end-user emissions trading, was quantified as a range because the precise increase in uncertainty for end users switching to indirectly traceable NTGs under the counterfactual scenario could not be obtained. SGCs disagreed about the exact increase in uncertainty of

Table 5-15. Time Series of Quantified Benefits and Costs ($)

Year	SGC Production Benefits (a)	End-User Operations and Maintenance Cost Savings (b)	End-User Emissions Trading Benefits		Total Benefits		NTRM Program Total (Social) Costs
			Lower Bound (c)	Upper Bound (d)	Lower Bound (a+b+c)	Upper Bound (a+b+d)	
1990							35,000
1991							75,000
1992							75,000
1993	681,009				681,009	681,009	142,000
1994	694,259	1,722,257	25,908	77,724	2,442,425	2,494,241	60,000
1995	735,931	5,493,225	591,041	1,773,123	6,820,198	8,002,280	408,000
1996	743,483	5,471,021	324,716	974,147	6,539,219	7,188,650	242,000
1997	731,027	5,384,656	525,092	1,575,276	6,640,775	7,690,958	410,000
1998	741,607	5,669,115	534,278	1,602,833	6,944,999	8,013,554	462,000
1999	738,502	5,907,151	987,606	3,030,336	7,633,259	9,675,990	444,000
2000	732,231	6,714,241	1,662,977	5,053,089	9,109,449	12,499,561	428,000
2001	716,360	6,730,189	2,229,509	6,759,506	9,676,058	14,206,055	214,000
2002	734,595	6,918,783	1,665,041	5,074,983	9,318,419	12,728,361	312,222
2003	735,694	7,112,938	1,483,049	4,791,462	9,331,681	12,640,094	312,222
2004	736,831	7,312,823	1,459,322	4,731,664	9,508,977	12,781,318	312,222
2005	738,000	7,518,615	1,424,357	4,562,665	9,680,972	12,819,281	312,222
2006	739,210	7,730,494	1,978,695	6,225,682	10,448,400	14,695,386	312,222
2007	740,454	7,948,648	1,044,022	3,421,662	9,733,124	12,110,764	312,222
Total (NPV $2001)	5,398,420	39,319,882	6,705,572	20,782,581	51,423,874	65,500,883	2,407,897

Source: RTI estimates.

using GMISs compared to NTRMs. However, most agreed that between 0.1 and 0.3 percent was a reasonable range. In 2001, the lower bound estimate for emission trading benefits was $2.2 million and the upper bound was $6.8 million. Combining all benefits for 2001 yields a total calculated benefit of between $9.7 and $14.2 million.

Whereas the quantified benefits up to and including 2001 are assessments based on the current and past market value of emissions allowances, the quantified benefits for the years 2002 through 2007 should be treated as moving estimates. Prices set in early auctions of emissions allowances for future compliance years were used to calculate emissions trading benefits in the near future. However, as those compliance years approach, those credits may become more or less valuable depending on the marginal cost of pollution abatement during those years and market conditions. The early auction prices were used because they were the best available estimate of the value of one future emissions allowance. The prices for future allowances are also affected by the market conditions during the time in which the auction is held.

The quantified benefits may not fully capture the total impact resulting from the loss in confidence experienced by end users that are forced to use indirectly traceable NTGs under the counterfactual scenario. Although we were able to quantify the direct behavioral adjustment of end users given a range of increases in incremental uncertainty, we were not able to capture indirect effects on business operations due to changes in their perception of NTGs that result from the increase in the number of steps away from the primary standards at NIST. The majority of end users interviewed for this analysis prefer to use NTGs that are directly traceable to NIST standards because of their belief that their measurements and calibrations are more defensible and that there is less variability in the NTGs purchased from the vendor over time. Most SGCs agreed that their customers' perceptions of their protocol gases and other products may be adversely affected by the introduction of the GMIS intermediate step.

5.7.2 Measures of the Net Benefits of the NTRM Program

In this section, we calculate three measures of the net benefits of the NTRM program: the benefit-cost ratio, the NPV, and the social rate of return.

If B_t is the total net benefits to SGCs and end users accrued to all beneficiaries in year t, and C_t is the cost to NIST of the program in year t, then the benefit-cost ratio for the program is given by

$$(B/C) = \frac{\sum_{i=0}^{n} \frac{B_{(t+i)}}{(1+r)^i}}{\sum_{i=0}^{n} \frac{C_{(t+i)}}{(1+r)^i}} \qquad (5.1)$$

where t is the first year in which benefits or costs occur, n is the number of years the benefits or costs occur, and r is the social rate of discount. Because benefits and program costs may occur at different time periods, both are expressed in present-value terms before the ratio is calculated.

The NPV of the NIST NTRM program can be computed as

$$NPV = \sum_{i=0}^{n} \left[\frac{B_{(t+i)}}{(1+r)^i} - \frac{C_{t+i}}{(1+r)^i} \right] \quad . \qquad (5.2)$$

The social rate of return is the value of r that sets NPV equal to 0 in Eq. (5.2).

For the NTRM program, the following parameter values were used to calculate economic returns:

t = 1990: the first year in which NIST incurred development costs

n = 17: the number of years from 1990 to 2007

r = 7 percent: the inflation-adjusted social discount rate recommended by the Office of Management and Budget.

As shown in Table 5-15, NIST expenditures begin in 1990. However, benefits associated with NIST sulfur SRMs are identified beginning in 1993 with the first production of NTRMs.

The three measures of economic return are provided in Table 5-16. The estimated net benefits to industry from the program greatly exceed NIST's investment costs for both the lower and upper bounds of our estimate.

Table 5-16. Economic Impact of NIST NTRM Program
Economic impacts reflect benefits and costs from 1990 projected through 2007.

Measure of Social Return[a]	Lower Bound	Upper Bound
Benefit-to-cost ratio	21.4	27.2
Net benefits (NPV $2001)	$49,015,977	$63,092,986
Social rate of return	221%	228%

[a]Based on a 7 percent inflation-adjusted social discount rate.

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Appendix A: Interview Guides

Scoping Questionnaire—Specialty Gas Companies

Scoping Questionnaire—Specialty Gas Companies

Introduction

Research Triangle Institute (RTI) is conducting a study of the NTRM Program on behalf of the National Institute of Standards and Technology (NIST). As part of this study, we will quantitatively and qualitatively assess the economic benefits of NTRMs to industry and evaluate the role of NIST's Gas Mixture NTRM program in the supply of NTRMs. To accomplish this task, we will construct a "counterfactual scenario" describing the reference gas material supply chain in the absence of the gas mixture NTRM. This counterfactual scenario may describe, for example, how specialty gas companies would change their business practices and end users their consumption patterns in the absence of the NTRM program.

Our preliminary hypothesis is that NTRMs' primary economic impact is that they lower the costs and increase the availability of high-quality NIST-traceable EPA protocol gases. Availability includes both adequate supply and diversity of high-quality NIST-traceable gases. To test this hypothesis, we plan to speak with specialty gas companies, industry experts, and end users of reference gases. We believe that these entities are the key to understanding the benefits of NTRMs and describing what the world would look like without the NIST Gas Mixture NTRM program.

RTI is a nonprofit organization and frequently cooperates with industry on economic impact studies of this type. As such we have established appropriate systems that respect the confidentiality of our private-sector participants. ***Any information provided to support this study will remain strictly confidential***. Information specific to an individual organization will not be presented explicitly in any reports and will not be attributed to any organization. Furthermore, all data will be presented in the aggregate to prevent the disclosure of information about any one firm's business practices or production volumes.

At the conclusion of the study, we will produce a report summarizing industry's current uses and future needs for gas mixture NTRMs. This report will be made available at no cost to all organizations that participate in the study. You may return this questionnaire via email to oconnor@rti.org or via fax at (919) 514-6683. Should you have any questions, call Alan O'Connor at (919) 541-7186.

1. Contact Information

Company name: ______________________________

Contact name: ______________________________

Division and title of contact: ______________________________

Contact address: ______________________________

Contact phone: ______________________________

Contact fax: ______________________________

Contact email: ______________________________

Date and time of interview: ______________________________

2. Production of NIST-Traceable Gases

This section requests background information on annual production volumes of NIST-traceable gases at your firm. This information will be used to develop a market model to examine the impact of the absence of the NTRM program.

2.1 Approximately how many cylinders of **1 percent, NIST-traceable** gas does your firm produce each year?

Cylinders: ______________________________

2.2 Do you use reference material other than NTRMs to certify these gases?

☐ No, we use only NTRMs.
☐ Yes, we also use SRMs to certify approximately ____ % of production because:

____
____
____
____

2.3 How many cylinders of gas can you currently certify using one NTRM?

Cylinders: ______________________________

2.4 Approximately how much does your firm spend annually on activities and labor to support its participation in the NTRM program?

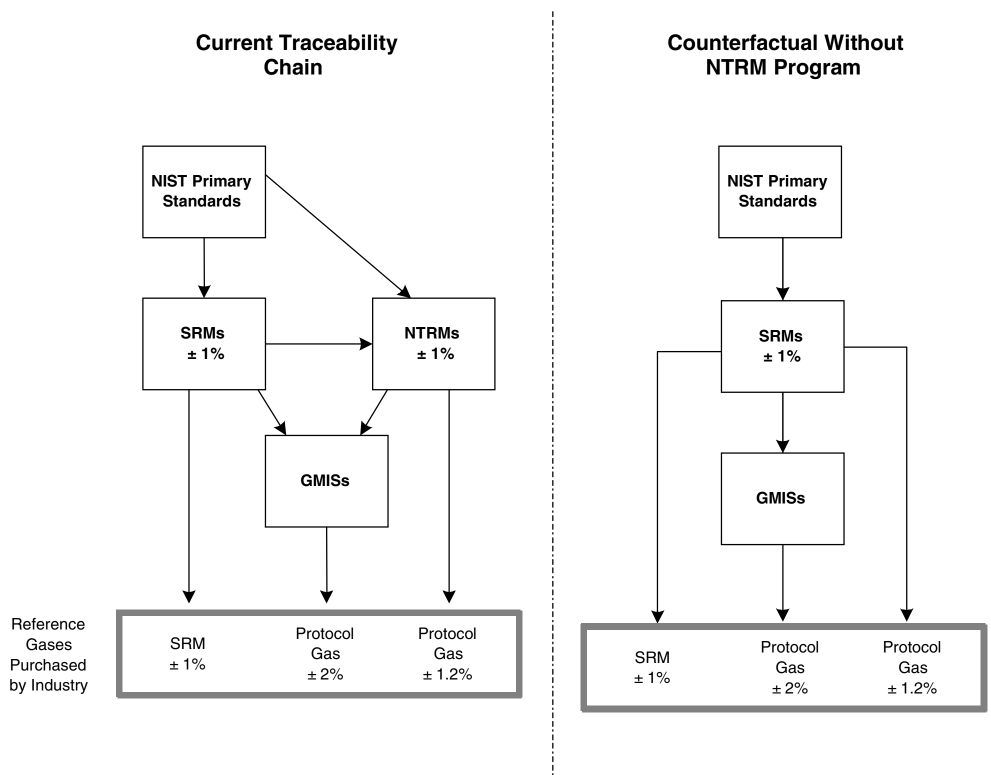
Dollars: ______________________________

2.5 Approximately how many cylinders of **2 percent, NIST-traceable** gas does your firm produce each year?

Cylinders: ______________________________

3. The Counterfactual World without NIST's NTRM Program

The World Without the NTRM Program



3.1 It is our hypothesis that in a world without the NTRM program, your firm would use NIST SRMs to certify 1 percent, EPA protocol-type gases. Because NIST can certify only a small number of SRMs each year, the market for NIST SRMs will be tight. We hypothesize that manufacturers of 1 percent gases will take either or both of the following actions to increase the number of cylinders they can produce with one SRM:

- ➤ Expand operations to increase the number of cylinders that can be certified simultaneously, and/or
- ➤ Increase the average cylinder size.

The 2 percent NIST-traceable gas market would remain largely unaffected because they would be produced from GMISs certified against SRMs. The right-hand portion of the above illustration portrays this hypothesis. Do you believe this is a fair representation of the gas certification process in the absence of NIST's NTRM program?

- ☐ Yes
- ☐ Partially agree—we would expand our operations but would not alter our current distribution of cylinder sizes.
- ☐ Partially agree—we would not expand our operations but would alter our current distribution of cylinder sizes.
- ☐ No, please explain

____

____

____

____

3.2 Under the counterfactual scenario, we hypothesize that your firm may increase the number of cylinders that can be certified against one SRM by expanding your operations. Doing so would allow more cylinders to be certified simultaneously against an SRM. Would your firm expand its operations?

☐ Yes

3.2.1 We would possibly expand the number of cylinders certified per SRM by ___________ (percent or cylinders).

3.2.2 This expansion, including labor and R&D costs as well as capital equipment, may cost as much as ___________ dollars.

3.2.3 Other comments

____

____

____

____

☐ No, please explain

____

____

____

____

3.3 We hypothesize that your firm may increase the volume of gas within an average cylinder by altering your current distribution of cylinder sizes toward larger cylinders. Would your firm take this action?

☐ Yes

3.3.1 This adjustment, including labor and R&D costs as well as capital equipment, may cost as much as ___________ dollars.

3.3.2 Other comments

☐ No, please explain

3.4 Would your unit costs for producing 1 percent gases increase or decrease in the absence of the NTRM program? Would unit costs for producing 2 percent gases increase or decrease?

3.5 Would you anticipate any bottlenecks (i.e., delays and back order time) in your production and certification processes under this scenario? Please explain.

☐ Yes ☐ No

Please explain

____

____

____

____

3.6 If your firm maintains multiple production facilities for NIST-traceable gases, is it likely that the firm may consolidate operations at fewer facilities?

☐ Yes ☐ No

Please explain

____

____

____

____

3.7 Would your firm offer the same species of NIST-traceable gases in the absence of the NTRM program?

☐ Yes

☐ No

If not, why would they not be produced? What would be the approximate drop in the production volume (by cylinder)?

____

____

____

____

4. End Users

4.1 As part of the market analysis portion of this project, we are analyzing the impacts of the NTRM program on end users, such as automotive OEMs and electric utilities. To help us develop a market model of NIST-traceable gas end users, please estimate the percentage of NIST-traceable gases consumed by industry.

Industry	**Percent of 1% Market**	**Percent of 2% Market**
Electric Utilities		
Transportation Equipment Firms		
Petrochemical Firms		
Government Agencies		
Independent Testing and Monitoring Organizations		
University and Research Laboratories		
Other (please specify)		
Other (please specify)		

4.2 Of your total sales of 1 percent reference gases, what is your approximate sales by gas type?

Gas	**Percent of 1% Gas Sales**	**Major Consuming Industries**
NO		
NO_x		
O_2		
SO_2		
CO		
CO_2		
Propane		
Methane		

Thank you for contributing to this important research effort.

Questionnaire—Specialty Gas Companies

Questionnaire—Specialty Gas Companies

Introduction

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Our preliminary hypothesis is that NTRMs' primary economic impact is that they lower the costs and increase the availability of high-quality NIST-traceable EPA protocol gases. Availability includes both adequate supply and diversity of high-quality NIST-traceable gases. To test this hypothesis, we plan to speak with specialty gas companies, industry experts, and end users of reference gases. We believe that these entities are the key to understanding the benefits of NTRMs and describing what the world would look like without the NIST Gas Mixture NTRM program.

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Date and time of interview: ______________________________

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2.1 Approximately how many cylinders of **1 percent, NIST-traceable** gas does your firm produce each year?

Cylinders: ______________________________

2.2 Do you use reference material other than NTRMs to certify these gases?

- ☐ No, we use only NTRMs.
- ☐ Yes, we also use SRMs to certify approximately ____ % of production because:

____

____

____

____

2.3 How many cylinders of gas can you currently certify using one NTRM?

Cylinders: ______________________________

2.4 Approximately how much does your firm spend annually on activities and labor to support its participation in the NTRM program?

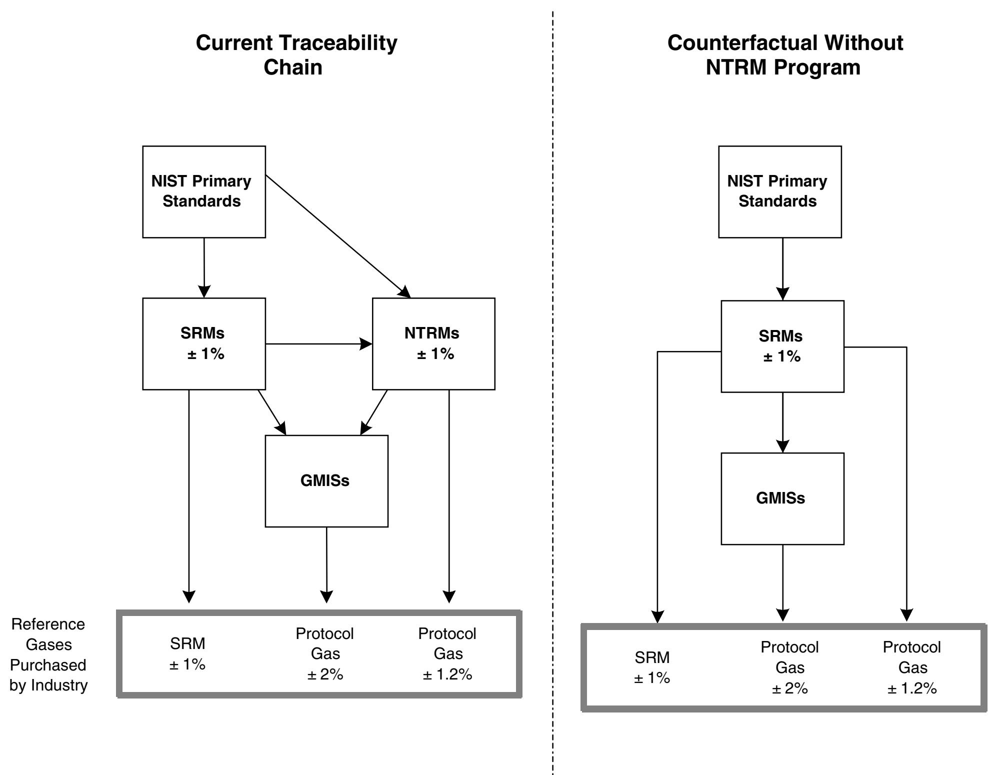
Dollars: ______________________________

2.5 Approximately how many cylinders of **2 percent, NIST-traceable** gas does your firm produce each year?

Cylinders: ______________________________

3. The Counterfactual World without NIST's NTRM Program

The World Without the NTRM Program



3.1 Would your unit costs for producing 1 percent gases increase or decrease in the absence of the NTRM program? Would unit costs for producing 2 percent gases increase or decrease?

____

3.2 Would you anticipate any bottlenecks (i.e., delays and back order time) in your production and certification processes under this scenario? Please explain.

☐ Yes ☐ No

Please explain

____

3.3 If your firm maintains multiple production facilities for NIST-traceable gases, is it likely that the firm may consolidate operations at fewer facilities?

☐ Yes ☐ No

Please explain

____

3.4 Would your firm offer the same species of NIST-traceable gases in the absence of the NTRM program?

☐ Yes

☐ No

If not, why would they not be produced? What would be the approximate drop in the production volume (by cylinder)?

____

4. End Users

4.1 As part of the market analysis portion of this project, we are analyzing the impacts of the NTRM program on end users, such as automotive OEMs and electric utilities. To help us develop a market model of NIST-traceable gas end users, please estimate the percentage of NIST-traceable gases consumed by industry.

Industry	Percent of 1% Market	Percent of 2% Market
Electric Utilities		
Transportation Equipment Firms		
Petrochemical Firms		
Government Agencies		
Independent Testing and Monitoring Organizations		
University and Research Laboratories		
Other (please specify)		
Other (please specify)		

4.2 Of your total sales of 1 percent reference gases, what is your approximate sales by gas type?

Gas	Percent of 1% Gas Sales	Major Consuming Industries
NO		
NO_x		
O_2		
SO_2		
CO		
CO_2		
Propane		
Methane		

Thank you for contributing to this important research effort.

Questionnaire—End Users of NIST-Traceable Gas-Mixture Standards

Questionnaire—End Users of NIST-Traceable Gas Mixture Standards

Introduction

Research Triangle Institute (RTI) is conducting a study of the NTRM Program on behalf of the National Institute of Standards and Technology (NIST). As part of this study, we will quantitatively and qualitatively assess the economic benefits of NTRMs to industry and evaluate the role of NIST's Gas Mixture NTRM program in the supply of NIST-traceable gas mixture standards. To accomplish this task, we will construct a counterfactual scenario describing the reference gas material supply chain in the absence of the gas mixture NTRM. This counterfactual scenario may describe, for example, how specialty gas companies would change their business practices and end users their consumption patterns in the absence of the NTRM program.

Our preliminary hypothesis is that NTRMs' primary economic impact is to lower the costs and increase the availability of high-quality NIST-traceable EPA protocol gases. Availability includes both adequate supply and diversity of high-quality NIST-traceable gases. To investigate this hypothesis, we are speaking with specialty gas companies, industry experts, and end users of reference gases. We believe that these entities are the key to understanding the benefits of NTRMs and describing what the world would look like without the NIST Gas Mixture NTRM program.

RTI is a nonprofit organization and frequently cooperates with industry on economic impact studies of this type. As such we have established appropriate systems that respect the confidentiality of our private-sector participants. ***Any information provided to support this study will remain strictly confidential***. Information specific to an individual organization will not be presented explicitly in any reports and will not be attributed to any organization. What is more, all data will be presented in the aggregate to prevent the disclosure of information about any one firm's business practices or production volumes.

At the conclusion of the study, we will produce a report summarizing industry's current uses and future needs for gas mixture NTRMs. This report will be made available at no cost to all organizations that participate in the study. You may return this questionnaire via email to oconnor@rti.org or via fax at (919) 514-6683. Should you have any questions, call Alan O'Connor at (919) 541-7186.

1. Contact Information

Company name: ______________________

Contact name: ______________________

Division and title of contact: ______________________

Contact address: ______________________

Contact phone: ______________________

Contact fax: ______________________

Contact email: ______________________

Date and time of interview: ______________________

Is your response for your plant, division, or company? ______________

1.1 Definitions

This questionnaire frequently refers to "1 percent" and "2 percent" NIST-traceable gas mixture standards. These gases are defined by their analytical uncertainty. Therefore:

- **1 percent gases** refers to NIST-traceable gas mixture standards, such as EPA protocol gases, that are certified to be + or – 1 percent relative uncertainty. These gases, produced by specialty gas manufacturers, are one step away from the primary standard, NIST Standard References Materials (SRMs) or NIST-Traceable Reference Materials (NTRMs).
- **2 percent gases** refers to NIST-traceable gas mixture standards, such as EPA protocol gases, that are certified to be + or – 2 percent relative uncertainty. These gases, produced by specialty gas manufacturers, are certified by Gas Manufacturer Intermediate Standards (GMISs), which are themselves certified by the primary standard, NIST SRMs or NTRMs.

2. Current NIST-Traceable Gas Usage

This section requests information about your current consumption of NIST-traceable, gas mixture reference and calibration standards.

2.1 Please indicate which NIST-traceable gas mixture standards you use, by activity. You may select more than one type of NIST-traceable gas per row. If you are responding to this questionnaire electronically, double click on each check box to select it.

	NIST-Traceable Gases			
Activity	**NIST SRMs**	**1 percent NIST-traceable Gases**	**2 percent NIST-traceable Gases**	**In-house standards**
Continuous Emissions Monitoring Systems (CEMS)				
Daily CEMS Calibration Error Tests	☐	☐	☐	☐
Verify Daily CEMS Calibration Error Tests	☐	☐	☐	☐
Quarterly CEMS Calibration Linearity Checks	☐	☐	☐	☐
Verify Quarterly CEMS Calibration Linearity Checks	☐	☐	☐	☐
Verify Quality of Third-Party Standards	☐	☐	☐	☐
Annual Relative Accuracy Assessments	☐	☐	☐	☐
Semiannual Relative Accuracy Assessments	☐	☐	☐	☐
Bias and Adjustment	☐	☐	☐	☐
Ambient Air, Monitoring, and Emissions Testing				
Daily Calibration	☐	☐	☐	☐
Verify Daily Calibration	☐	☐	☐	☐
Quarterly Calibration	☐	☐	☐	☐
Verify Quarterly Calibration	☐	☐	☐	☐
Verify Quality of Third-Party Standards	☐	☐	☐	☐
Production Management				
Input Stream Monitoring	☐	☐	☐	☐
Product Development	☐	☐	☐	☐
Product Testing	☐	☐	☐	☐
Verify Quality of Third-Party Standards	☐	☐	☐	☐

2.2 Are there other applications not mentioned in Question 2.1 for which you use NIST-traceable gas mixture standards? If so, please list the application and the "type" of standard used.

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2.3 Approximately how many cylinders of gas mixture standards do you use each year?

Cylinders of 1 percent gas: ______________________

Cylinders of 2 percent gas: ______________________

3. NIST-Traceable Gas Usage under the Counterfactual Scenario

Without NTRMs, SGCs' capacity to produce 1 percent NIST-traceable gases would be greatly reduced. However, the availability of 2 percent NIST-traceable gases would be unaffected. This section asks you to consider a world where 1 percent gases are expensive and difficult to obtain. Environmental compliance can be maintained using 2 percent gases, but firms may opt to use 1 percent gases to decrease uncertainty of measurements and increase operating efficiencies. We ask you if and how substituting 2 percent standards for 1 percent standards may affect your operations, including operation levels of CEM systems, participation in the SO_2 emissions trading program, and other issues. We understand that these questions are highly hypothetical; your best estimates are all we ask for.

3.1 Does your firm currently use 1 percent gases?

☐ Yes. Please continue.

☐ No. End of questionnaire, thank you for participating.

3.2 The table below asks for activities for which you currently use NIST-traceable 1 percent gases voluntarily and could use 2 percent gases. The third column estimates the approximate percentage drop in your total 1 percent gas use the switch to 2 percent gas would cause.

Activity	NIST-Traceable Gases	
	Can Switch from 1 Percent to 2 Percent	**Percent Reduction in Total 1 Percent Gas Use**
Continuous Emissions Monitoring Systems (CEMS)		
Daily CEMS Calibration Error Tests	☐	%
Verify Daily CEMS Calibration Error Tests	☐	%
Quarterly CEMS Calibration Linearity Checks	☐	%
Verify Quarterly CEMS Calibration Linearity Checks	☐	%
Verify Quality of Third-Party Standards	☐	%
Annual Relative Accuracy Assessments		
Semiannual Relative Accuracy Assessments	☐	%
Bias and Adjustment	☐	%
Ambient Air, Monitoring, and Emissions Testing	☐	%
Daily Calibration	☐	%
Verify Daily Calibration	☐	%
Quarterly Calibration		
Verify Quarterly Calibration	☐	%
Verify Quality of Third-Party Standards	☐	%
Production Management	☐	%
Input Stream Monitoring	☐	%
Product Development	☐	%
Product Testing	☐	%
Verify Quality of Third-Party Standards	☐	%

3.3 Would using 2 percent gas to calibrate your Continuous Emissions Monitoring System(s) instead of 1 percent gas affect the operating levels of pollution control equipment at your firm?

☐ Yes, operating levels would increase by ______ percent, at an estimated approximate annual cost of $_________ per ___________.

☐ No, operating levels would not change.

☐ No, we do not calibrate CEMS using 1 percent gas.

Comments: ____

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3.4 Do you operate ambient air, soil, or water monitoring systems? If so, would the use of 2 percent gas in the place of 1 percent gas affect these operations?

☐ No, we do not operate ambient monitoring systems or ambient monitoring systems that are calibrated by gas mixture standards.

☐ No, we currently use 2 percent gas to calibrate these systems.

☐ No, these systems would not be affected.

☐ Yes, please explain: ____

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3.5 Would using 2 percent gas instead of 1 percent gas affect your firm's activities in the SO_2 Emissions Trading program? Examples of changes include using credits that would otherwise be sold or banked or buying more credits.

☐ Yes, we would buy _________ percent more credits.

☐ Yes, we would reduce the number of credits sold or banked by _________ percent.

☐ No, we would not change our current regimen.

☐ No, we do not participate in the SO_2 Emissions Trading Program.

Comments: ____

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3.6 Would using 2 percent gas affect the quality of the fuels selected for input into the electricity generation process or other production processes at your firm, such as petrochemical operations?

- ☐ No, such operating decisions would not be affected.
- ☐ Yes, please explain: ____________________

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3.7 What other business or production costs impacts would your company incur as a result of switching from 1 percent to 2 percent gases?

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4. Comments

4.1 Do you have any comments about this study, the benefits of the NTRM program, or that you would like to submit to NIST?

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4.2 We will mail you a copy of the final report at no cost to you. Thank you for participating in this important research effort.