Adipic Acid Production Project Protocol

Workgroup Comment Draft

Version 1.0

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Notes on the Workgroup Comment Draft

This document represents a complete protocol draft which requires additional feedback to polish into a final protocol for adoption. Workgroup members have the opportunity to review and comment on this draft prior to its review by the public at large.

Written comments must be received by the close of business (6:00 pm Pacific) on Wednesday, November 20. Comments should be organized by protocol section, and may be submitted to tanderson@climateactionreserve.org, preferably in the form of a MS Word document. Reserve staff will review Workgroup comments and implement any necessary protocol changes. Workgroup members will also have the option of submitting comments during the public comment period, expected to begin in late-November. If you have any questions, please contact Trevor Anderson at tanderson@climateactionreserve.org or (213) 891-6927.

Acknowledgements

Staff (alphabetical)

<u>Version 1.0</u>

Lead Author

Trevor Anderson

Supporting Authors

Max DuBuisson
Craig Ebert
Heather Raven

Workgroup

The list of workgroup members below comprises all individuals and organizations who have assisted in developing the protocol. For more information, see section 4.3 of the Reserve Program Manual.

Seth Baruch	Carbonomics, LLC
Phillip Cunningham	Ruby Canyon Engineering, Inc
William Flederbach	ClimeCo Corporation
John McDougal	Element Markets
Lambert Schneider	Öko-Institut

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Table of Contents

Abbreviations and Acronyms ... 1
1 Introduction ... 3
2 The GHG Reduction Project ... 4
2.1 Background ... 4
2.2 Project Definition ... 5
2.3 The Project Developer ... 6
3 Eligibility Rules ... 7
3.1 Location ... 7
3.2 Project Start Date ... 7
3.3 Project Crediting Period ... 8
3.4 Additionality ... 8
3.4.1 The Performance Standard Test ... 9
3.4.2 The Legal Requirement Test ... 10
3.5 Regulatory Compliance ... 12
4 The GHG Assessment Boundary ... 13
5 Quantifying GHG Emission Reductions ... 16
5.1 Quantifying Baseline Emissions ... 17
5.1.1 Baseline Nitric Acid Recovery Ratio ... 25
5.1.2 Mitigating Leakage ... 26
5.2 Quantifying Project Emissions ... 27
5.2.1 Calculating Project N_2O Emissions in the Off Gas ... 27
5.2.2 Calculating Project Emissions from Hydrocarbon Use ... 28
5.2.3 Calculating Project Emissions from Off Gas Reheating ... 30
6 Project Monitoring ... 32
6.1 Monitoring Requirements ... 32
6.1.1 System Installation and Certification ... 33
6.1.2 Calibration ... 34
6.1.3 Accuracy Testing ... 34
6.2 QA/QC Requirements ... 34
6.2.1 Frequency of Testing ... 35
6.2.2 Data Management ... 36
6.3 Missing Data Substitution ... 36
6.4 Monitoring Parameters ... 37
7 Reporting Parameters ... 51
7.1 Project Submittal Documentation ... 51

7.2 Record Keeping 51
7.3 Reporting Period and Verification Cycle 52
8 Verification Guidance 53
8.1 Standard of Verification 53
8.2 Monitoring Plan 53
8.3 Verifying Project Eligibility 53
8.4 Core Verification Activities 54
8.5 Adipic Acid Production Verification Items 55
8.5.1 Project Eligibility and CRT Issuance 55
8.5.2 Quantification 57
8.5.3 Risk Assessment 57
8.5.4 Completing Verification 58
9 Glossary of Terms 59
10 References 61
Appendix A Development of the Performance Standard 62

List of Tables

Table 2.1. Approved N_2O Control Technologies for Adipic Acid Projects 6
Table 4.1. Description of all Sources, Sinks, and Reservoirs 14
Table 5.1. 100-year Global Warming Potential for Non-CO_2 GHGs 16
Table 6.1. Adipic Acid Project Monitoring Parameters 37
Table 8.1. Summary of Eligibility Criteria for an Adipic Acid Project 54
Table 8.2. Eligibility Verification Items 56
Table 8.3. Quantification Verification Items 57
Table 8.4. Risk Assessment Verification Items 58

List of Figures

Figure 2.1. Typical Process Flowsheet for Catalytic Decomposition of N_2O 5
Figure 4.1. General illustration of the GHG Assessment Boundary 13
Figure 5.1. Organizational Chart of Equations for Adipic Acid Projects 17

List of Equations

Equation 3.1. Performance Standard Test for Projects with a Technology Enhancement 9
Equation 3.2. Calculating the Project Utilization Rate 10
Equation 3.3 Calculating the Historical Utilization Rate 10
Equation 5.1. Calculating GHG Emission Reductions 16
Equation 5.2. Calculating Annual Baseline N_2O Abatement Efficiency in Adipic Acid Production 18
Equation 5.3. Calculating Total Annual Baseline N_2O Emissions Before any Emissions Control Treatment 19
Equation 5.4. Calculating Annual Abated Baseline N_2O Emissions 20
Equation 5.5. Calculating Annual Baseline N_2O Abatement Efficiency in Baseline Year with Maximum Adipic Acid Production 20
Equation 5.6. Calculating Annual Baseline N_2O Abatement Efficiency in Baseline Year with Minimum Adipic Acid Production 21
Equation 5.7. Calculating Annual Baseline N_2O Abatement Efficiency when Reporting Period Adipic Acid Production is in between Baseline Minimum and Maximum Production Values 21
Equation 5.8. Calculating the Slope of the Linear Trend Line between the Abatement Efficiency Values based on the Minimum and Maximum Baseline Adipic Acid Production Values 22
Equation 5.9. Calculating the *y-intercept* of the Linear Trend Line between the Abatement Efficiency Values based on the Minimum and Maximum Baseline Adipic Acid Production Values 22
Equation 5.10. Calculating Total N_2O Emissions during the Reporting Period before any Emissions Control Treatment 25
Equation 5.11. Calculating Nitric Acid Recovery Ratio 26
Equation 5.12. Calculating Baseline Emissions 26
Equation 5.13. Project Emissions 27
Equation 5.14. Project N_2O Emissions in the Off Gas Routed to Emissions Control Units 28
Equation 5.15. Project Emissions from Hydrocarbon Use 29
Equation 5.16. Project Carbon Dioxide Emissions from Hydrocarbon Use 29

Equation 5.17. Project Methane Emissions from Hydrocarbon Use....30
Equation 5.18. Project Emissions from Off Gas Reheating 30
Equation 5.19. Project Emissions from Steam Export 30
Equation 5.20. Project Emissions from Off Gas Utilization 31
Equation 5.21. Project Emissions from Off Gas Heating 31

Abbreviations and Acronyms

AAP	Adipic Acid Plant
AE	Abatement Efficiency
ARB	Air Resources Board
ASTM	American Society for Testing and Material Information
BACT	Best available control technology
CAA	Clean Air Act
CEMS	Continuous emission monitoring system
CFR	Code of Federal Regulations
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COI	Conflict of interest
CRT	Climate Reserve Tonne
DAHS	Data acquisition and handling system
EPA	U.S. Environmental Protection Agency
FTIR	Fourier transform infrared spectroscopy
GHG	Greenhouse gas
GWP	Global warming potential
HC	Hydrocarbon
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KA	Cyclohexanone (K)/cyclohexanol (A)
kg	Kilogram
kt	Kiloton
lb	Pound

m	Meter
Mg	Megagram
MW	MegaWatt
MWh	MegaWatt-hour
NDIR	Non-dispersive infrared sensor
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxide; refers to NO and NO_2
NOV	Notice of violation
NOVA	Notice of verification activities
NSCR	Non-selective catalytic reduction
N_2O	Nitrous oxide
O2	Oxygen
PSD	Prevention of Significant Deterioration
QA/QC	Quality assurance and quality control
RATA	Relative accuracy test audit
RP	Reporting period
SCR	Selective catalytic reduction
Reserve	Climate Action Reserve
SSR	Source, sink, and reservoir
t	Metric ton (or tonne)
TRU	Thermal reduction unit
UR	Utilization rate

1 Introduction

The Climate Action Reserve (Reserve) Adipic Acid Production Project Protocol provides guidance to account for, report, and verify greenhouse gas (GHG) emission reductions associated with the installation and use of a nitrous oxide (N_2O) emission control technology to reduce N_2O emissions as a byproduct of adipic acid production.

The Climate Action Reserve is an environmental nonprofit organization that promotes and fosters the reduction of greenhouse gas (GHG) emissions through credible market-based policies and solutions. A pioneer in carbon accounting, the Reserve serves as an approved Offset Project Registry (OPR) for the State of California's Cap-and-Trade Program and plays an integral role in supporting the issuance and administration of compliance offsets. The Reserve also establishes high quality standards for offset projects in the North American voluntary carbon market and operates a transparent, publicly-accessible registry for carbon credits generated under its standards.

Project developers that initiate N_2O abatement projects at adipic acid plants (AAPs) ("adipic acid projects") use this document to quantify and register GHG reductions with the Reserve. The protocol provides eligibility rules, methods to calculate reductions, performance-monitoring instructions, and procedures for reporting project information to the Reserve. Additionally, all project reports receive independent verification by ISO-accredited and Reserve-approved verification bodies. Guidance for verification bodies to verify reductions is provided in the Reserve Verification Program Manual[1] and Section 8 of this protocol.

This protocol is designed to ensure the complete, consistent, transparent, accurate, and conservative quantification and verification of GHG emission reductions associated with an adipic acid project.[2]

[1] Available at http://www.climateactionreserve.org/how/verification/verification-program-manual/.
[2] See the WRI/WBCSD GHG Protocol for Project Accounting (Part I, Chapter 4) for a description of GHG reduction project accounting principles.

2 The GHG Reduction Project

2.1 Background

Hexanedioic acid, commonly known as adipic acid, is among the top 50 synthetic chemicals produced in the United States each year. Current annual global production is estimated at 2.5 million metric tons[3]. The largest use for adipic acid is in the manufacture of nylon 6,6 polyamide via its reaction with 1,6-hexamethylenediamine. Nylon 6,6 polymer, discovered by W. H. Carothers in the early 1930s, is now used in carpets, tire cord, safety air bags, apparel, upholstery, auto parts, and in hundreds of other applications that impact our life in many ways.

Most adipic acid produced in the world today is manufactured from cyclohexane feedstock. Cyclohexane is converted to cyclohexanol (A), or a cyclohexanone (K)/cyclohexanol (A) mixture (KA), and the product KA is purified in the initial synthesis steps. In a second series of process steps, KA is reacted with nitric acid (HNO_3) to produce adipic acid, which is then purified by crystallization. Nitric acid oxidation of KA results in an unavoidable production of circa 1 mole of N_2O per mole of adipic acid produced. Nitric oxide (NO) is also produced in the HNO_3 oxidation step, and is generally absorbed from the reaction off-gases and re-converted to nitric acid for process recycle.[4]

Adipic acid N_2O abatement technology is similar to the abatement technology at nitric acid facilities.[5] However, unlike nitric acid production, adipic acid production cannot tolerate the associated pressure change with secondary abatement (abatement in the burner/ammonia oxidation reactor [“AOR”] where the reaction occurs). As a result, abatement is limited to tertiary abatement, installing technology to scrub the facility’s waste off gas downstream of the AOR.

Currently, most adipic acid facilities are fitted with some N_2O abatement technology. Control technology fall into four types of systems, as described in Table 2.1 below. Figure 2.1 below portrays a typical process flowsheet for the catalytic decomposition of N_2O, one of the four approved abatement methods in this protocol. The most appropriate type of control technology is also typically highly facility specific.

[3] The Human Metabolomics Database, “Metabocard for Adipic Acid (HMDB0000448),” accessed September 12, 2019, http://www.hmdb.ca/metabolites/HMDB0000448#references.
[4] Castellan, A., Bart, J. C. J., & Cavallaro, S. (1991). Industrial production and use of adipic acid. *Catalysis Today*, *9*(3), 237-254.
[5] Climate Action Reserve Nitric Acid Production Project Protocol Version 2.2, April 18, 2019. Available here: http://www.climateactionreserve.org/how/protocols/nitric-acid-production/

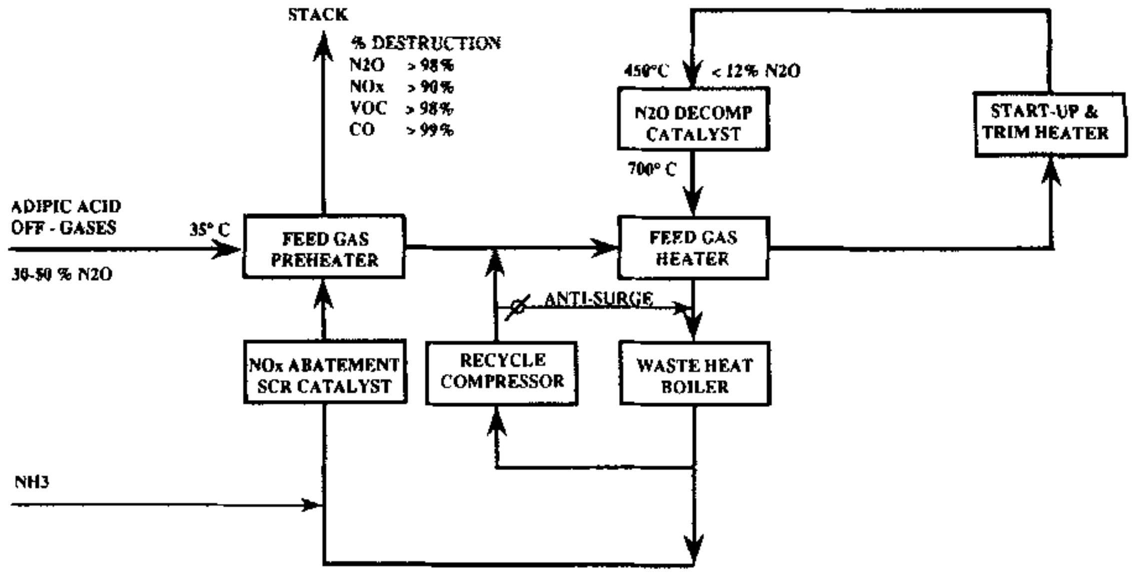

Figure 2.1. Typical Process Flowsheet for Catalytic Decomposition of N_2O

In the U.S., there is often a trade-off between N_2O abatement and the abatement of other potentially harmful pollutants, such as nitrogen oxide (NO_x). AAPs can send their off gas to an N_2O control technology, such as a thermal reduction unit (TRU) (See Table 2.1), which reduces N_2O but only has a limited capacity to reduce NO_x emissions, or can send their off gas to a NO_x-specific selective catalytic reduction (SCR) technology ("SCR de-NO_x unit"), which reduces NO_x emissions but not N_2O emissions. Because N_2O is not regulated and NO_x emissions are regulated under the Clean Air Act (CAA) (Section 3.4.2), AAPs will only utilize their N_2O control technology, e.g., TRUs, when they are falling below their legal NO_x limits. In the absence of an offset system or a regulatory reason to reduce GHG emissions, facilities have no incentive to make a capital investment to adjust their operations to eliminate the NO_x/N_2O trade-off. With an incentive, an AAP could increase the utilization of existing N_2O control technology and/or install a new N_2O control technology.

2.2 Project Definition

For the purpose of this protocol, the adipic acid GHG reduction project is defined as 1) the installation and operation of a new, previously uninstalled N_2O abatement technology and/or 2) the enhancement of an existing control technology at a single adipic acid plant (AAP) that results in the reduction of N_2O emissions that would otherwise have been vented to the atmosphere.

N_2O emissions can be abated by one of the four types of approved technologies listed in Table 2.1. Other control technologies that avoid N_2O emissions from the production of adipic acid not listed in Table 2.1 may also be permissible, pending review by and approval from the Reserve.

Table 2.1. Approved N_2O Control Technologies for Adipic Acid Projects

Abatement Type	Description	Example
Catalytic Destruction	Destroy N_2O using a catalyst – selective catalytic reduction (SCR) or non-selective catalytic reduction (NSCR)	Noble or precious metal catalysts
Thermal Destruction	Destroy N_2O in using reducing flame burners with pre-mixed CH_4 or natural gas	Thermal Reduction Units (TRUs)
Recycling / Utilization Technologies	Utilize N_2O as a reactant or input to produce other products	Using N_2O off gas as an oxidant to produce phenol from benzene
Recycle to Nitric Acid	Recycle N_2O to create nitric acid by burning the gas at high temperatures with steam	Nitrogen recycling adiabatic reactor

An "enhancement" of an existing control technology is loosely defined as the retrofit, commissioning, and/or otherwise general modification of an existing technology that increases the abatement technology utilization rate compared to its historical usage (Section 3.4.1). The utilization rate is simply defined as the percent of time the abatement technology is in use.

Box 2.1. Notes on the Utilization Rate:

The utilization rate (UR) in the Workgroup Comment Draft is adopted from the definition for "utilization factor (%)" in The GHG Protocol's "Calculating N_2O Emissions from the Production of Adipic Acid (Version 2.1)" by WRI and WBSCD as the percent of time abatement technology was in use. The IPCC Tier 2 method for estimating N_2O emissions from adipic acid production also recommends an abatement system utilization factor in order to account for any down-time of the emission abatement equipment (i.e., time the equipment is not operating) as good practice. It is also the Reserve's intent with the Adipic Acid Production Project Protocol to incentivize the increased utilization of N_2O abatement technology at AAPs (See Section 3.4.1).

Projects may only be implemented at existing, relocated, or upgraded AAPs. The protocol does not apply to new AAPs constructed on or after January 22, 2020, with the exception of new AAPs for which a permit application for construction was submitted to the appropriate regulating authorities prior to January 22, 2020.

2.3 The Project Developer

The "project developer" is an entity that has an active account on the Reserve, submits a project for listing and registration with the Reserve, and is ultimately responsible for all project reporting and verification. Project developers may be owners of adipic acid facilities, entities that specialize in project development, or N_2O abatement technology suppliers. The project developer must have clear ownership of the project's GHG reductions. Ownership of the GHG reductions must be established by clear and explicit title, and the project developer must attest to such ownership by signing the Reserve's Attestation of Title form.[6] The project developer must be the entity with liability for the emissions of the AAP (i.e., the entity named on the facility's Title V permit), unless the rights to the emissions reductions have been transferred to another entity.

[6] Attestation of Title form available at http://www.climateactionreserve.org/how/program/documents/.

3 Eligibility Rules

Projects that meet the definition of a GHG reduction project in Section 2.2 must fully satisfy the following eligibility rules in order to register with the Reserve.

Eligibility Rule I:	Location	→	*U.S. and its tribal lands and territories*
Eligibility Rule II:	Project Start Date	→	*No more than 12 months prior to project submission*
Eligibility Rule III:	Project Crediting Period	→	*Emission reductions may only be reported during the crediting period; the crediting period may be renewed one time*
Eligibility Rule IV:	Additionality	→	*Meet performance standard*
		→	*Exceed regulatory requirements*
Eligibility Rule V:	Regulatory Compliance	→	*Compliance with all applicable laws*

3.1 Location

Only projects located at adipic acid production facilities in the United States (U.S.) and on U.S. tribal lands are eligible to register with the Reserve.

3.2 Project Start Date

The project start date is defined as the date on which production first commences after the installation or enhancement of specific N_2O control technology, as defined in section 2.2. For the purposes of this protocol, a project is eligible if N_2O control technology exists at the adipic acid plant prior to the project start date, but the installation of a new N_2O control technology or enhancement of an existing one results in additional N_2O abatement. Projects such as these will recognize the delta in emissions benefits.

To be eligible, the project must be submitted to the Reserve no more than 12 months after the project start date.[7], Projects may always be submitted for listing by the Reserve prior to their start date. For projects that are transferring to the Reserve from other offset registries, start date guidance can be found in the Program Manual.

[7] Projects are considered submitted when the project developer has fully completed and filed the appropriate Project Submittal Form, available at http://www.climateactionreserve.org/how/program/documents/.

Box 3.1. Notes on Project Start Date:

With new protocols (i.e., for Versions 1.0), the Climate Action Reserve typically allows for a period of 24 months, as opposed to 12 months, prior to the Effective Date of the protocol for projects to be submitted to the Reserve for listing. It is the Reserve's understanding that this would not be beneficial or necessary for the Adipic Acid Production Project Protocol. However, if deemed worthwhile by stakeholders, the following requirements can be added:

> For a period of 12 months from the Effective Date of this protocol (Version 1.0), projects with start dates no more than 24 months prior to the Effective Date of this protocol are eligible. Specifically, projects with start dates on or after January 23, 2018 are eligible to register with the Reserve if submitted by January 22, 2020. Projects with start dates prior to January 23, 2018 are not eligible under this protocol.

3.3 Project Crediting Period

The crediting period for projects under this protocol is ten years. At the end of a project's first crediting period, project developers may apply for eligibility under a second crediting period. However, the Reserve will cease to issue Climate Reserve Tonnes (CRTs) for GHG reductions if at any point in the future, N_2O abatement becomes legally required, as defined by the terms of the legal requirement test (see Section 3.4.2). Thus, the Reserve will issue CRTs for GHG reductions quantified and verified according to this protocol for a maximum of two ten-year crediting periods after the project start date, or until the date the project activity is required by law.

The project crediting period begins at the project start date regardless of whether sufficient monitoring data are available to verify GHG reductions. Projects will be eligible to apply for a second crediting period, provided the project meets the eligibility requirements of the most current version of the protocol at the time of such application. If a project developer wishes to apply for eligibility under a second, ten-year crediting period, they must do so no sooner than six months before the end date of the initial crediting period.

A project may be eligible for a second crediting period even if the project has failed to maintain continuous reporting up to the time of applying for a second crediting period, provided the project developer elects to take a zero-credit reporting period for any period for which continuous reporting was not maintained.[8] The second crediting period shall begin on the day following the end date of the initial crediting period.

3.4 Additionality

The Reserve strives to register only projects that yield surplus GHG reductions that are additional to what would have occurred in the absence of a carbon offset market.

Projects must satisfy the following tests to be considered additional:

1. The performance standard test
2. The legal requirement test

[8] See zero-credit reporting period guidance and requirements in the Reserve Program Manual, http://www.climateactionreserve.org/how/program/program-manual/.

3.4.1 The Performance Standard Test

Projects pass the performance standard test by meeting a performance threshold, i.e., a standard of performance applicable to all adipic acid projects, established by this protocol. The performance threshold represents installation and operation of a better than business-as-usual N_2O control system at an AAP.

For projects with new installations, projects automatically pass the performance standard test by installing a new approved N_2O control technology not previously installed at the AAP, as listed in Table 2.1 and below:

1. a catalytic destruction or absorption system,
2. a thermal destruction system,
3. a system that recycles or utilizes captured N_2O as a reactant or production input and avoids direct N_2O emissions,
4. a system that recycles captured N_2O into recovered nitric acid and avoids N_2O emissions upstream from the production of conventional nitric acid, or
5. another control technology that avoids N_2O emissions from the production of adipic acid, pending Reserve approval.

Both the installation of a technology completely new to the AAP and/or the installation of a redundant technology are eligible, so long as the technology was not installed and in operation prior to the project start date.

For projects with enhancements of existing technology, projects pass the performance standard test when the utilization rate (%) in the project exceeds the historical utilization rate (%), i.e., when the percent of time the technology is used in the project exceeds the amount of time it was used historically, as determined using the following set of equations. As further explained in Section 5.1, to assess historical operations, this protocol utilizes a baseline look-back period, defined as the five most recent years of operation prior to the project start date.

Equation 3.1. Performance Standard Test for Projects with a Technology Enhancement

$$UR_P > UR_H$$

Where,			Units
UR_P	=	Percent of time the abatement technology was in use during the current year, or reporting period, of the project, see Equation 3.2	%
UR_H	=	Historical average percent of time the abatement technology was in use during the 5-year baseline look-back period, see Equation 3.3	%

Equation 3.2. Calculating the Project Utilization Rate

$$UR_P = \frac{ATU_{n,P}}{OD_{n,P}} \times 100$$

Where,

			Units
UR_P	=	Percent of time the abatement technology was in use during the current year, or reporting period, of the project, P	%
$ATU_{n,P}$	=	Number of days, n, of abatement technology utilization during the current year, or reporting period, of the project, P	days
$OD_{n,P}$	=	Number of days, n, of AAP operation during the current year or reporting period of the project, P	days

Equation 3.3 Calculating the Historical Utilization Rate

$$UR_H = AVERGE\left[\left(\frac{ATU_{n,B1}}{OD_{n,B1}} \times 100\right) + \left(\frac{ATU_{n,B2}}{OD_{n,B2}} \times 100\right) + \left(\frac{ATU_{n,B3}}{OD_{n,B3}} \times 100\right) + \left(\frac{ATU_{n,B4}}{OD_{n,B4}} \times 100\right) + \left(\frac{ATU_{n,B5}}{OD_{n,B5}} \times 100\right)\right]$$

Where,

			Units
UR_H	=	Historical average percent of time the abatement technology was in use during the 5-year period predating the project	%
$ATU_{n,B}$	=	Number of days, n, of abatement technology utilization during year B of the 5-year baseline look-back period	days
$OD_{n,B}$	=	Number of days, n, of AAP operation during year B of the 5-year baseline look-back period	days
B	=	Given year in the 5-year baseline look-back period	N/A

Box 3.2. Question on the Utilization Rate:

Should the Utilization Rate (UR) be based on operational days (as is the current case) or on operational hours?

The performance standard test is applied as of the project start date, and is evaluated each verification. Projects with new installations that pass the applicable performance standard test during the initial reporting period pass the test for the duration of their ten year crediting period, while enhancements of existing technologies need to pass the applicable performance standard test each year of the ten year crediting period. However, if the project chooses to upgrade to a newer version of the protocol, it must meet the performance standard test of that version of the protocol, applied as of the original project start date. Similarly, if a project developer wishes to apply for a second crediting period, the project must meet the eligibility requirements of the most current version of this protocol, including any updates to the performance standard test, applied as of the project start date.

3.4.2 The Legal Requirement Test

All projects are subject to a legal requirement test to ensure that the GHG reductions achieved by a project would not otherwise have occurred due to federal, state, or local regulations, or other legally binding mandates. A project passes the legal requirement test when there are no laws, statutes, rules, regulations, ordinances, court orders, governmental agency actions, enforcement actions, environmental mitigation agreements, permitting conditions, permits or other legally binding mandates requiring the abatement of N_2O at the project site.

To satisfy the legal requirement test, project developers must submit a signed Attestation of Voluntary Implementation form[9] prior to the commencement of verification activities each time the project is verified (see Section 8). In addition, the project's Monitoring Plan (Section 6) must include procedures that the project developer will follow to ascertain and demonstrate that the project at all times passes the legal requirement test.

As of the Effective Date of this protocol, the Reserve could identify no existing federal, state or local regulations that obligate AAPs to abate N_2O emissions.[10] However, Section 3.4.2.1 evaluates an identified existing regulation that *could* regulate N_2O emissions from AAPs. If an eligible project begins operation at a plant that later becomes subject to a regulation, ordinance, or permitting condition that calls for the abatement of N_2O, emission reductions may be reported to the Reserve up until the date that N_2O is legally required to be abated. Similarly, if the adipic acid plant's N_2O emissions are included under an emissions cap (e.g. under a state or federal cap-and-trade program), emission reductions may likewise be reported to the Reserve until the date that the emissions cap takes effect.

3.4.2.1 U.S. EPA GHG Permitting Requirements under the Clean Air Act

There are some existing federal regulations that may impact adipic acid project GHG emissions. Historically, the EPA regulated GHG emissions from major stationary sources under the Clean Air Act ("CAA").[11] Under this rule, commonly referred to as the "Tailoring Rule", all existing stationary sources emitting more than 100,000 tons (approximately 90,719 metric tons, "t") of CO_2e emissions per year were required to obtain Title V operating permits for GHG emissions. Additionally, facilities were required to obtain Prevention of Significant Deterioration ("PSD") permits that address GHG emissions for 1) new source construction with emissions of 100,000 tons CO2e per year or more and 2) major facility modifications resulting in GHG emission increases of 75,000 tons (approximately 68,000 t) of CO_2e per year or more.[12]

However, in 2014, the Supreme Court struck down the Title V provision of the Tailoring Rule;[13] therefore, facilities are no longer required to report GHG emissions or control technology in their Title V permit. In the ruling, the Supreme Court found that facilities may still be subject to reporting on PSD permits for GHGs only if the facility is required to obtain a PSD permit for other, non-GHG pollutants.

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[9] Attestation forms are available at http://www.climateactionreserve.org/how/program/documents/.

[10] NO_X emissions from adipic acid production facilities are regulated under the Clean Air Act and NO_X Transport Rule, both of which provide guidelines for NO_X emission controls. Regulations that limit NO_X emissions from adipic acid plants do not require the installation of specific NO_X control technologies; as a result, there is no direct or indirect regulatory requirement to control N_2O. While N_2O is incidentally controlled by the use of certain thermal technologies, this is taken into account in the Performance Standard Test.

[11] U.S. EPA published the final rulemaking, "Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule; Final Rule," in the Federal Register 3 June 2010. The rulemaking is commonly referred to as the "Tailoring Rule," and amended 40 CFR Parts 51, 52, 70, and 71. http://www.gpo.gov/fdsys/pkg/FR-2010-06-03/pdf/2010-11974.pdf#page=1

[12] United States Environmental Protection Agency, "PSD and Title V Permitting Guidance for Greenhouse Gases," March 2011, https://www.epa.gov/sites/production/files/2015-12/documents/ghgpermittingguidance.pdf.

[13] Utility Air Regulatory Group v. Environmental Protection Agency et. al., No. 12–1146 (Supreme Court of the United States June 23, 2019).

When necessary, PSD permits for GHG emissions require an assessment of "best available control technology" (BACT), with the permitting authority ultimately mandating installation of a selected BACT. It is possible that future PSD permits may require installation of the same abatement technologies that are currently being voluntarily deployed as part of adipic acid projects. By legally mandating these technologies, PSD permit requirements may make them ineligible for carbon offsets because implementation of these projects would no longer be voluntary.

Voluntarily-implemented adipic acid projects will continue to be eligible for CRTs until the date the project activity is required by law. Verifiers will need to review PSD permits to ensure that projects are able to pass the Legal Requirement Test.

3.5 Regulatory Compliance

As a final eligibility requirement, project developers must attest that project activities do not cause material violations of applicable laws (e.g., air, water quality, safety, etc.). To satisfy this requirement, project developers must submit a signed Attestation of Regulatory Compliance form[14] prior to the commencement of verification activities each time the project is verified. Project developers are also required to disclose in writing to the verifier any and all instances of legal violations – material or otherwise – caused by the project activities.

A violation should be considered to be "caused" by project activities if it can be reasonably argued that the violation would not have occurred in the absence of the project activities. If there is any question of causality, the project developer shall disclose the violation to the verifier.

If a verifier finds that project activities have caused a material violation, then CRTs will not be issued for GHG reductions that occurred during the period(s) when the violation occurred. Individual violations due to administrative or reporting issues, or due to "acts of nature," are not considered material and will not affect CRT crediting. However, recurrent administrative violations directly related to project activities may affect crediting. Verifiers must determine if recurrent violations rise to the level of materiality. If the verifier is unable to assess the materiality of the violation, then the verifier shall consult with the Reserve.

[14] Attestation forms are available at http://www.climateactionreserve.org/how/program/documents/.

4 The GHG Assessment Boundary

The GHG Assessment Boundary delineates the GHG sources, sinks, and reservoirs (SSRs) that must be assessed by project developers in order to determine the net change in emissions caused by an adipic acid project. As the project may include existing N_2O control technologies that are either replaced, expanded, or absorbed into new treatment regimes, most of the SSRs are evaluated in both the baseline and project scenarios.

Figure 4.1 illustrates all relevant GHG SSRs associated with adipic acid project activities and delineates the GHG Assessment Boundary.

Table 4.1 provides greater detail on each SSR and justification for the inclusion or exclusion of certain SSRs and gases from the GHG Assessment Boundary.

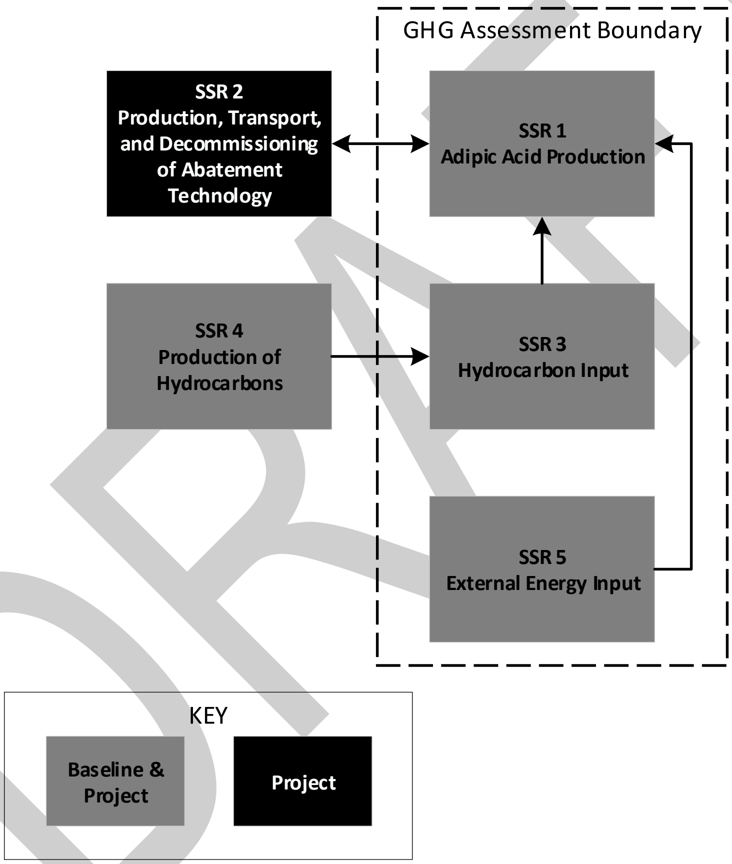

Figure 4.1. General illustration of the GHG Assessment Boundary

Table 4.1. Description of all Sources, Sinks, and Reservoirs

SSR	Source Description	Gas	Included (I) or Excluded (E)	Quantification Method	Baseline (B) or Project (P)	Justification/Explanation
1	Adipic acid production process unit (burner inlet to stack)	CO_2	E	N/A	B, P	Excluded, as project activity is unlikely to impact emissions relative to baseline activity.
		CH_4	E	N/A	B, P	Excluded, as project activity is unlikely to impact emissions relative to baseline activity.
		N_2O	I	N_2O sampled before and after destruction	B, P	N_2O from production reaction is a primary effect and a major emission source.
2	Emissions from production, transport, and decommissioning of the N_2O abatement device	CO_2	E	N/A	P	Considered insignificant, upstream and downstream secondary GHG effects.
		CH_4				
		N_2O				
3	Hydrocarbon used as reducing agent, for reheating the off gas, or for combustion fuel for thermal reduction units (*if applicable*)	CO_2	I	GHG emissions based on additional amounts of reducing agent or energy used during the project	B, P	If hydrocarbons are used as a reducing agent to enhance efficiency of the N_2O abatement system, additional GHG emissions from the project activity will occur.
		CH_4	I	GHG emissions based on additional amounts of reducing agent or energy used during the project		
		N_2O	E	N/A	B, P	Project activity only leads to CO_2 and/or CH_4 emissions.

SSR	Source Description	Gas	Included (I) or Excluded (E)	Quantification Method	Baseline (B) or Project (P)	Justification/Explanation
4	Emissions related to the production of hydrocarbon (*if applicable*)	CO_2	E	N/A	B, P	GHG emissions related to the production of hydrocarbons used as reducing agent are insignificant.
		CH_4				
		N_2O				
5	Emissions from external energy that may be used to reheat the off gas before entering N_2O abatement units (*if applicable*)	CO_2	I	GHG emissions based on additional amounts of energy used during the project	B, P	If additional energy is used to reheat off gas and that energy is not recovered and used within the system, additional GHG emissions from the project activity will occur.
		CH_4				
		N_2O				

Box 4.1. Question on the GHG Assessment Boundary:

Does the Reserve need to evaluate for inclusion GHG emissions associated with the increased utilization of N_2O abatement technology (e.g., increases in energy use)?

5 Quantifying GHG Emission Reductions

GHG emission reductions from an adipic acid project are quantified by comparing actual project emissions to the calculated baseline emissions. Baseline emissions are an estimate of the GHG emissions from sources within the GHG Assessment Boundary (see Section 4) that would have occurred in the absence of the project. Project emissions are actual GHG emissions that occur at sources within the GHG Assessment Boundary. Project emissions must be subtracted from the baseline emissions to quantify the project's total net GHG emission reductions (Equation 5.1). GHG emission reductions must be quantified and verified on at least an annual basis. Project developers may choose to quantify and verify GHG emission reductions on a more frequent basis if they desire. The length of time over which GHG emission reductions are periodically quantified and verified is called the "reporting period." The length of time over which GHG reductions are verified is called a "verification period."

Equation 5.1. Calculating GHG Emission Reductions

$$\boldsymbol{ER = BE - PE}$$

Where,

			Units
ER	=	Total emission reductions for the reporting period	tCO_2e
BE	=	Total baseline emissions for the reporting period, from all SSRs in the GHG Assessment Boundary (as calculated in Section 5.1)	tCO_2e
PE	=	Total project emissions for the reporting period, from all SSRs in the GHG Assessment Boundary (as calculated in Section 0)	tCO_2e

As of this writing, the Reserve relies on values for global warming potential (GWP) of non-CO_2 GHGs published in the IPCC Fourth Assessment Report: Climate Change 2007 (AR4).[15] The values relevant for this protocol are provided in Table 5.1 below, and are to be used for all nitric acid production projects unless and until the Reserve issues written guidance to the contrary.

Table 5.1. 100-year Global Warming Potential for Non-CO_2 GHGs

Non-CO_2 GHG	100-Year GWP (CO_2e)
Methane (CH_4)	25
Nitrous Oxide (N_2O)	298

[15] Available here: https://ipcc.ch/publications_and_data/publications_and_data_reports.shtml

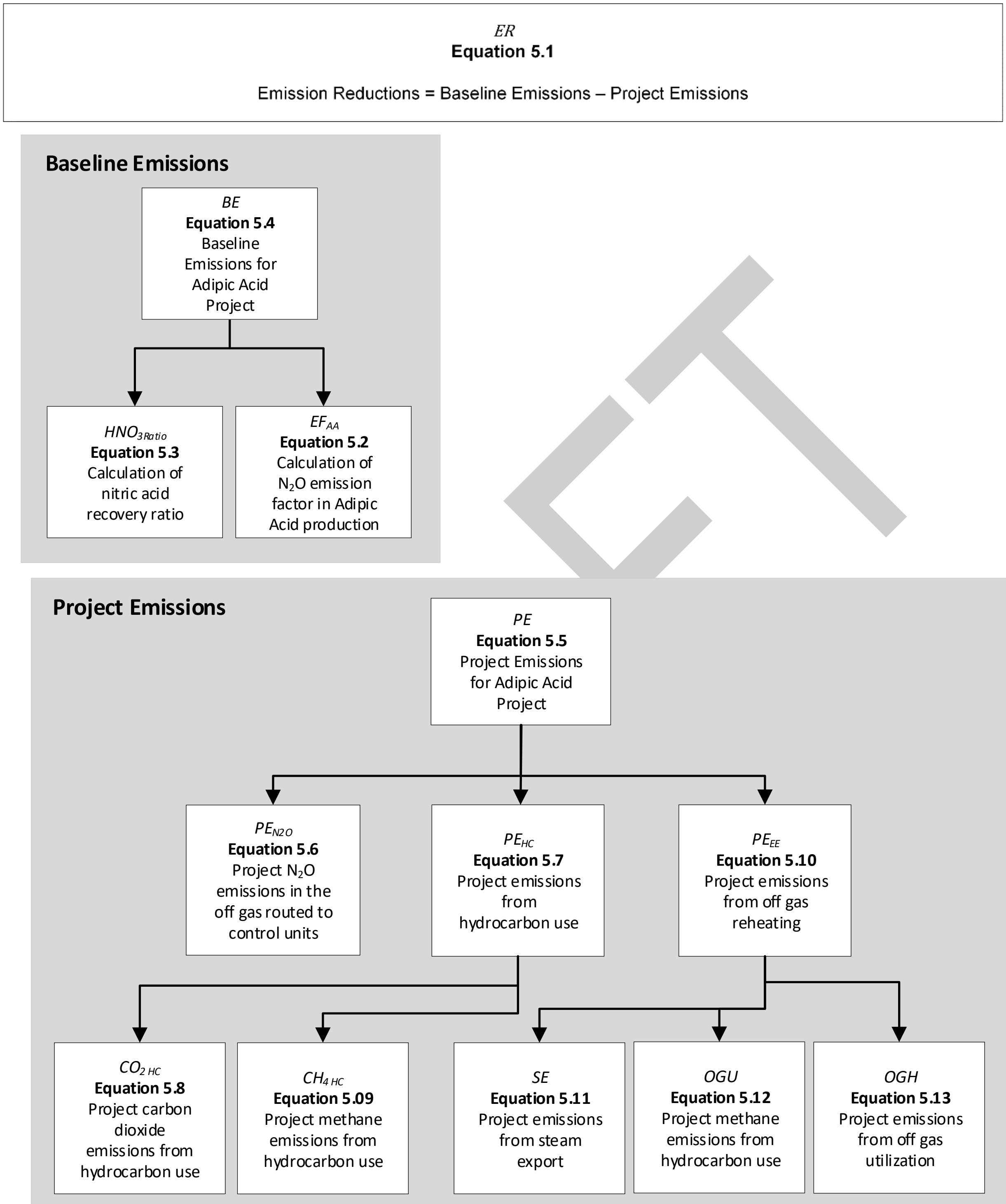

Figure 5.1. Organizational Chart of Equations for Adipic Acid Projects

5.1 Quantifying Baseline Emissions

Baseline emissions represent the GHG emissions within the GHG Assessment Boundary that would have occurred in the absence of the adipic acid project. Total baseline emissions for the reporting period are estimated by calculating and summing the emissions from all relevant baseline SSRs that are included in the GHG Assessment Boundary (as indicated in Figure 4.1 and Table 4.1). Baseline GHG emissions are based on the quantity of N_2O in the tail/off gas before it enters the project abatement technology.

To set the baseline, this protocol utilizes a baseline look-back period, defined as the five most recent years of operation prior to the project start date. If five consecutive years of historical data are not available, and/or if one of the five consecutive years is determined to be justifiably anomalous, the project may instead use five non-consecutive years of data (i.e., exclude the anomalous year and add another year's data from the next available historical record). Under these circumstances, an explanation and justification for excluding the anomalous campaign must be included in the monitoring plan and verification report for the project.

As a large amount of N_2O emissions are already abated from voluntarily installed abatement technology at each AAP, and as historical N_2O emissions from adipic acid production vary with the types of technologies and level of emission controls employed by each AAP (Section 2.1), in order to ensure the baseline is conservative and representative of only the incremental emissions reduced beyond historical levels, this protocol requires projects to determine an annual facility-specific Baseline N_2O Abatement Efficiency (AE)s for each year of the baseline look-back period, as shown in Equation 5.2.

Equation 5.2. Calculating Annual Baseline N_2O Abatement Efficiency in Adipic Acid Production

$$AE_B = \left(\frac{RE_{B,N_2O}}{TE_{B,N_2O}}\right) \times 100$$

Where,

			Units
AE_B	=	N_2O abatement efficiency rate in year B of the 5-year baseline look-back period	%
$RE_{B,N2O}$	=	Measured N_2O reduced and destroyed by the N_2O emission control unit in year B of the 5-year baseline look-back period abatement efficiency rate in year y of the 5-year baseline look-back period, B	tN_2O
$TE_{B,N2O}$	=	Measured total N_2O emissions during year B in the 5-year baseline look-back period before any emissions control treatment (e.g., destruction)	tN_2O

The AE represents the percent of the AAP's N_2O emissions that are destroyed by the N_2O emission control unit in the given year, B, in the baseline look-back period. To make this calculation, the full amount of N_2O produced in the given year, B, of the baseline look-back period prior to any destruction is calculated through Equation 5.3, which uses direct measurements of the tail/off gas flow.

Equation 5.3. Calculating Total Annual Baseline N_2O Emissions Before any Emissions Control Treatment

$$TE_{B,N_2O} = \left[\sum_{cu}(F_{B,cu} \times N_2O_{B,conc,cu} \times OH_{B,cu}) + \sum_{ncu}(F_{B,ncu} \times N_2O_{B,conc,ncu} \times OH_{B,ncu})\right]$$

Where,			<u>Units</u>
$TE_{B,N2O}$	=	Measured total N_2O emissions during year B of the 5-year baseline look-back period before any emissions control treatment (e.g., destruction)	tCO_2e
$F_{B,cu}$	=	Volume flow rate in the off gas during year B of the 5-year baseline look-back period to the N_2O control unit	m^3 / hour
$F_{B,ncu}$	=	Volume flow rate in the off gas during year B of the 5-year baseline look-back period to the non-N_2O control unit	m^3 / hour
$N_2O_{B,conc,cu}$	=	N_2O concentration in the off gas during year B of the 5-year baseline look-back period to the N_2O control unit	tN_2O / m^3
$N_2O_{B,conc,ncu}$	=	N_2O concentration in the off gas during year B of the 5-year baseline look-back period to the non- N_2O control unit	tN_2O / m^3
$OH_{B,cu}$	=	Operating hours in year B of the 5-year baseline look-back period by N_2O control unit	Hours
$OH_{B,ncu}$	=	Operating hours in year B of the 5-year baseline look-back period by non- N_2O control unit	Hours
cu	=	Each installed N_2O emissions control unit (e.g. thermal reduction unit, adiabatic reactor, absorption media, or other N_2O abatement device)	
ncu	=	Each installed non-N_2O emissions control unit (e.g. selective catalytic reduction unit or other non-N_2O abating device), inclusive of any bypassed and direct venting of N_2O emissions	

Next, to determine the amount of N_2O that is destroyed in the given year, B, in the baseline look-back period, Equation 5.4 measures the amount of off gas directed to each control unit and multiplies it by the efficiency of the respective N_2O control unit.

Equation 5.4. Calculating Annual Abated Baseline N_2O Emissions

$$RE_{B,N_2O} = \left[\sum_{cu}(F_{B,cu} \times N_2O_{B,conc,cu} \times OH_{B,cu}) \times E_{cu}\right]$$

Where,			Units
$RE_{B,N2O}$	=	Total N_2O reduced and destroyed by the N_2O emission control unit in year B of the 5-year baseline look-back period	tCO_2e
$F_{B,cu}$	=	Volume flow rate in the off gas flowing into the N_2O control unit during year B of the 5-year baseline look-back period	m^3 / hour
$N_2O_{B,conc,cu}$	=	N_2O concentration in the off gas flowing into the N2O control unit during year B of the 5-year baseline look-back period	tN_2O / m^3
$OH_{B,cu}$	=	Operating hours in year B of the baseline look-back period of the N_2O control unit	Hours
$E_{B,cu}$	=	N_2O destruction efficiency, expressed as a fraction of total N_2O destroyed, of the N_2O emissions control unit	
cu	=	Each installed N_2O emissions control unit (e.g. thermal reduction unit, adiabatic reactor, absorption media, or other N_2O abatement device)	

In order for the baseline to be dynamically tied to the amount of actual N_2O emissions created by an AAP in a project reporting period, the AE must be multiplied by actual project reporting period emissions. However, the correct AE value to use in the calculation of baseline emissions (Equation 5.12) is dependent on the amount of adipic acid production in a project reporting period.

If the amount of adipic acid produced in the project reporting period is *greater than or equal to* the maximum amount of adipic acid produced in the baseline look-back period (i.e., $AA_{RP} \geq AA_{B,MAX}$), then the project must use the AE associated with the year B in the baseline look-back period of maximum adipic acid production, as displayed in Equation 5.5.

Equation 5.5. Calculating Annual Baseline N_2O Abatement Efficiency in Baseline Year with Maximum Adipic Acid Production

$$AE_{B,MAX} = \left(\frac{RE_{B,MAX,N_2O}}{TE_{B,MAX,N_2O}}\right) \times 100$$

Where,			Units
$AE_{B,MAX}$	=	N_2O abatement efficiency rate in year B of the 5-year baseline look-back period with maximum, MAX, adipic acid production	%
$RE_{B,MAX,N2O}$	=	Measured N_2O reduced and destroyed by the N_2O emission control unit in year B of the 5-year baseline look-back period with maximum, MAX, adipic acid production	tN_2O
$TE_{B,MAX,N2O}$	=	Measured total N_2O emissions during year B in the 5-year baseline look-back period with maximum, MAX, adipic acid production before any emissions control treatment (e.g., destruction)	tN_2O

If the amount of adipic acid produced in the project reporting period is *less than or equal to* the minimum amount of adipic acid produced in the baseline look-back period (i.e., $AA_{RP} \leq AA_{B,MIN}$), then the project must use the AE associated with the year B in the baseline look-back period of minimum adipic acid production, as displayed in Equation 5.6.

Equation 5.6. Calculating Annual Baseline N_2O Abatement Efficiency in Baseline Year with Minimum Adipic Acid Production

$$AE_{B,MIN} = \left(\frac{RE_{B,MIN,N_2O}}{TE_{B,MIN,N_2O}}\right) \times 100$$

Where,

			Units
$AE_{B,MIN}$	=	N_2O abatement efficiency rate in year B of the 5-year baseline look-back period with minimum, MIN, adipic acid production	%
$RE_{B,MIN,N2O}$	=	Measured N_2O reduced and destroyed by the N_2O emission control unit in year B of the 5-year baseline look-back period with minimum, MIN, adipic acid production	tN_2O
$TE_{B,MIN,N2O}$	=	Measured total N_2O emissions during year B in the 5-year baseline look-back period with minimum, MIN, adipic acid production before any emissions control treatment (e.g., destruction)	tN_2O

If the amount of adipic acid produced in the project reporting period is *greater than the minimum* amount of adipic acid produced in the baseline look-back period *and less than the maximum* amount of adipic acid produced in the baseline look-back period (i.e., $AA_{B,MIN} < AA_{RP} < AA_{B,MAX}$), then the project must use a simple linear regression analysis, bound by the baseline minimum and maximum adipic acid production values, to determine the AE interval within the range to use, as described in Equation 5.7 through Equation 5.9.

Equation 5.7. Calculating Annual Baseline N_2O Abatement Efficiency when Reporting Period Adipic Acid Production is in between Baseline Minimum and Maximum Production Values

$$AE_{IN} = (m \times AA_{RP}) + b) \times 100$$

Where,

			Units
AE_{IN}	=	N_2O baseline abatement efficiency rate when adipic acid production in the project reporting period is in between the minimum and maximum adipic acid production values from the 5-year baseline look-back period	%
AA_{RP}	=	Measured adipic acid production in the project reporting period	t
m	=	Slope of the linear trend line between the AE values based on the minimum and maximum adipic acid production values from the 5-year baseline look-back period	
b	=	y-intercept of the linear trend line between the AE values based on the minimum and maximum adipic acid production values from the 5-year baseline look-back period	

Equation 5.8. Calculating the Slope of the Linear Trend Line between the Abatement Efficiency Values based on the Minimum and Maximum Baseline Adipic Acid Production Values

$$\boldsymbol{m = (\frac{AE_{B,MAX} - AE_{B,MIN}}{AA_{B,MAX} - AA_{B,MIN}})}$$

Where,			<u>Units</u>
m	=	Slope of the linear trend line between the AE values based on the minimum and maximum adipic acid production values from the 5-year baseline look-back period	
$AE_{B,MAX}$	=	N_2O abatement efficiency rate in year B of the 5-year baseline look-back period with maximum, MAX, adipic acid production	%
$AE_{B,MIN}$	=	N_2O abatement efficiency rate in year B of the 5-year baseline look-back period with minimum, MIN, adipic acid production	%
$AA_{B,MAX}$	=	Maximum annual adipic acid production in the 5-year baseline look-back period	t
$AA_{B,MIN}$	=	Minimum annual adipic acid production in the 5-year baseline look-back period	t

Equation 5.9. Calculating the *y-intercept* of the Linear Trend Line between the Abatement Efficiency Values based on the Minimum and Maximum Baseline Adipic Acid Production Values

$$\boldsymbol{b = AE_B - (m \times AA_B)}$$

Where,			<u>Units</u>
b	=	y-intercept of the linear trend line between the AE values based on the minimum and maximum adipic acid production values from the 5-year baseline look-back period	
AE_B	=	N_2O abatement efficiency rate in year B of the 5-year baseline look-back period	%
m	=	Slope of the linear trend line between the AE values based on the minimum and maximum adipic acid production values from the 5-year baseline look-back period	
AA_B	=	Adipic acid production in year B of the 5-year baseline look-back period	t

Note, any value for AE_B and AA_B from the 5-year baseline look-back period may be used, so long as they are both from the same year, B, e.g., $AE_{B,MAX}$ and $AA_{B,MAX}$ or $AE_{B,MIN}$ and $AA_{B,MIN}$

In lieu of the above equations (Equation 5.7 – Equation 5.9), software (e.g., Microsoft Excel) may be used to plot a linear trend line and applying that linear equation to the current report period's adipic acid production level, bounded by the baseline maximum and minimum production values.

Box 5.1. Note on the N_2O Abatement Efficiency:

It's the Reserve's understanding that historically in the U.S., AAPs have faced a trade-off between abating N_2O emissions voluntarily and abating NO_X emissions as legally mandated by the CAA. As adipic acid production increases, so do both N_2O and NO_X emissions. However, this means a greater portion of the tail/off gas is sent to NOx-SCR unit to meet the CAA legal requirements, resulting in greater NO_X abatement and less N_2O abatement. As such, there is an inverse relationship between adipic acid production and N_2O abatement at AAPs; i.e., in years with greater adipic acid production, there is less N_2O abatement. As the Reserve is trying to best capture the most likely continued scenario at the U.S. AAPs in the absence of the project (i.e., in the absence of a new N_2O abatement or enhancement to an existing one) with the CAA requirement, it's likely for this inverse to hold true moving forward. Therefore, the Reserve reasons that if adipic acid production in the project reporting period is greater than or equal to the maximum amount of adipic acid produced annually in the baseline, then it's reasonable to assume the baseline N_2O abatement efficiency associated with the baseline year of maximum production is to be maintained in that year of the project. The opposite is true if adipic acid production in a given project reporting period is less than or equal to the minimum amount of adipic produced annually in the baseline. In the event the amount of adipic acid produced in the reporting period falls in between the baseline annual minimum and maximum production values, the linear trendline approach is followed to determine the most appropriate abatement efficiency in between the associated minimum and maximum abatement efficiencies.

The Reserve understands the same trade-off scenario/abatement history is not faced by other countries. However, what are the Workgroup Members' thoughts on the abatement efficiency approach's suitability for other countries?

Equation 5.10 utilizes direct measurements taken in reporting year to determine the total amount of N_2O produced before any N_2O emissions are destroyed.

Equation 5.10. Calculating Total N_2O Emissions during the Reporting Period before any Emissions Control Treatment

$$TE_{RP,N_2O} = \left[\sum_{cu}(F_{RP,cu} \times N_2O_{RP,conc,cu} \times OH_{RP,cu}) + \sum_{ncu}(F_{RP,ncu} \times N_2O_{RP,conc,ncu} \times OH_{RP,ncu})\right]$$

Where,			Units
$TE_{RP,N2O}$	=	Measured total N_2O emissions during the reporting period before any emissions control treatment (e.g., destruction)	tCO_2e
$F_{RP,cu}$	=	Volume flow rate in the off gas during the reporting period to the N_2O control unit	m^3 / hour
$F_{RP,ncu}$	=	Volume flow rate in the off gas during the reporting period to the non-N_2O control unit	m^3 / hour
$N_2O_{RP,conc,cu}$	=	N_2O concentration in the off gas during the reporting period to the N_2O control unit	tN_2O / m^3
$N_2O_{RP,conc,ncu}$	=	N_2O concentration in the off gas during the reporting period to the non- N_2O control unit	tN_2O / m^3
$OH_{RP,cu}$	=	Operating hours in the reporting period by N_2O control unit	Hours
$OH_{RP,ncu}$	=	Operating hours in the reporting period by non- N_2O control unit	Hours
cu	=	Each installed N_2O emissions control unit (e.g. thermal reduction unit, adiabatic reactor, absorption media, or other N_2O abatement device)	
ncu	=	Each installed non-N_2O emissions control unit (e.g. selective catalytic reduction unit or other non-N_2O abating device), inclusive of any bypassed and direct venting of N_2O emissions	

5.1.1 Baseline Nitric Acid Recovery Ratio

Equation 5.11 shows the calculation for the recovery of nitric acid (HNO_3) as a function of N_2O conversion to NO, which is then converted to HNO_3 in the downstream process. This only applies to recycling technologies that convert a portion of the N_2O in the exhaust to beneficial byproducts rather than simply oxidizing the N_2O to nitrogen (N_2) and oxygen (O_2) (conventional technology). The calculation establishes a ratio of HNO_3 to adipic acid as an average of HNO_3 to an average of adipic acid over the baseline look-back period. This ratio is then compared to the ratio of HNO_3 to adipic acid in the reporting period (RP).

Equation 5.11. Calculating Nitric Acid Recovery Ratio

$$HNO_{3_{Ratio}} = \frac{HNO_{3_H}}{AA_H} - \frac{HNO_{3_{RP}}}{AA_{RP}}$$

Where,

			Units
$HNO_{3,Ratio}$	=	Ratio of nitric acid (HNO_3) to adipic acid	tHNO3/tAA
$HNO_{3,H}$	=	Average annual tonnes HNO_3 during the 5-year baseline look-back period	t
AA_H	=	Average annual tonnes adipic acid during the 5-year baseline look-back period	t
$HNO_{3,RP}$	=	Measured HNO_3 production in project reporting period	t
AA_{RP}	=	Measured adipic acid production in the project reporting period	t

In Equation 5.12, adipic acid production, the appropriate N_2O abatement efficiency, the project emissions prior to destruction in the reporting period, and nitric acid recovery ratios from the previous equations are used to calculate baseline emissions.

Equation 5.12. Calculating Baseline Emissions

$$BE = \left[\left(TE_{RP,N_2O} \times (1 - AE)\right) + \left(\mathrm{HNO}_{3\,Ratio} \times AA_{RP} \times EF_{N_2O}\right) \right] \times GWP_{N_2O}$$

Where,

			Units
BE	=	Baseline emissions during the reporting period	tCO_2e
$TE_{RP,N2O}$	=	Measured total N_2O emissions during the reporting period before any emissions control treatment (e.g., abatement)	tN_2O
AE	=	Baseline N_2O abatement efficiency	%
HNO_{3Ratio}	=	Ratio of HNO_3 to AA	$tHNO_3$ / tAA
AA_{RP}	=	Measured adipic acid production in the project reporting period	t
EF_{N2O}	=	IPCC emission factor for N_2O emissions per HNO_3 production = 0.0025	tN_2O / $tHNO_3$
GWP_{N2O}	=	Global warming potential of N_2O	tCO_2e / tN_2O

5.1.2 Mitigating Leakage

Secondary effects, i.e., leakage, may occur if a facility begins to over-produce adipic acid because the value of the carbon offset creates a perverse incentive to shift production to AAPs with Reserve adipic acid projects. If leakage were to occur, a portion of the CRTs would not be representative of real GHG emission reductions.

To reduce the risk of leakage, a cap (AA_{cap}) is applied on the maximum amount of adipic acid production allowable for crediting. This does not mean AAPs with adipic acid projects cannot expand production; they just cannot earn CRTs associated with production above the AA_{cap}. For this protocol, the AA_{cap} for each AAP is set as the maximum adipic acid production limit allowed in the its Clean Air Act Title V Operating permit.

If the amount of adipic acid produced during a given project reporting period exceeds AA_{cap}, then N_2O and HNO_3 values measured beyond the cap (i.e., AA_{RP} will equal AA_{cap}) are to be eliminated from the calculation of HNO_3 recovery ratio in Equation 5.10and the baseline emissions in Equation 5.12. Additionally, the N_2O abatement efficiency for use in Equation 5.12 is already bound by historical adipic acid production values.

Box 5.2. Note on Leakage and Mitigating the Risk of Production Shifting:

While the economic incentives that caused leakage in past, international adipic acid carbon offset projects are different than the current economic incentives in the United States (i.e., the current value of the average voluntary carbon credit in the U.S. is significantly less than the historical value of international carbon credits (e.g.,), pricing for U.S. carbon credits could increase drastically over the next 5 -10 years due to multiple potential demand factors post-2020. Examples include the California Compliance Offset Program, CORSIA, Article 6 under the Paris Agreement, and potentially, the inclusion in a Federal compliance scheme. There is potential these demand factors could be realized within a project's first crediting period. Therefore, the Reserve proposes setting a cap on creditable production values based on the maximum adipic acid production limit allowed in an AAP's CAA Title V Operating permit. AAPs face fines for exceeding their production limits, and it's the Reserve's understanding that this production limit is difficult to adjust.

5.2 Quantifying Project Emissions

Project emissions are actual GHG emissions that occur within the GHG Assessment Boundary as a result of the project activity. Project emissions must be quantified every reporting period on an *ex post* basis.

Equation 5.13. Project Emissions

$$PE = PE_{N_2O} + PE_{HC} + PE_{EE}$$

Where,			Units
PE	=	Project emissions during the reporting period	tCO_2e
PE_{N2O}	=	GHG emissions from N_2O in the off gas during the reporting period (Equation 5.6)	tCO_2e
PE_{HC}	=	GHG emissions from the use of hydrocarbons as a reducing agent or to reheat off gas during the reporting period (Equation 5.8)	tCO_2e
PE_{EE}	=	GHG emissions from external energy used to reheat the off gas during the reporting period (Equation 5.11)	tCO_2e

5.2.1 Calculating Project N_2O Emissions in the Off Gas

N_2O abatement is not 100% efficient. Therefore, N_2O emissions that are not destroyed by abatement technology are measured and included as project emissions.

Equation 5.14. Project N_2O Emissions in the Off Gas Routed to Emissions Control Units

$$PE_{N_2O} = \left[\sum_{cu}(F_{cu} \times N_2O_{conc,cu} \times OH_{RP,cu}) + \sum_{ncu}(F_{ncu} \times N_2O_{conc,ncu} \times OH_{RP,ncu})\right] \times GWP_{N_2O}$$

Where,			Units
PE_{N2O}	=	Measured project N_2O emissions in the off gas to project control units during the reporting period	tCO_2e
F_{cu}	=	Volume flow rate in the off gas during the reporting period by N_2O control unit	m^3 / hour
F_{ncu}	=	Volume flow rate in the off gas during the reporting period by non-N_2O control unit	m^3 / hour
$N_2O_{conc,cu}$	=	N_2O concentration in the off gas during the reporting period by N_2O control unit	tN_2O / m^3
$N_2O_{conc,ncu}$	=	N_2O concentration in the off gas during the reporting period by non- N_2O control unit	tN_2O / m^3
$OH_{RP,cu}$	=	Operating hours in reporting period by N_2O control unit	Hours
$OH_{RP,ncu}$	=	Operating hours in reporting period by non- N_2O control unit	Hours
GWP_{N2O}	=	Global warming potential of N_2O	tCO_2e / tN_2O
cu	=	Each installed N_2O emissions control unit (e.g. thermal reduction unit, adiabatic reactor, absorption media, or other N_2O abatement device)	-
ncu	=	Each installed non-N_2O emissions control unit (e.g. selective catalytic reduction unit or other non-N_2O abating device), inclusive of any bypassed and direct venting of N_2O emissions	-

5.2.2 Calculating Project Emissions from Hydrocarbon Use

Hydrocarbons can be used as a reducing agent, to reheat off gas to enhance the N_2O reduction efficiency or simply as a combustion source for thermal treatment, which leads to CO_2 and CH_4 emissions. The project emissions related to hydrocarbon input to the project shall be calculated. In cases where hydrocarbon use for N_2O control technology that predates the project exists, the difference in baseline and project scenario hydrocarbon use shall be calculated. If the project developer demonstrates that the implementation of project activities reduces emissions from hydrocarbon use over baseline N_2O control technology hydrocarbon usage, project developers may assert zero project emissions from hydrocarbon use.

Equation 5.15. Project Emissions from Hydrocarbon Use

$$PE_{HC} = CO_{2_{HC}} + CH_{4_{HC}}$$

Where,			Units
PE_{HC}	=	Net GHG emissions from the use of hydrocarbons as a reducing agent or to reheat off gas during the reporting period	tCO_2e
CO_{2HC}	=	Net GHG emissions as CO_2 from hydrocarbon use during the reporting period (equation 5.8)	tCO_2e
CH_{4HC}	=	Net GHG emissions as CH_4 from hydrocarbon use during the reporting period (equation 5.9)	tCO_2e

Hydrocarbons (organic compounds made up of carbon and hydrogen) are used primarily as a combustible fuel source (e.g. natural gas, which is mostly methane, propane, and butane). For calculation of the GHG emissions related to hydrocarbons, those that are combusted to produce heat and/or steam are completely converted to CO_2 (Equation 5.16) while CH_4 in fuel or reducing agent is emitted directly to the atmosphere as CH_4 (Equation 5.17) and is not converted to CO_2. In Equation 5.16, the hydrocarbon CO_2 emission factor (EF_{HC}) is given by the molecular weight of the hydrocarbon and CO_2 and the chemical reaction when hydrocarbons are converted.[16]

Equation 5.16. Project Carbon Dioxide Emissions from Hydrocarbon Use

$$CO_{2_{HC}} = \sum_{cu,p} (\rho_{HC} \times Q_{HC,RP} \times EF_{HC,RP}) - \sum_{cu,b} (\rho_{HC} \times Q_{HC,H} \times EF_{HC,H})$$

Where,			Units
CO_{2HC}	=	Net GHG emissions as CO_2 from converted hydrocarbon during the reporting period	tCO_2e
ρ ρ_{HC}	=	Hydrocarbon density	t / m^3
$Q_{HC,H}$	=	Historical average annual quantity of hydrocarbon, with two or more molecules of carbon, during the 5-year period predating the project (i.e. not methane)	m^3
$Q_{HC,RP}$	=	Quantity of hydrocarbon, with two or more molecules of carbon, input during the reporting period (i.e. not methane)	m^3
$EF_{HC,H}$	=	Historical average annual carbon emission factor of hydrocarbon, with two or more molecules of carbon, from use during the 5-year baseline look-back period	tCO_2e / tHC
$EF_{HC,RP}$	=	Carbon emission factor of hydrocarbon use during the reporting period	tCO_2e / tHC
cu	=	Each installed N_2O emissions control unit (e.g. thermal reduction unit, adiabatic reactor, absorption media, or other N_2O abatement device)	-

[16] For example, where CH_4 is used as hydrocarbon, each converted tonne of CH_4 results in 44/16 tonnes of CO_2, thus the hydrocarbon emission factor is 2.75.

Equation 5.17. Project Methane Emissions from Hydrocarbon Use

$$CH_{4_{HC}} = \sum_{cu} \rho_{CH_4} \times (Q_{CH_{4,RP}} - Q_{CH_{4,H}}) \times GWP_{CH_4}$$

Where,			Units
CH_{4HC}	=	Net GHG emissions as CH_4 from unconverted hydrocarbon (methane) during the reporting period	tCO_2e
ρ ρ_{CH4}	=	Methane density	t / m^3
$Q_{CH4,RP}$	=	Quantity of methane used during the reporting period	m^3
$Q_{CH4,H}$	=	Historical average annual quantity of methane used during the 5-year period predating the project	m^3
GWP_{CH4}	=	Global warming potential of CH_4	tCO_2e / tCH_4
cu	=	Each installed N_2O emissions control unit (e.g. thermal reduction unit, adiabatic reactor, absorption media, or other N_2O abatement device)	-

5.2.3 Calculating Project Emissions from Off Gas Reheating

If an external energy source is used to adjust off gas temperatures at the inlet of the N_2O destruction facility and the additional energy is not recovered before the off gas is released to the atmosphere, then GHG emissions from the energy used shall be calculated and included as project emissions.

Equation 5.18. Project Emissions from Off Gas Reheating

$$PE_{EE} = SE + OGU + OGH$$

Where,			Units
PE_{EE}	=	Project emissions from external energy during the reporting period	tCO_2e
SE	=	Emissions from net change in steam export during the reporting period (equation 5.11)	tCO_2e
OGU	=	Emissions from net change in off gas utilization during the reporting period (equation 5.12)	tCO_2e
OGH	=	Emissions from net change in off gas heating during the reporting period (equation 5.13)	tCO_2e

Equation 5.19. Project Emissions from Steam Export

$$SE = \left[\frac{(ST_B - ST_{RP}) \times OH_{RP}}{\eta_{ST}}\right] \times EF_{ST}$$

Where,			Units
SE	=	Emissions from net change in steam export during the reporting period	tCO_2e
ST_B	=	Baseline steam export during a reporting period	MW
ST_{RP}	=	Project steam export during the reporting period	MW
OH_{RP}	=	Operating hours in reporting period	Hours
η_{ST}	=	Efficiency of steam generation	Fraction
EF_{ST}	=	Fuel emission factor for steam generation	tCO_2e / MWh

Equation 5.20. Project Emissions from Off Gas Utilization

$$OGU = \left[\frac{(EE_B - EE_{RP}) \times OH_{RP}}{\eta_r}\right] \times EF_r$$

Where,			Units
OGU	=	Emissions from net change in off gas utilization during the reporting period	tCO_2e
EE_B	=	Baseline energy export from off gas utilization during a reporting period	MW
EE_{RP}	=	Project energy export from off gas utilization during the reporting period	MW
OH_{RP}	=	Operating hours in reporting period	Hours
η_r	=	Efficiency of replaced technology	Fraction
EF_r	=	Fuel emission factor for replaced technology	tCO_2e / MWh

Equation 5.21. Project Emissions from Off Gas Heating

$$OGH = \left[\frac{EI_{OGH}}{\eta_{OGH}}\right] \times EF_{OGH}$$

Where,			Units
OGH	=	Emissions from net change in off gas heating during the reporting period	tCO_2e
EI_{OGH}	=	Energy input for additional off gas heating during the reporting period	MWh
η_{OGH}	=	Efficiency of additional off gas heating	Fraction
EF_{OGH}	=	Emission factor for additional off gas heating	tCO_2e / MW

6 Project Monitoring

The Reserve requires a Monitoring Plan to be established for all monitoring and reporting activities associated with the project. The Monitoring Plan will serve as the basis for verifiers to confirm that the monitoring and reporting requirements in this section and Section 7 have been and will continue to be met, and that consistent, rigorous monitoring and record keeping is ongoing at the project site. The Monitoring Plan must cover all aspects of monitoring and reporting contained in this protocol and must specify how data for all relevant parameters in Table 6.1 will be collected and recorded.

At a minimum, the Monitoring Plan shall include the frequency of data acquisition; a record keeping plan (see Section 7.2 for minimum record keeping requirements); the frequency of instrument cleaning, inspection, field check, and calibration activities; the role of individuals performing each specific monitoring activity; and a detailed project diagram. The Monitoring Plan should include QA/QC provisions to ensure that data acquisition and meter calibration are carried out consistently and with precision.

Finally, the Monitoring Plan must include procedures that the project developer will follow to ascertain and demonstrate that the project at all times passes the legal requirement test (Section 3.4.2).

To ensure that all aspects of monitoring and reporting are met, the project developer shall follow the relevant guidance in this section as well as the relevant sections of the United States Code of Federal Regulations Title 40 (40 CFR), Part 60 and Part 75 as indicated below. Part 60 and Part 75 provide guidance on the standards of performance for stationary emission sources and continuous emission monitoring systems (CEMS) for NO_X emission testing, which is also applicable to N_2O emission testing at adipic acid production facilities. These parts outline the minimum requirements for the installation, evaluation, monitoring, and record keeping for CEMS (see Section 7.2 of this protocol for Reserve minimum record keeping requirements).

Specifically, the project developer shall follow Appendix B of Part 75 that covers QA/QC procedures for CEMS.

If both Part 60 and Part 75 appear to address the same matter, then to the extent that their provisions are irreconcilably inconsistent, the Reserve intends the more specific provision to control/govern the subject and Part 75 to prevail over Part 60.

Project developers are responsible for monitoring the performance of the project and ensuring that the operation of all N_2O control system and other project-related equipment is consistent with the manufacturer's recommendations for each component of the system. Installation and certification of the emission monitoring system in accordance with this section of this protocol should take place prior to the project start date.

6.1 Monitoring Requirements

Direct measurements of the N_2O concentration in the tail gas/off gas and the flow rate of the tail gas/off gas shall be made using a continuous emission monitoring system (CEMS). CEMS is the most accurate monitoring method because N_2O emissions are measured continuously from a specific source.[17] Elements of a CEMS include a platform and sample probe within the stack to withdraw a sample of the tail gas, an analyzer to measure the concentration of the N_2O (typically a non-dispersive infrared sensor (NDIR) or Fourier transform infrared (FTIR) spectroscopy) in the tail gas, and a flow meter within the stack to measure the flow rate of the tail gas. The emissions are calculated from the concentration of N_2O in the tail gas/off gas and the flow rate of the tail gas/off gas. A CEMS continuously withdraws and analyzes a sample of the gas and continuously measures the N_2O concentration and flow rate of the gas.[18]

6.1.1 System Installation and Certification

The project developer shall follow the requirements for CEMS installation and initial certification detailed in section 60.13 of 40 CFR Part 60, Performance Specification 2 of Appendix B of 40 CFR Part 60, and section 6 of Appendix A of 40 CFR Part 75. CEMS must be installed and operational before conducting performance tests on the system. In order to achieve operational status, the project developer must show that the CEMS also meets manufacturer's requirements or recommendations for installation, operation, and calibration.

Projects utilizing a CEMS that was initially installed for a purpose other than the monitoring of an adipic acid project (e.g. to monitor NO_X abatement) must still meet all of the requirements of this section. If any of the required tests listed below were not conducted or the requirements were not met at the time of initial installation and certification, the project developer must conduct the tests and ensure that the requirements are met prior to the project start date.

The following initial certification requirements are summarized from 40 CFR Part 75. Please refer to the CFR sections referenced above for all installation and certification requirements.

- 7-day calibration error test to evaluate the accuracy and stability of a gas analyzer's or flow monitor's calibration over a period of unit operation.
- Linearity check to determine whether the response of the N_2O concentration monitor is linear across its range by challenging CEMS with three different levels of calibration gas concentrations.
- Relative Accuracy Test Audit (RATA) to determine the accuracy of the system by comparing N_2O emissions data recorded by the CEMS to data collected concurrently with an emission reference test method. All RATA of CEMS must be conducted by a testing body conforming to the requirements of ASTM D7036-04.[19]
- Bias test to ensure that the monitoring system is not biased low with respect to the reference method, based on RATA results.
- Cycle time test to ensure that the monitoring system is capable of completing at least one cycle of sampling, analyzing, and data recording every 15 minutes.[20]
- Automated data acquisition and handling system (DAHS) verification to ensure that all emission calculations are performed correctly and that the missing data substitution methods are applied properly.

[17] This method is consistent with Approach 1 from the World Business Council for Sustainable Development and the "A" rated approach from the U.S. Department of Energy.
[18] U.S. EPA Technical Support Document for the Adipic Acid Production Sector: Proposed Rule for Mandatory Reporting of Greenhouse Gases, Office of Air and Radiation, January 22, 2009.
[19] 40 CFR Part 75, Appendix A, section 6.1.2(a).
[20] 40 CFR Part 60, 60.13(e)(2).

6.1.2 Calibration

The calibration procedures from Performance Specification 2 of Appendix B of 40 CFR Part 60 and Appendix A of 40 CFR Part 75 shall be followed for CEMS measuring N_2O emissions and abatement efficiency according to this protocol. Calibration test procedures are outlined in Performance Specification 2, Appendix B of Part 60 and section 6.3, Appendix A of Part 75. The performance specifications for the 7-day calibration error test and linearity check are described in section 3.1 and 3.2 of Appendix A of Part 75.

6.1.3 Accuracy Testing

The relative accuracy and RATA procedures from Appendix A and B (Performance Specification 2) of 40 CFR Part 60 and Appendix A of 40 CFR Part 75 shall be followed for CEMS used in Adipic Acid Production projects. The guidance for NO_X CEMS shall be used for N_2O emission monitoring where the CEMS relative accuracy shall not exceed 10% at any operating level at which a RATA is performed.[21]

Because there is not a standard reference test method for N_2O CEMS at this time, a RATA for the verification of a FTIR or NDIR installation for N_2O analysis may use any of the following:

- U.S. EPA test method 320[22] for the measurement of vapor phase organic and inorganic emissions by extractive FTIR spectroscopy[23]
- ASTM D6348-03 method for the determination of gaseous compound by extractive direct interface FTIR spectroscopy[24]
- ISO/DIS 21258 stationary source emissions determination of the mass concentration of N_2O reference method for NDIR[25]
- Other NDIR methods used in AM0034 or AM0028, or performance specification-based reference method such as EPA method 7E.[26]

6.1.3.1 Sampling

For all RATA, a minimum of nine test runs have to be conducted for a period of at least 21 minutes for each run. More test runs may be completed with the option to exclude up to three test runs from the audit. However, all data must be reported, including the rejected data.[27] For details on RATA sampling, see the relative accuracy test procedures and performance specifications in Performance Specification 2, Appendix B of 40 CFR Part 60 and Appendix A of 40 CFR Part 75.

6.2 QA/QC Requirements

The quality assurance and quality control (QA/QC) provisions required for this protocol shall be included in the Monitoring Plan and consistent in stringency, data reporting, and documentation with the CEMS QA/QC program described in Appendix B of 40 CFR Part 75 (see Section 7 of this protocol for further record-keeping requirements).

[21] 40 CFR Part 75, Appendix A, section 3.3.4(a).
[22] EPA Air Emission Measurement Center (EMC), Method 320 - Vapor Phase Organic and Inorganic Emissions by Extractive FTIR
[23] 40 CFR Part 63, Appendix A.
[24] 40 CFR Part 60, 60.17(a)(82).
[25] ISO 21258:2010, Stationary source emissions -- Determination of the mass concentration of dinitrogen monoxide (N_2O) -- Reference method: Non-dispersive infrared method
[26] EPA Air Emission Measurement Center (EMC), Method 7E - Nitrogen Oxide - Instrumental Analyzer
[27] 40 CFR Part 60, Appendix B, section 8.4.4

The following QA/QC requirements are summarized from Appendix B of 40 CFR Part 75. Please refer to the CFR sections referenced above for all QA/QC requirements.

- Procedures for preventative maintenance of the monitoring system
- Record keeping and reporting procedures
- Testing, maintenance, and repair activity records for CEMS or any component of CEMS
- Calibration error test and linearity check procedures
- Calibration and linearity adjustment procedures
- RATA procedures, such as sampling and analysis methods

6.2.1 Frequency of Testing

The schedule for the frequency of testing required for CEMS is described in section 2, Appendix B of 40 CFR Part 75. At a minimum, the following schedule must be followed for tests relevant to N_2O analysis using CEMS.

Daily assessments to quality-assure the hourly data recorded by the CEMS as of the date when CEMS completes certification testing:

- Calibration error test for N_2O analyzer
- Calibration adjustments for N_2O analyzer
- Data validation
- Quality assurance
- Data recording

Quarterly assessments apply as of the calendar quarter following the calendar quarter in which the CEMS is provisionally certified:

- Calibration error test for flow meter
- Calibration adjustments for flow meter
- Linearity check in quarters for which there is no RATA
- Leak check for CEMS utilizing differential pressure flow meters
- Data validation
- Linearity and leak check grace period
- Flow-to-load ratio or gross heat rate evaluation for projects located at an adipic acid plant that produces either electrical or thermal output

Semiannual and annual assessments apply as of the calendar quarter following the calendar quarter in which the CEMS is provisionally certified:

- RATA
- Data validation
- RATA grace period
- Bias adjustment factor applied if a monitor fails the bias test

For CEMS that were installed and certified for NO_X abatement prior to implementation of the adipic acid project, the daily, quarterly, semi-annual, and annual assessments detailed above only need to be performed, documented, and verified as of the project start date, not as of the date when the CEMS originally completed certification testing for NO_X abatement. For CEMS that were installed specifically for adipic acid project implementation, assessments must be performed, documented, and verified as of the date that the CEMS was certified.

If the quarterly calibration error test reveals accuracy outside of a +/- 3% threshold, calibration by the manufacturer or a certified service provider is required for the flow meter. For the interval between the last successful calibration error test and the calibration error test that revealed accuracy outside +/- 3% threshold, conservativeness will determine what flow meter data are used in emission reduction calculations. If the quarterly calibration error test reveals accuracy outside of a +/- 3% threshold, calibration by the manufacturer or a certified service provider is required for the flow meter. For the interval between the last successful calibration error test and the calibration error test that revealed accuracy outside +/- 3% threshold, conservativeness will determine what flow meter data are used in emission reduction calculations. Whether the calibration error is detected prior to the project start date or in a reporting period determines whether the metered values are used without correction or are adjusted based on the greatest calibration drift recorded at the time of calibration. The verification body shall confirm that any adjustments to the metered values result in the most conservative calculation of emission reductions. Any adjustments shall be made for the entire period from the last successful calibration error test until such time that the meter is properly calibrated and re-installed.

6.2.2 Data Management

Data management procedures are an important component of a comprehensive QA/QC plan. Data management procedures are described throughout Appendix B of 40 CFR Part 75 and include the following items.[28]

- Check for temporal consistency in production data and emission estimates. If outliers exist, an explanation could be required as to changes in the facility operations or other factors. A monitoring error is probable if differences between annual data cannot be explained by changes in activity levels, changes concerning fuels or input material, or changes concerning the emitting process.
- Determine the reasonableness of the emission estimate by comparing it to previous year's estimates.
- Maintain data documentation, including comprehensive documentation of data received through personal communication.
- Check that changes in data or methodology are documented.

6.3 Missing Data Substitution

In situations where the N_2O CEMS is missing data, the project developer shall follow the missing data substitution procedures for NO_X CEMS found in section 75.33 of 40 CFR Part 75. In summary, missing data from the operation of the CEMS may be replaced with substitute data to determine the N_2O emissions during the period for which CEMS data are missing. The owner or operator of the CEMS can substitute for missing N_2O concentration data using the procedures specified in section 75.33.[29]

For each hour of missing data, the project developer shall calculate substitute data for N_2O concentration based on the previous 2,160 quality-assured monitor operating hours for the

[28] The data management items are gathered from section 7.3 of the U.S. EPA Technical Support Document for the Adipic Acid Production Sector: Proposed Rule for Mandatory Reporting of Greenhouse Gases, Office of Air and Radiation, January 22, 2009.

[29] 40 CFR75, 75.33, Standard missing data procedures for SO_2, NO_X, Hg, and flow rate.

CEMS. The data substitution procedures depend on the percentile of available monitoring data from the system and the length of the missing data period. If there are no prior quality-assured data or minimal available data (the minimum percent is specified in section 75.33), the owner or operator must substitute the minimum potential N_2O concentration for missing data in the baseline and the maximum potential N_2O concentration for missing data in the project, per the following:

- Minimum – Baseline:
    - N_2O monitoring at the inlet of the control technology
- Maximum – Project:
    - N_2O monitoring at the outlet of the control technology

6.4 Monitoring Parameters

Prescribed monitoring parameters necessary to calculate baseline and project emissions are provided in Table 6.1.

Table 6.1. Adipic Acid Project Monitoring Parameters

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
General Project Parameters						
	Regulations	Project developer attestation of compliance with regulatory requirements relating to the composting project	Environmental regulations	n/a	Each verification	Information used to: 1) To demonstrate ability to meet the legal requirement test – where regulation would require the abatement of N_2O or the installation of certain NO_X emission control technology that will impact N_2O emissions at an AAP. 2) To demonstrate compliance with associated environmental rules, e.g., criteria pollutant emission standards, health and safety, etc.
	ER	Emission reductions for the reporting period	tCO_2e	C	Per reporting period	
	GWP_{N2O}	Global warming potential of N_2O	tCO_2e/tN_2O	R	Per reporting period	
	GWP_{CH_4}	Global warming potential of CH_4	tCO_2e / tCH_4	R	Per reporting period	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	cu	Each installed N_2O emissions control unit (e.g. thermal reduction unit, adiabatic reactor, absorption media, or other N_2O abatement device)	All applicable units	O	Each verification	
	ncu	Each installed non- N_2O emissions control unit (e.g. selective catalytic reduction unit or other non- N_2O abating device), inclusive of any bypassed and direct venting of N_2O emissions	All applicable units	O	Each verification	
Baseline Calculation Parameters						
	UR_H	Historical average percent of time the abatement technology was in use during the 5-year baseline look-back period	%	c	Once	
	$ATU_{n,y}$	Number of days, n, of abatement technology utilization during year y of the 5-year baseline look-back period	days	o	Once	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$OD_{n,y}$	Number of days, n, of AAP operation during year y of the 5-year baseline look-back period	days	o	Once	
	BE	Baseline emissions for the reporting period	tCO_2e	C	Per reporting period	Emissions that would have occurred in the absence of the project activity
	AE	N_2O abatement efficiency	%	O	Once	
	AE_B	Annual abatement efficiency in year B of the 5-year baseline look-back period	%	O	Once	
	$AA_{B,MAX}$	Maximum annual adipic acid production during the 5-year baseline look-back period	T	M, o	Once	
	$AA_{B,MIN}$	Minimum annual adipic acid production during the 5-year baseline look-back period	T	M, o	Once	
	$AE_{B,MAX}$	N_2O abatement efficiency in year B of the 5-year baseline look-back period with maximum, MAX, adipic acid production	%	C	Once	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$AE_{B,MIN}$	N_2O abatement efficiency in year B of the 5-year baseline look-back period with minimum, MIN, adipic acid production	%	C	Once	
	AE_{IN}	N_2O baseline abatement efficiency rate when adipic acid production in the project reporting period is in between the minimum and maximum adipic acid production values from the 5-year baseline look-back period	t	c	Per reporting period, as needed	
	m	Slope of the linear trend line between the AE values based on the minimum and maximum adipic acid production values from the 5-year baseline look-back period		c	Per reporting period, as needed	
	b	y-intercept of the linear trend line between the AE values based on the minimum and maximum adipic acid production values from the 5-year baseline look-back period		c	Per reporting period, as needed	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	TE_{B,N_2O}	Measured total N_2O emissions during the baseline reporting year before any emissions control treatment (e.g., destruction)	tN_2O	C	Once	
	RE_{B,N_2O}	Total N_2O reduced and destroyed by the N_2O emission control unit in the baseline reporting period	tN_2O	C	Once	
	$F_{B,cu}$	Volume flow rate in the off gas during the baseline reporting year to the N_2O control unit	m^3 / hour	M		Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
	$F_{B,ncu}$	Volume flow rate in the off gas during the baseline reporting year to the non-N_2O control unit	m^3 / hour	M		Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
	$N_2O_{B,conc,cu}$	N_2O concentration in the off gas during the baseline reporting year to the N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the off gas prior to entering the any control or non-control equipment

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$N_2O_{B,conc,ncu}$	N_2O concentration in the off gas during the baseline reporting year to the non-N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
	$OH_{B,cu}$	Operating hours in baseline reporting year by N_2O control unit	Hours	M	Totaled once for the reporting period	
	$OH_{B,ncu}$	Operating hours in baseline reporting year by non- N_2O control unit	Hours	M	Totaled once for the reporting period	`
	E_{cu}	N_2O destruction efficiency, expressed as a fraction of total N_2O destroyed, of the N_2O emissions control unit	-	O	Once	
	TE_{RP,N_2O}	Measured total N_2O emissions during the reporting period before any emissions control treatment (e.g., destruction)	tCO_2e	C	Totaled once for the reporting period	
	$F_{RP,cu}$	Volume flow rate in the off gas during the reporting period to the N_2O control unit	m^3 / hour	M	Every one minute	Note this measurement is taken in the off gas prior to entering the any control or non-control equipment

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$F_{RP,ncu}$	Volume flow rate in the off gas during the reporting period to the non-N_2O control unit	m^3 / hour	M	Every one minute	Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
	$N_2O_{RP,conc,cu}$	N_2O concentration in the off gas during the reporting period to the N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
	$N_2O_{RP,conc,ncu}$	N_2O concentration in the off gas during the reporting period to the non- N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
	$OH_{RP,cu}$	Operating hours in reporting period by N_2O control unit	Hours	O	Totaled once for the reporting period	
	$OH_{RP,ncu}$	Operating hours in reporting period by non-N_2O control unit	Hours	O	Totaled once for the reporting period	
	$HNO_{3\ Ratio}$	Ratio of HNO_3 to AA	$tHNO_3$ / tAA	C	Per reporting period	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	HNO_{3H}	Average annual tons HNO_3 during the 5-year period predating the project	$tHNO_3$	O	Once	
	AA_H	Average annual tons AA during the 5-year period predating the project	tAA	O	Once	
	$HNO_{3\,RP}$	Tonnes HNO_3 in reporting period	$tHNO_3$	M	Daily, totaled for the reporting period	
	AA_{RP}	Tonnes AA in reporting period	tAA	M	Daily, totaled for the reporting period	
	EF_{N2O}	IPCC emission factor for N_2O emissions per HNO_3 production = 0.0025	tN_2O / $tHNO_3$	R	Per reporting period	
	TE_{RP,N_2O}	Measured total N_2O emissions during the reporting period before any emissions control treatment (e.g., abatement)	tN_2O	m	Per reporting period	
	ρ_{HC}	Hydrocarbon density	t / m^3	m	Per reporting period	
	$Q_{HC,H}$	Historical average annual quantity of hydrocarbon, with two or more molecules of carbon, during the 5-year period predating the project (i.e. not methane)	m^3	O	Once	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$EF_{HC,H}$	Historical average annual GHG emissions as CH_4 from hydrocarbon use during the 5-year period predating the project	tCO_2e / tHC	C	Once	Given by the molecular weight of the hydrocarbon and CO_2 and the chemical reaction when hydrocarbons are converted
	ρ_{CH_4}	Methane density	t / m^3	M	Per reporting period	
	$Q_{CH4,H}$	Historical average annual quantity of methane used during the 5-year period predating the project	m^3	O	Once	
	ST_B	Baseline steam export during a reporting period	MW	C	Once	
	$EE_B EE_b$	Baseline energy export from off gas utilization during a reporting period	MW	C	Once	
	AA_{CAP}	Creditable upper adipic acid production limit	t adipic acid	o	Per reporting period/each verification	
Project Calculation Parameters						
	$UR_{n,P}$	Percent of time the abatement technology was in use during the current year, or reporting period, of the project	%	c	Per reporting period	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$ATU_{n,P}$	Number of days, n, of abatement technology utilization during the current year, or reporting period, of the project, P	days	o	Per reporting period	
	$OD_{n,P}$	Number of days, n, of AAP operation during the current year or reporting period of the project, P	days	o	Per reporting period	
	PE	Project emissions during the reporting period	tCO_2e	C	Per reporting period	Emissions resulting from project activities
	PE_{N_2O}	Measured project N_2O emissions in the off gas to project N_2O control units during the reporting period	tCO_2e	C	Per reporting period	
	PE_{HC}	Net GHG emissions from the use of hydrocarbons as a reducing agent or to reheat off gas during the reporting period	tCO_2e	C	Per reporting period	
	PE_{EE}	GHG emissions from external energy used to reheat the off gas during the reporting period	tCO_2e	C	Per reporting period	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$F_{RP,cu}$	Volume flow rate in the tail gas during the reporting period by N_2O control unit	m^3 / hour	M	Every one minute	Data collected using a gas volume flow meter and processed using appropriate software programs. The meter will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the tail gas after exiting the control equipment.
	$F_{RP,ncu}$	Volume flow rate in the off gas during the reporting period to the non-N_2O control unit	m^3 / hour	M	Every one minute	Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
	F_{cu}	Volume flow rate in the off gas during the reporting period by N_2O control unit	m^3 / hour	M	Every one minute	Data collected using a gas volume flow meter and processed using appropriate software programs. The meter will be calibrated according to manufacturer specification and recognized industry standards.
	$N_2O_{RP,conc,cu}$	N_2O concentration in the tail gas during the reporting period to the N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the tail gas after exiting the control equipment.

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$N_2O_{RP,conc,ncu}$	N2O concentration in the off gas during the reporting period to the non - N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards.
	$N_2O_{conc,cu}$	N_2O concentration in the off gas during the reporting period by N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards.
	$N_2O_{conc,ncu}$	N2O concentration in the off gas during the reporting period by non-N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards.
	$OH_{RP,cu}$	Operating hours in reporting period by N_2O control unit	Hours	O	Totaled once for the reporting period	
	$OH_{RP,ncu}$	Operating hours in reporting period by non-N_2O control unit	Hours	O	Totaled once for the reporting period	
	$CO_{2_{HC}}$	Net GHG emissions as CO_2 from hydrocarbon use during the reporting period	tCO_2e	C	Per reporting period	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	$CH_{4_{HC}}$	Net GHG emissions as CH_4 from hydrocarbon use during the reporting period	tCO_2e	C	Per reporting period	
	ρ_{HC}	Hydrocarbon density	t / m^3	m	Per reporting period	
	$Q_{HC,RP}$	Quantity of hydrocarbon, with two or more molecules of carbon, input during the reporting period (i.e. not methane)	m^3	O	Daily	
	$EF_{HC,RP}$	GHG emissions as CH_4 from hydrocarbon use during the reporting period	tCO_2e / tHC	C	Per reporting period	Given by the molecular weight of the hydrocarbon and CO2 and the chemical reaction when hydrocarbons are converted
	ρ_{CH_4}	Methane density	t / m^3	M	Per reporting period	
	$Q_{CH4,RP}$	Quantity of methane used during the reporting period	m^3	O	Daily	
	SE	Emissions from net change in steam export during the reporting period	tCO_2e	C	Per reporting period	
	OGU	Emissions from net change in tail/off gas utilization during the reporting period	tCO_2e	C	Per reporting period	
	OGH	Emissions from net change in tail/off gas heating during the reporting period	tCO_2e	C	Per reporting period	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
	ST_{RP}	Project steam export during the reporting period	MW	C	Once	
	η_{ST}	Efficiency of steam generation	Fraction	C	Once	Manufacturer supplied information
	EF_{ST}	Fuel emission factor for steam generation	tCO_2e / MWh	C	Per reporting period	From fuel supplier certificate or default value
	OH_{RP}	Operating hours in reporting period	Hours	O	Totaled once for the reporting period	
	EE_{RP}	Project energy export from tail/off gas utilization during the reporting period	MW	C	Once	
	η_{r}	Efficiency of replaced technology	Fraction	C	Once	Manufacturer supplied information
	EF_{r}	Fuel emission factor for replaced technology	tCO_2e / MWh	C	Per reporting period	From fuel supplier certificate or default value
	EI_{OGH}	Energy input for additional tail/off gas heating during the reporting period	MWh	M or C	Monthly	
	η_{OGH}	Efficiency of additional tail/off gas heating	Fraction	C	Once	Manufacturer supplied information
	EF_{OGH}	Emission factor for additional tail/off gas heating	tCO_2e / MW	C	Once	From fuel supplier certificate or default value

7 Reporting Parameters

This section provides requirements and guidance on reporting rules and procedures. A priority of the Reserve is to facilitate consistent and transparent information disclosure among project developers. Project developers must submit verified emission reduction reports to the Reserve for every reporting period.

7.1 Project Submittal Documentation

Project developers must provide the following documentation to the Reserve in order to register an adipic acid project:

- Project Submittal form
- Project diagram
- Signed Attestation of Title form
- Signed Attestation of Voluntary Implementation form
- Signed Attestation of Regulatory Compliance form
- Verification Report
- Verification Statement

Project developers must provide the following documentation each reporting period in order for the Reserve to issue CRTs for quantified GHG reductions:

- Verification Report
- Verification Statement
- Project diagram (if changed from previous reporting period)
- Signed Attestation of Title form
- Signed Attestation of Voluntary Implementation form
- Signed Attestation of Regulatory Compliance form

At a minimum, the above project documentation (except for the project diagram) will be available to the public via the Reserve's online registry. Further disclosure and other documentation may be made available on a voluntary basis through the Reserve. Project submittal forms can be found at http://www.climateactionreserve.org/how/program/documents/.

7.2 Record Keeping

For purposes of independent verification and historical documentation, project developers are required to keep all information outlined in this protocol for a period of 10 years after the information is generated or 7 years after the last verification. This information will not be publicly available, but may be requested by the verifier or the Reserve.

System information the project developer should retain includes:

- All data inputs for the calculation of the project emission reductions, including all required sampled data
- Copies of all solid waste, air, water, and land use permits, Notices of Violations (NOVs), and any administrative or legal consent orders dating back at least five years prior to the project start date, and for each subsequent year of project operation
- Executed Attestation of Title, Attestation of Regulatory Compliance, and Attestation of Voluntary Implementation forms

- Plant design information (nameplate capacity and operating parameters per manufacturer's operating manual) and diagrams/drawings of the AAP
- Diagram schemes showing the type of and detailed components of the N_2O control system and where it is or where it will be installed
- Automated extractive gas analyzer or monitor information (model number, serial number, calibration procedures)
- Gas volume flow meter information (model number, serial number, calibration procedures)
- Plans or diagram schemes showing the selection of data measuring points upstream and/or downstream to the N_2O control system
- Calibration results for all meters
- Information relevant to the N_2O abatement catalysts (composition, operation, and installation)
- The total production of adipic acid, number of operating hours, and control unit utilization rate per reporting period
- Onsite fossil fuel use records
- Onsite grid electricity use records
- Results of CO_2e annual reduction calculations
- Initial and annual verification records and results
- All maintenance records relevant to the N_2O control system and monitoring equipment

Calibrated gas analyzer information that the project developer should retain includes:

- Date, time, and location of N_2O measurement
- N_2O measurement instrument type and serial number
- Date, time, and results of instrument calibration
- Corrective measures taken if instrument does not meet performance specifications

7.3 Reporting Period and Verification Cycle

Project developers must report GHG reductions resulting from project activities during each reporting period. Although projects must be verified annually at a minimum, the Reserve will accept verified emission reduction reports on a sub-annual basis, should the project developer choose to have a sub-annual reporting period and verification schedule (e.g., monthly, quarterly, or semi-annually).

Reporting periods must be contiguous; there must be no time gaps in reporting during the crediting period of a project once the initial reporting period has commenced.

To meet the annual verification deadline, the project developer must have the required verification documentation (see Section 7.1) submitted within 12 months of the end of each reporting period. A reporting period cannot exceed 12 months, and no more than 12 months of emission reductions can be verified at once, except during a project's initial verification. Although there is some flexibility in the length of the initial reporting period, the project developer must still meet the 12-month verification deadline.

8 Verification Guidance

This section provides verification bodies with guidance on verifying GHG emission reductions associated with the project activity. This verification guidance supplements the Reserve's Verification Program Manual and describes verification activities in the context of reducing GHG emissions through adipic acid projects at AAPs.

Verification bodies trained to verify adipic acid projects must be familiar with the following documents:

- Climate Action Reserve Program Manual
- Climate Action Reserve Verification Program Manual
- Climate Action Reserve Adipic Acid Production Project Protocol

The Reserve's Program Manual, Verification Program Manual, and project protocols are designed to be compatible with each other and are available on the Reserve's website at http://www.climateactionreserve.org.

Only ISO-accredited verification bodies trained by the Reserve for this project type are eligible to verify adipic acid project reports. Verification bodies approved under other project protocol types are not permitted to verify adipic acid projects. Information about verification body accreditation and Reserve project verification training can be found on the Reserve website at http://www.climateactionreserve.org/how/verification/.

8.1 Standard of Verification

The Reserve's standard of verification for adipic acid projects is the Adipic Acid Production Project Protocol (this document), the Reserve Program Manual, and the Verification Program Manual. To verify an adipic acid project report, verification bodies apply the guidance in the Verification Program Manual and this section of the protocol to the standards described in Sections 2 through 7 of this protocol. Sections 2 through 7 provide eligibility rules, methods to calculate emission reductions, performance monitoring instructions and requirements, and procedures for reporting project information to the Reserve.

8.2 Monitoring Plan

The Monitoring Plan serves as the basis for verification bodies to confirm that the monitoring and reporting requirements in Section 6 and Section 7 have been met, and that consistent, rigorous monitoring and record keeping is ongoing at the project site. Verification bodies shall confirm that the Monitoring Plan covers all aspects of monitoring and reporting contained in this protocol and specifies how data for all relevant parameters in Table 6.1 are collected and recorded.

8.3 Verifying Project Eligibility

Verification bodies must affirm an adipic acid project's eligibility according to the rules described in this protocol. The table below outlines the eligibility criteria for adipic acid projects. This table does not present all criteria for determining eligibility comprehensively; verification bodies must also look to Section 3 and the verification items list in Table 8.1.

Table 8.1. Summary of Eligibility Criteria for an Adipic Acid Project

Eligibility Rule	Eligibility Criteria	Frequency of Rule Application
Start Date	Projects must be submitted for listing within 12 months of the project start date	Once during first verification
Location	United States and U.S. territories and tribal areas	Once during first verification
Performance Standard	For new installations, the installation of a previously uninstalled N_2O control technology at an AAP; For enhancements, the increased utilization of the existing N_2O control technology compared historical utilization	Every verification
Legal Requirement Test	Signed Attestation of Voluntary Implementation form and monitoring procedures for ascertaining and demonstrating that the project passes the legal requirement test	Every verification
Regulatory Compliance Test	Signed Attestation of Regulatory Compliance form and disclosure of all non-compliance events to verifier; project must be in material compliance with all applicable laws	Every verification

8.4 Core Verification Activities

The Adipic Acid Project Protocol provides explicit requirements and guidance for quantifying the GHG reductions associated with reducing N_2O emissions at adipic acid plants. The Verification Program Manual describes the core verification activities that shall be performed by verification bodies for all project verifications. They are summarized below in the context of an adipic acid project, but verification bodies must also follow the general guidance in the Verification Program Manual.

Verification is a risk assessment and data sampling effort designed to ensure that the risk of reporting error is assessed and addressed through appropriate sampling, testing, and review. The three core verification activities are:

1. Identifying emission sources, sinks, and reservoirs (SSRs)
2. Reviewing GHG management systems and estimation methodologies
3. Verifying emission reduction estimates

Identifying emission sources, sinks, and reservoirs
The verification body reviews for completeness the sources, sinks, and reservoirs identified for a project.

Reviewing GHG management systems and estimation methodologies
The verification body reviews and assesses the appropriateness of the methodologies and management systems that the adipic acid project operator uses to gather data on plant operations and N_2O emissions and to calculate baseline and project emissions.

Verifying emission reduction estimates
The verification body further investigates areas that have the greatest potential for material misstatements and then confirms whether or not material misstatements have occurred. This involves site visits to the project facility to ensure the systems on the ground correspond to and are consistent with data provided to the verification body. In addition, the verification body recalculates a representative sample of the performance or emissions data for comparison with

data reported by the project developer in order to double-check the calculations of GHG emission reductions.

8.5 Adipic Acid Production Verification Items

The following tables provide lists of items that a verification body needs to address while verifying an adipic acid project. The tables include references to the section in the protocol where requirements are further specified. The table also identifies items for which a verification body is expected to apply professional judgment during the verification process. Verification bodies are expected to use their professional judgment to confirm that protocol requirements have been met in instances where the protocol does not provide (sufficiently) prescriptive guidance. For more information on the Reserve's verification process and professional judgment, please see the Verification Program Manual.

Note: These tables shall not be viewed as a comprehensive list or plan for verification activities, but rather guidance on areas specific to adipic acid projects that must be addressed during verification.

8.5.1 Project Eligibility and CRT Issuance

Table 8.2 lists the criteria for reasonable assurance with respect to eligibility and CRT issuance for adipic acid projects. These requirements determine if a project is eligible to register with the Reserve and/or have CRTs issued for the reporting period. If any requirement is not met, either the project may be determined ineligible or the GHG reductions from the reporting period (or subset of the reporting period) may be ineligible for issuance of CRTs, as specified in Sections 2, 3, and 6.

Table 8.2. Eligibility Verification Items

Protocol Section	Eligibility Qualification Item	Apply Professional Judgment?
	Verify that the project meets the definition of an adipic acid project	No
	Verify whether the AAP is existing, upgraded, relocated or restarted	No
	Verify ownership of the reductions by reviewing the Attestation of Title	No
	Verify that the project only consists of activities at a single AAP operating within the U.S. or its territories	No
	Verify project start date	No
	Verify accuracy of project start date based on operational records	Yes
	Verify that the project has documented and implemented a Monitoring Plan	No
	Verify that project is within its 10-year crediting period	No
	Verify that the project meets the Performance Standard Test	No
	Confirm execution of the Attestation of Voluntary Implementation form to demonstrate eligibility under the Legal Requirement Test	No
	Confirm that neither the Title V nor PSD permit for the AAP includes language requiring installation of N_2O control technology	No
	Verify that the Monitoring Plan contains procedures for ascertaining and demonstrating that the project passes the Legal Requirement Test at all times	Yes
	Verify that the project activities comply with applicable laws by reviewing any instances of non-compliance provided by the project developer and performing a risk-based assessment to confirm the statements made by the project developer in the Attestation of Regulatory Compliance form	Yes
	Verify that monitoring meets the requirements of the protocol. If it does not, verify that a variance has been approved for monitoring variations	No
	Verify that all components of the CEMS adhered to the field check and calibration schedule specified in the protocol. If they do not, verify that a variance has been approved for monitoring variations or that adjustments have been made to data per the protocol requirements	No
	Verify that installation and initial certification of the N_2O CEMS were completed according to manufacturer specifications and the requirements of this protocol	No
	Verify that the calibration test procedures were properly followed, including the calibration error test and linearity check	No
	Verify that the relative accuracy test audits were completed according to the required procedure and schedule	No
	If used, verify that data substitution methodology was properly applied	No
n/a	If any variances were granted, verify that variance requirements were met and properly applied	Yes

8.5.2 Quantification

Table 8.3 lists the items that verification bodies shall include in their risk assessment and recalculation of the project's GHG emission reductions. These quantification items inform any determination as to whether there are material and/or immaterial misstatements in the project's GHG emission reduction calculations. If there are material misstatements, the calculations must be revised before CRTs are issued.

Table 8.3. Quantification Verification Items

Protocol Section	Qualification Item	Apply Professional Judgment?
	Verify that SSRs included in the GHG Assessment Boundary correspond to those required by the protocol and those represented in the project diagram for the reporting period / Verify that all SSRs in the GHG Assessment Boundary are accounted for	No
	Verify that the baseline emissions are properly aggregated	No
	Verify that the project emissions were calculated according to the protocol with the appropriate data	No
	Verify that the project developer correctly monitored, quantified, and aggregated electricity use	Yes
	Verify that the project developer correctly monitored, quantified, and aggregated fossil fuel use	Yes
	Verify that the project developer applied the correct emission factors for fossil fuel combustion and grid-delivered electricity	No
	Verify that the project developer correctly applied emission factors	No
	If default emission factors are not used, verify that project-specific emission factors are based on official source-tested emissions data or are from an accredited source test service provider	No
	Verify that the appropriate calculations were performed by the project developer and quantification and equation processes were followed.	No
	Verify that the project developer correctly calculated and applied AE	No
	Verify that the project developer correctly calculated the nitric acid recovery ratio, *if applicable*	No
	Verify that the project developer correctly accounted for N_2O emissions at the inlet and outlet of the control system for the project, as applicable	No
	Verify that the project developer correctly quantified hydrocarbon use for the project, *if applicable*	No
	Verify that the project developer correctly quantified external energy inputs or was correct in not estimating this source due to capture and use of the additional energy within the system	Yes
	Verify that the project emissions calculations were calculated according to the protocol with the appropriate data	No

8.5.3 Risk Assessment

Verification bodies will review the following items in Table 8.4 to guide and prioritize their assessment of data used in determining eligibility and quantifying GHG emission reductions.

Table 8.4. Risk Assessment Verification Items

Protocol Section	Item that Informs Risk Assessment	Apply Professional Judgment
	Verify that the project Monitoring Plan is sufficiently rigorous to support the requirements of the protocol and proper operation of the project	Yes
	Verify that appropriate monitoring equipment is in place to meet the requirements of the protocol	No
	Verify that the individual or team responsible for managing and reporting project activities are qualified to perform this function	Yes
	Verify that appropriate training was provided to personnel assigned to GHG reporting duties	Yes
	Verify that all contractors are qualified for managing and reporting GHG emissions if relied upon by the project developer. Verify that there is internal oversight to assure the quality of the contractor's work	Yes
	Verify that all required records have been retained by the project developer	No

8.5.4 Completing Verification

The Verification Program Manual provides detailed information and instructions for verification bodies to finalize the verification process. It describes completing a Verification Report, preparing a Verification Statement, submitting the necessary documents to the Reserve, and notifying the Reserve of the project's verified status.

9 Glossary of Terms

Accredited verifier	A verification firm approved by the Climate Action Reserve to provide verification services for project developers.
Additionality	Project activities that are above and beyond "business as usual" operation, exceed the baseline characterization, and are not mandated by regulation.
Anthropogenic emissions	GHG emissions resultant from human activity that are considered to be an unnatural component of the Carbon Cycle (i.e., fossil fuel destruction, de-forestation, etc.).
Biogenic CO_2 emissions	CO_2 emissions resulting from the destruction and/or aerobic decomposition of organic matter. Biogenic emissions are considered to be a natural part of the Carbon Cycle, as opposed to anthropogenic emissions.
Carbon dioxide (CO_2)	The most common of the six primary greenhouse gases, consisting of a single carbon atom and two oxygen atoms.
CO_2 equivalent (CO_2e)	The quantity of a given GHG multiplied by its total global warming potential. This is the standard unit for comparing the degree of warming which can be caused by different GHGs.
Direct emissions	GHG emissions from sources that are owned or controlled by the reporting entity.
Effective Date	The date of adoption of this protocol by the Reserve board: *expected January 22, 2020*.
Emission factor (EF)	A unique value for determining an amount of a GHG emitted for a given quantity of activity data (e.g., metric tons of carbon dioxide emitted per barrel of fossil fuel burned).
Fossil fuel	A fuel, such as coal, oil, and natural gas, produced by the decomposition of ancient (fossilized) plants and animals.
Greenhouse gas (GHG)	Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), or perfluorocarbons (PFCs).
GHG reservoir	A physical unit or component of the biosphere, geosphere, or hydrosphere with the capability to store or accumulate a GHG that has been removed from the atmosphere by a GHG sink or a GHG captured from a GHG source.
GHG sink	A physical unit or process that removes GHG from the atmosphere.
GHG source	A physical unit or process that releases GHG into the atmosphere.

Global Warming Potential (GWP)	The ratio of radiative forcing (degree of warming to the atmosphere) that would result from the emission of one unit of a given GHG compared to one unit of CO_2.
Indirect emissions	Reductions in GHG emissions that occur at a location other than where the reduction activity is implemented, and/or at sources not owned or controlled by project participants.
Metric ton (t, tonne)	A common international measurement for the quantity of GHG emissions, equivalent to about 2204.6 pounds or 1.1 short tons.
Methane (CH_4)	A potent GHG with a GWP of 21, consisting of a single carbon atom and four hydrogen atoms.
MMBtu	One million British thermal units.
Mobile combustion	Emissions from the transportation of employees, materials, products, and waste resulting from the combustion of fuels in company owned or controlled mobile combustion sources (e.g., cars, trucks, tractors, dozers, etc.).
Project baseline	A "business as usual" GHG emission assessment against which GHG emission reductions from a specific GHG reduction activity are measured.
Project developer	An entity that undertakes a GHG project, as identified in Section 2.2 of this protocol.
Verification	The process used to ensure that a given participant's GHG emissions or emission reductions have met the minimum quality standard and complied with the Reserve's procedures and protocols for calculating and reporting GHG emissions and emission reductions.
Verification body	A Reserve-approved firm that is able to render a verification opinion and provide verification services for operators subject to reporting under this protocol.

10 References

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Appendix A Development of the Performance Standard

A.1 Emission Controls at Adipic Acid Plants

A.1.1 Existing Controls

Currently, most adipic acid facilities are fitted with some N_2O abatement technology. Although there is no federal requirement to control N_2O emission in the United States (except under limited circumstances, see Section 3.4.2.1) all Western industrialized countries voluntarily installed abatement technology in the 1990s.[30]

The most appropriate type of control technology can be highly facility specific. Among the two existing adipic acid plants in the United States, the Ascend adipic acid plant has a Thermal Reduction Unit ("TRU") installed, which abated approximately 83% of the facility's N_2O emissions[31] in 2017, whereas the INVISTA adipic acid plant abates using specially designed boilers that generate steam from process-derived waste streams and N_2O-specific selective catalytic reduction ("SCR") systems, which achieved 97% abatement in 2017.[32,33] Because adipic acid production is so emissions intensive, even after abating the majority of their emissions, these two facilities still released 7.4 million tCO_2e in 2017, and thus have substantial opportunity for additional emission reductions.

A.1.2 Potential Controls and Eligible Project Activities

Adipic acid N_2O abatement technology is similar to the abatement technology at nitric acid facilities. In the Reserve's Nitric Acid Protocol, abatement can either be secondary (abatement in the burner/ammonia oxidation reactor ["AOR"] where the reaction occurs) or tertiary (abatement of the waste off gas downstream of the AOR). However, unlike nitric acid production, adipic acid production cannot tolerate the associated pressure change with secondary abatement. As a result, abatement is limited to installing technology to scrub the facility's off gas. Control technology falls into four types of systems, outlined in Table A.1.

[30] Heike Mainhardt and Dina Kruger, "N_2O Emissions from Adipic Acid and Nitric Acid Production," accessed June 25, 2019, https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/3_2_Adipic_Acid_Nitric_Acid_Production.pdf.
[31] United States Environmental Protection Agency, "Ascend - Cantonment, FL, GHG Facility Details."
[32] United States Environmental Protection Agency, "Invista - Victoria, TV, GHG Facility Details."
[33] INVISTA's West Powerhouse ("WPH") Victoria plant has a comparably high abatement level because it was required to install GHG control technology as part of their Prevention of Significant Deterioration ("PSD") permitting under the Clean Air Act after a major source modification (40 CFR § 124.41). For more information, see Section 3.1 "Federal Regulations".

Table A.1. Review of Potential Control Technologies at Adipic Acid Plants[34]

Abatement Type	Description	Example Equipment
Catalytic Destruction	Destroy N_2O using a catalyst	Noble or precious metal catalysts
Thermal Destruction	Destroy N_2O in using reducing flame burners with pre-mixed methane or natural gas.	Thermal Reduction Units
Recycling/Utilization Technologies	Utilize N_2O as a reactant or input produce other products.	Using N_2O off gas as an oxidant to produce phenol from benzene.
Recycle to Nitric Acid	Recycle N_2O to create nitric acid by burning the gas at high temperatures with steam.	Nitrogen recycling adiabatic reactor

Existing facilities can reduce their emissions beyond a business-as-usual level in two ways. First, they could utilize their existing emissions control technology at a higher rate, or they could install new emissions abatement control technology. Increasing the use of existing abatement technology is particularly pertinent to U.S. AAPs; all plants were early movers in installing abatement technology. However, there are often barriers (financial or otherwise) that make it impracticable to fully utilize the existing technology to abate N_2O.

For example, if a facility has TRU, there can be a trade-off between N_2O abatement and abating other potentially harmful pollutants such as NO_x.[35] Facilities can send their off gas to the TRU, which reduces N_2O[36] but has only a limited capacity to reduce NO_x emissions, or send their off gas to a NO_x-specific SCR ("SCR de-NO_x unit"), which reduces NO_x emissions but not N_2O emissions. The SCR de-NO_x unit also creates some GHG emissions due to the ammonia used during operation. Because N_2O is not regulated and NO_x emissions are regulated under the Clean Air Act, facilities will only utilize their TRUs when they are falling below their legal NO_x limits. In the absence of an offset system or a regulatory reason to reduce GHG emissions, facilities have no incentive to make a capital investment to adjust their operations to eliminate the NO_x/N_2O trade-off. With an incentive, a facility could in practice increase TRU utilization by finding a pathway to reduce NO_x.

[34] IEA Greenhouse Gas R&D Programme, "Abatement of Other Greenhouse Gases - Nitrous Oxide," September 2000, https://ieaghg.org/docs/General_Docs/Reports/PH3-29%20nitrous%20oxide.pdf. IEA Greenhouse Gas R&D Programme, "Abatement of Other Greenhouse Gases - Nitrous Oxide," September 2000, https://ieaghg.org/docs/General_Docs/Reports/PH3-29%20nitrous%20oxide.pdf.

[35] NO_X is a volatile organic compound that reacts with sunlight to create ground-level ozone (O_3), or smog. Ozone is one of six criteria air pollutants regulated under the Clean Air Act (40 CFR part 50). Historically, a prevalent NO_X control system (non-selective catalytic reduction systems, or NSCR) also destroyed up to 90% of the N_2O emissions (Heike Mainhard and Diana Kruger, "N2O Emissions from Adipic Acid and Nitric Acid Production," accessed June 25, 2019, https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/3_2_Adipic_Acid_Nitric_Acid_Production.pdf). However, NSCR technology was replaced in the late 1970s by NO_X-specific Selective Catalytic Reduction units ("SCRs") that were more cost effective and provide targeted reduction for only NO_x gases. Presently, both remaining adipic acid plants in the United States are fitted with SCR de-NO_x units.

[36] TRUs generate some emissions from the natural gas combustion during their operation.