U.S.
Adipic Acid Production

Protocol | Version 1.0 | September 30, 2020

Errata + Protocol

CLIMATE ACTION RESERVE

Adipic Acid Production Protocol
Version 1.0
ERRATA AND CLARIFICATIONS

The Climate Action Reserve (Reserve) published its Adipic Acid Production Protocol Version 1.0 in September 2020. While the Reserve intends for the Adipic Acid Production Protocol V1.0 to be a complete, transparent document, it recognizes that correction of errors and clarifications will be necessary as the protocol is implemented and issues are identified. This document is an official record of all errata and clarifications applicable to the Adipic Acid Production Protocol V1.0.[1]

Per the Reserve Offset Program Manual, both errata and clarifications are considered effective on the date they are first posted on the Reserve website. The effective date of each erratum or clarification is clearly designated below. All listed and registered adipic acid production projects must incorporate and adhere to these errata and clarifications when they undergo verification. The Reserve will incorporate both errata and clarifications into future versions of the protocol.

All project developers and verification bodies must refer to this document to ensure that the most current guidance is adhered to in project design and verification. Verification bodies shall refer to this document immediately prior to uploading any Verification Statement to assure all issues are properly addressed and incorporated into verification activities.

If you have any questions about the updates or clarifications in this document, please contact the Reserve at policy@climateactionreserve.org or (213) 891-1444 x3.

[1] See Section 4.3.4 of the Reserve Offset Program Manual for an explanation of the Reserve's policies on protocol errata and clarifications. "Errata" are issued to correct typographical errors. "Clarifications" are issued to ensure consistent interpretation and application of the protocol. For document management and program implementation purposes, both errata and clarifications are contained in this single document.

Errata and Clarifications (arranged by protocol section)

Section 6

Section 6

1. Daily Flow Interference Check Requirement (CLARIFICATION – July 27, 2021)

Section: 6.2.1 Frequency of Testing

Context: Table 6.1 in Section 6.2.1 lists the required tests to be conducted relevant to N_2O analysis using CEMS. A flow interference check of the flow meter is specified as a requirement under daily assessments. This requirement (designed as a QA/QC procedure for power plants under 40 CFR Part 75) is neither appropriate nor necessary for adipic acid plants. The semi-annual/annual RATA requirement will ensure the flow meter is properly calibrated.

Clarification: A daily flow interference check on the CEMS flow meter is not required under the protocol. Based on this update, Table 6.1 shall now read:

Test	Frequency		
	Daily	Quarterly	Semiannual or Annual
Calibration Error Test (N_2O, flow)	X		
Flow-to-Load Ratio (only applicable if the adipic acid plant produces electrical or thermal output)		X	
Leak Check (DP flow monitors)		X	
Linearity Check		X	
RATA (N_2O, flow)			X

2. Quarterly Flow-to-Load Ratio/Gross Heat Rate Evaluation Test Requirement (CLARIFICATION – July 27, 2021)

Section: 6.2.1 Frequency of Testing

Context: Table 6.1 in Section 6.2.1 lists the required tests to be conducted relevant to N_2O analysis using CEMS. A flow-to-load ratio or gross heat rate evaluation is specified as a requirement under quarterly assessments. Upon closer examination of 40 CFR Part 75 (Appendix A, 7.8), it clarifies that units that do not produce electrical output (in megawatts) or thermal output (in klb of steam per hour) are exempt from the flow-to-load ratio test requirements of section 2.2.5 of Appendix B.

Clarification: If the adipic acid plant where the project is located does not produce electrical or thermal output, then the project does not need to perform a quarterly flow-to-load ratio test. Based on this update, Table 6.1 shall now read:

Test	Frequency		
	Daily	Quarterly	Semiannual or Annual
Calibration Error Test (N_2O, flow)	X		

Test	Frequency		
	Daily	Quarterly	Semiannual or Annual
Flow-to-Load Ratio (only applicable if the adipic acid plant produces electrical or thermal output)		X	
Leak Check (DP flow monitors)		X	
Linearity Check		X	
RATA (N_2O, flow)			X

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Abbreviations and Acronyms

AAPP	Adipic Acid Production Protocol
AAP	Adipic acid plant
AE	Abatement efficiency
ASTM	American Society for Testing and Material Information
BACT	Best available control technology
CAA	Clean Air Act
CARB	California Air Resources Board
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	Kilotonne (or metric 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
O_2	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	Tonne (or metric ton)
TRU	Thermal reduction unit

1 Introduction

The Climate Action Reserve (Reserve) Adipic Acid Production Protocol (AAPP) 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. 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.[1]

The Reserve is an offset registry serving the California cap-and-trade program and the voluntary carbon market. The Reserve encourages actions to reduce GHG emissions and works to ensure environmental benefit, integrity, and transparency in market-based solutions to address global climate change. It operates the largest accredited registry for the California compliance market and has played an integral role in the development and administration of the state's cap-and- trade program. For the voluntary market, the Reserve establishes high quality standards for carbon offset projects, oversees independent third-party verification bodies, and issues and tracks the transaction of carbon credits (Climate Reserve Tonnes or CRTs) generated from such projects in a transparent, publicly accessible system. The Climate Action Reserve is a private 501(c)(3) non-profit organization based in Los Angeles, California.

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[2] and Section 8 of this protocol.

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

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 in a two-stage process. First, cyclohexane is air-oxidized to form either cyclohexanol (A) or a cyclohexanone (K)/cyclohexanol (A) mixture (KA). In the second stage, KA is reacted with nitric acid (HNO3) to produce adipic acid, which is then purified by crystallization. The HNO_3 oxidization of KA, however, creates N_2O as an unavoidable byproduct that is emitted in the facility's off gas. Adipic acid and N_2O are created in proportional molar ratios (i.e., for every molecule of adipic acid produced, a molecule of N_2O is produced as a byproduct.). The process is represented by the chemical reaction[4] in Figure 2.1 below. 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 recycling.[5]

$$(CH_2)_5CO\ [cyclohexanone] + (CH_2)_5CHOH\ [cyclohexanol] + wHNO_3 \rightarrow HOOC(CH_2)_4COOH\ [adipic\ acid] + xN_2O + yH_2O$$

Figure 2.1. Chemical Reaction to Produce Adipic Acid

Adipic acid N_2O abatement technology is similar to the abatement technology at nitric acid facilities.[6] 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 plants (AAPs) are fitted with some N_2O abatement technology. The most appropriate type of control technology is also typically highly facility specific. Control technology fall into four types of systems, as described in Table 2.1 below. Figure 2.2 below portrays a typical process flowsheet for the catalytic decomposition of N_2O, one of the four approved abatement methods in this protocol. Nevertheless, in 2018, U.S. AAPs were still responsible for a reported 10.3 million metric tons of carbon dioxide equivalent (tCO_2e)

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[3] The Human Metabolomics Database, "Metabocard for Adipic Acid (HMDB0000448)," accessed September 12, 2019, http://www.hmdb.ca/metabolites/HMDB0000448#references.
[4] United States Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016."
[5] Castellan, A., Bart, J. C. J., & Cavallaro, S. (1991). Industrial production and use of adipic acid. *Catalysis Today*, *9*(3), 237-254.
[6] Climate Action Reserve Nitric Acid Production Protocol Version 2.2, April 18, 2019. Available here: http://www.climateactionreserve.org/how/protocols/nitric-acid-production/

emissions,[7] a value that has increased each year from the year prior since 2015, while U.S. adipic acid production has risen gradually by roughly 10% since 1990 to approximately 830,000 metric tons.[8]

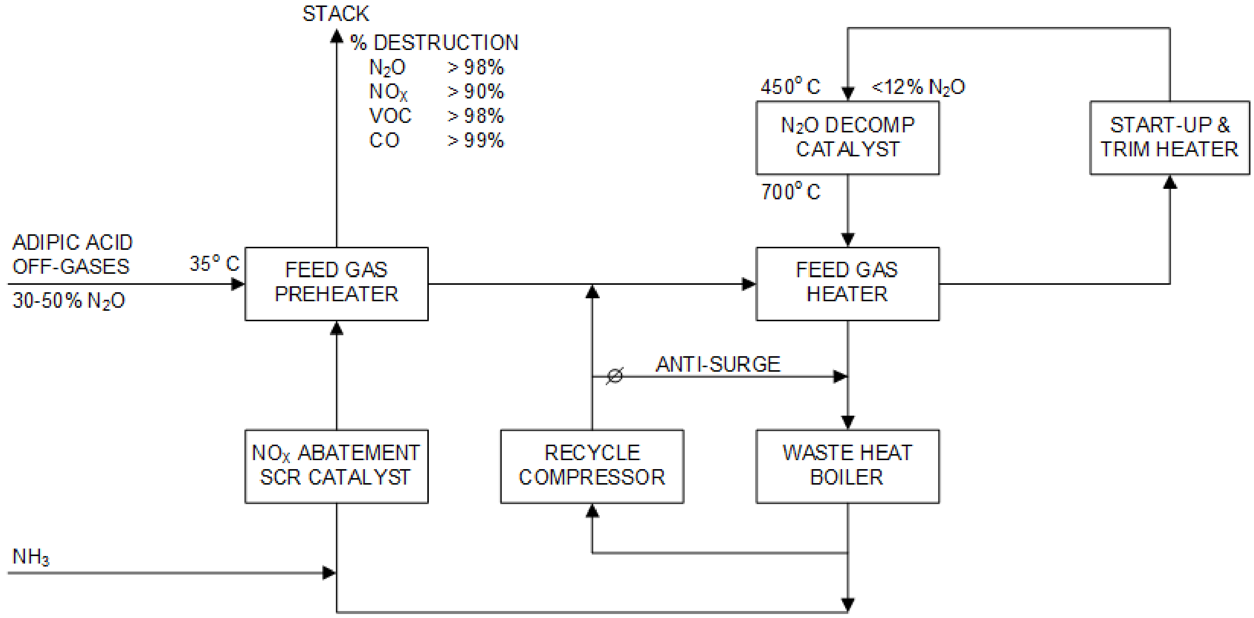

Figure 2.2. Typical Process Flowsheet for Catalytic Decomposition of N_2O

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-specific 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. Alternatively, AAPs 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 emissions are not regulated, and NO_x emissions are regulated under the U.S. Clean Air Act (CAA) (Section 3.4.2), AAPs will only utilize their N_2O control technology, e.g., TRUs, when they're 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 abatement efficiency of existing N_2O control technology and/or install new N_2O control technology to abate the remaining N_2O emissions above current abatement levels.

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

[7] U.S. Environmental Protection Agency (2019a). Greenhouse Gas Reporting Program (GHGRP) Facility Level Information on GHGs Tool (FLIGHT). Washington, D.C., October 3, 2019. Available at: https://ghgdata.epa.gov/ghgp/main.do#

[8] U.S. Environmental Protection Agency (2019b). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017. *EPA 430-R-19-001*. Washington, DC., April 11, 2019. Available at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2017

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 using flame burners with pre-mixed CH_4 or natural gas	Thermal Reduction Units (TRUs)
Recycle to Nitric Acid	Recycle N_2O to create nitric acid by burning the gas at high temperatures with steam	Nitrogen recycling adiabatic reactor
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

For the purpose of this protocol, an “enhancement” constitutes the implementation of a capital investment expenditure to improve the N_2O abatement efficiency of an existing control technology compared to historical N_2O abatement efficiency levels (See Section 3.4.1 and Section 5.1). Enhancements may range from improvements or changes to equipment in the AAP that augment control technology effects on emissions to full system retrofits, but *must require* an upfront cost for implementation.

Projects may only be implemented at existing, relocated, or upgraded AAPs. The protocol does not apply to new AAPs constructed on or after September 30, 2020 with the exception of new AAPs for which a permit application for construction was submitted to the appropriate regulating authorities prior to September 30, 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.[9] 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.

[9] 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 AAPs 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 AAP prior to the project start date, but the installation of a new N_2O control technology or enhancement of the existing one results in additional N_2O abatement.

To be eligible, the project must be submitted to the Reserve no more than 12 months after the project start date.[10] 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 Reserve Offset Program Manual.

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, including under an emissions cap or other emissions trading scheme (ETS).

[10] 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/.

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.[11] 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

3.4.1 The Performance Standard Test

In developing performance standards, the Reserve considers financial, economic, social, and technological drivers that may affect decisions to undertake a particular project activity. Standards are specified such that the large majority of projects that meet the standard are unlikely to have been implemented due to these other drivers. In other words, incentives created by the carbon market are likely to have played a critical role in decisions to implement projects that meet the performance standard.[12]

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. To assess additional performance, this protocol uses a technology-specific threshold: the installation and/or enhancement of an N_2O control system(s) at an AAP to improve and maintain improved levels of N_2O abatement efficiency better than business-as-usual levels (Section 5.1).

Both new installation and enhancement adipic acid projects face financial barriers to project implementation, with new investment costs estimated to range from roughly 10.6 million USD to 17.25 million USD and increased operating costs estimated to range from roughly 1.33 to 2.0 million USD per year.[13,14] Therefore, adipic acid projects automatically pass the performance standard test by either installing a new approved N_2O control technology not previously installed at the AAP and/or enhancing an existing one, as displayed in Table 2.1 and listed again below:

[11] See zero-credit reporting period guidance and requirements in the Reserve Offset Program Manual at http://www.climateactionreserve.org/how/program/program-manual/. See more information about reporting periods in Section 7.3 of this protocol.

[12] See "Additionality Determinations" in the Reserve Offset Program Manual.

[13] Schneider et al., 2010. Industrial N_2O Projects Under the CDM: Adipic Acid – A Case of Carbon Leakage? Stockholm Environment Institute. October 9, 2010.

[14] All currencies were converted from EURs to 2010 U.S. Dollars (USD) with an annual average conversion factor of 1.33 https://www.x-rates.com/average/?from=EUR&to=USD&amount=1&year=2010.

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

For new installations, both the installation of a technology completely new to the AAP and/or the installation of a redundant technology (e.g., a second TRU) are eligible, so long as the technology was not installed and in operation at any point prior to the project start date.

The performance standard test is applied as of the project start date, and is evaluated at the project's initial verification. Once a project is registered, it does not need to be evaluated against the performance standard test of any future version of the protocol for the duration of its first 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 (e.g., cap-and-trade programs, emissions trading schemes) 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[15] 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.[16] 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 AAPs'

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

[16] 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.

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).[17] 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 CO_2e 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.[18]

However, in 2014, the Supreme Court struck down the Title V provision of the Tailoring Rule;[19] 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.

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[20] 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.

[17] 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
[18] 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.
[19] Utility Air Regulatory Group v. Environmental Protection Agency et. al., No. 12–1146 (Supreme Court of the United States June 23, 2019).
[20] Attestation forms are available at http://www.climateactionreserve.org/how/program/documents/.

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.

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.

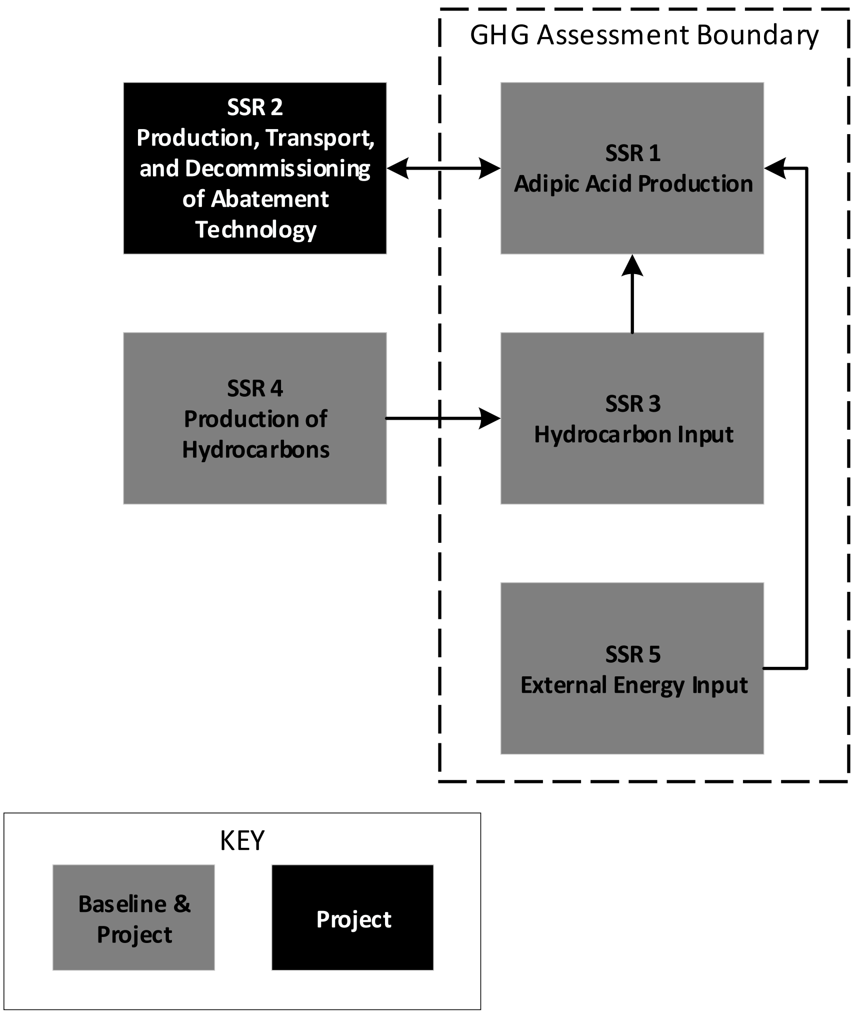

Figure 4.1. General illustration of the GHG Assessment Boundary

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	Excluded as the upstream and downstream emissions related to the N_2O abatement device(s) are one-time emissions occurring off-site and outside the control of the AAP, and are considered insignificant given the long project life.
		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	Excluded as 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	Excluded as GHG emissions related to the production of hydrocarbons used as reducing agent are one-time emissions occurring off-site and outside the control of the AAP, and are considered insignificant given the long project life.
		CH_4				
		N_2O				
5	Emissions from increased external energy use (*if applicable*)	CO_2	I	GHG emissions based on additional amounts of energy used during the project	B, P	If any additional energy is used as a result of the project beyond what is required in the baseline (e.g., increased utilization of N_2O abatement technology), additional GHG emissions from the project activity will occur and may be significant.
		CH_4				
		N_2O				

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 reported is called the "reporting period." The length of time over which GHG reductions are verified is called a "verification period."[21]

Equation 5.1. Calculating GHG Emission Reductions

$$ER = BE - PE$$

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, see Equation 5.2	tCO_2e
PE	=	Total project emissions for the reporting period, from all SSRs in the GHG Assessment Boundary, see Equation 5.7	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).[22] 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

[21] For more information on reporting and verification periods, see Section 7.3 of this protocol.
[22] Available here: https://ipcc.ch/publications_and_data/publications_and_data_reports.shtml.

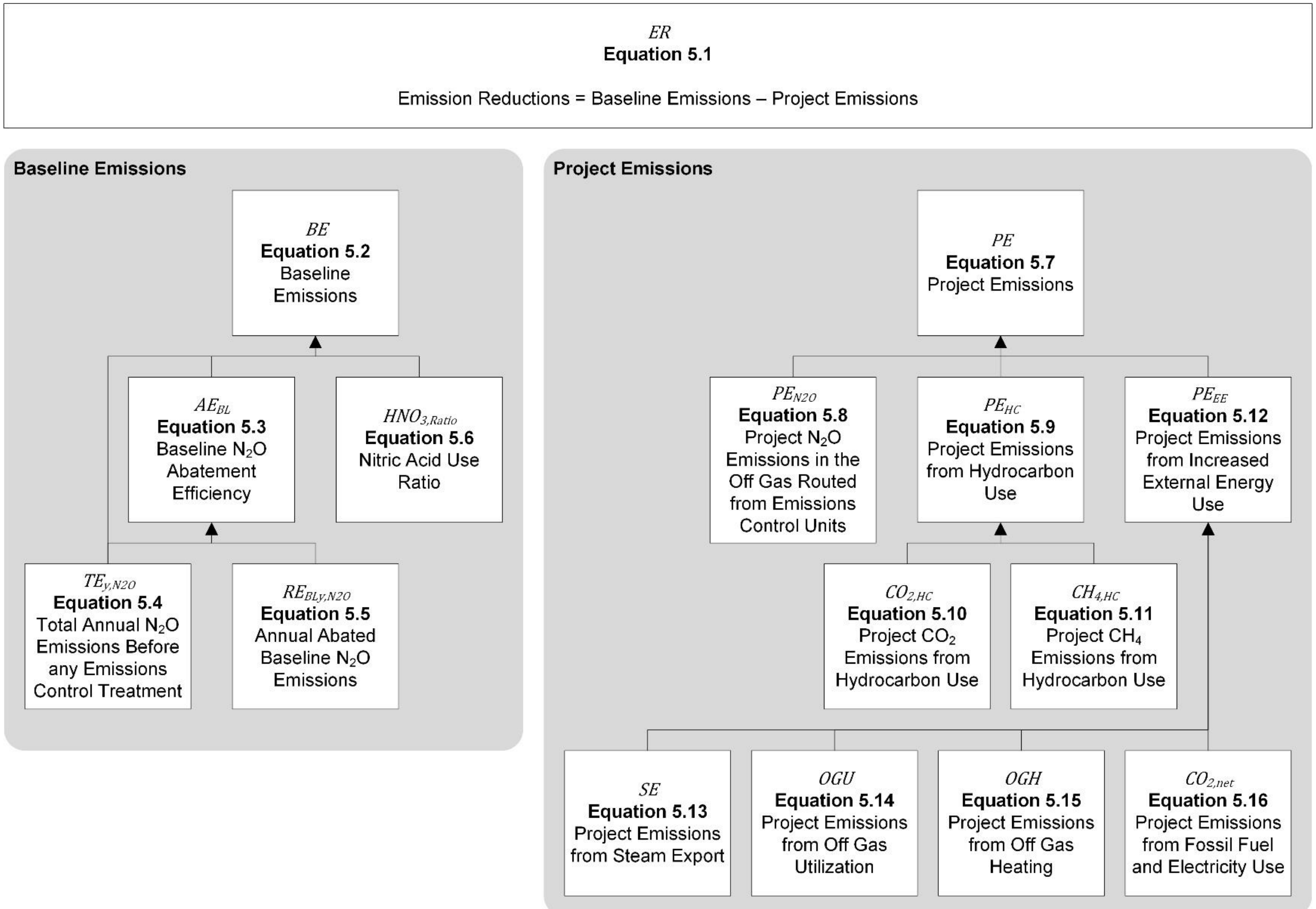

Figure 5.1. Organizational Chart of Equations for Adipic Acid Projects

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). The calculation of baseline emissions in Equation 5.2 requires inputs related to adipic acid production, the appropriate baseline N_2O abatement efficiency (AE), the project emissions prior to destruction in the reporting period, and nitric acid recovery ratios.

Equation 5.2. Baseline Emissions

$$BE = \left[\left(TE_{RP,N_2O} \times (1 - AE_{BL})\right) + (HNO_{3\,Ratio} \times AA_{RP} \times 0.0025) \right] \times GWP_{N_2O} \times (1 - ld)$$

Where,

			Units
BE	=	Baseline emissions during the reporting period	tCO_2e
$TE_{RP,N2O}$	=	Measured total N_2O emissions in off gas during the reporting period before any emissions control treatment (e.g., abatement), see Equation 5.4	tN_2O
AE_{BL}	=	Baseline N_2O abatement efficiency; either static ($AE_{BL,S}$) or dynamic ($AE_{BL,D}$), see Equation 5.3 or Section 5.1.2	%
HNO_{3Ratio}	=	Ratio of HNO_3 to AA, see Equation 5.6	$tHNO_3/tAA$
AA_{RP}	=	Measured adipic acid production in the project reporting period	tAA
0.0025	=	IPCC emission factor for N_2O emissions per HNO_3 production	$tN_2O/tHNO_3$
GWP_{N2O}	=	Global warming potential of N_2O, see Table 5.1	tCO_2e/tN_2O
ld	=	The proportion of adipic acid production in the reporting period assessed as being due to leakage into the project facility	

To ensure the baseline is conservative and representative of only the incremental emissions reduced beyond historical voluntary abatement levels, baseline GHG emissions are quantified using AAP-specific N_2O abatement efficiency (AE_{BL}) levels based on the quantity of N_2O in the off gas remaining after historical voluntary N_2O abatement.

For added flexibility, this protocol provides project developers with two options for setting the AAP-specific baseline N_2O AE_{BL}:

1. Static baseline N_2O AE based on a fixed, historical average AE – *or* –
2. Dynamic baseline N_2O AE that changes each reporting period based on historical maximum and minimum AEs, maximum and minimum adipic acid production levels, and current adipic acid production levels

Projects may choose to use either the static or dynamic baseline approach during the project's first reporting period, and may opt into the dynamic approach for any future reporting period. Once a project has adopted the dynamic approach in any given reporting period, the project must use the dynamic approach for the duration of the project's crediting period. Reserve approval must be obtained before the project can use the dynamic baseline approach in any given reporting period. Further details are provided on requirements for the static baseline approach and dynamic baseline approach in Section 5.1.1 and Section 5.1.2 respectively.

All data necessary to calculate AE_{BL} values must be provided to the Reserve and the project's verifier, and will be subject to verification, but such data will not be made public.

5.1.1 Static Baseline Approach

To set the static baseline average N_2O AE_{BL}, this protocol utilizes a baseline look-back period defined as *at least* the five most recent calendar years of operation prior to the project start date. Due to significant structural changes in the U.S. adipic acid production industry, it is not appropriate to use data prior to 2015. Therefore, if a project was to start in 2020, the project must use a 5-year historical baseline look-back period, starting in 2015. If a project was to start in 2021, the project must use a 6-year historical baseline look-back period, starting in 2015, etc.

The annual baseline AE represents the percent of the AAP's N_2O emissions that are destroyed by the N_2O emission control unit in the given baseline year, *BLy*, in the baseline look-back period.

To make this calculation, as seen in Equation 5.3, the annual baseline AE, AE_{BLy}, is calculated using the full amount of N_2O produced (following the elimination of outliers using the procedure set out below in Equation 5.3) in a given baseline year, *BLy*, of the baseline look-back period prior to any destruction ($TE_{y,N2O}$; Equation 5.4) and the amount of N_2O reduced and/or destroyed in the given year, *BLy*, of the baseline look back period ($RE_{BLy,N2O}$; Equation 5.5).[23] The static baseline, $AE_{BL,S}$, is then calculated as the mean of the individual annual AE values, AE_{BLy}, over the baseline look-back period, as seen in Equation 5.3. Individual AE values, AE_{BLy}, used to calculate the static baseline must not exceed 2 standard deviations below the mean. This is done to ensure against excessive variation in AE values within the historical baseline period. Individual AE values, AE_{BLy}, that do not fall within 2 standard deviations below the mean must be removed from the calculation of $AE_{BL,S}$, and be replaced with the highest remaining AE_{BLy}, from the remaining baseline look-back period AE_{BLy} values. This removal of outliers will happen once, followed by a recalculation of the mean using the remaining and replaced values, and the recalculated mean must be used as the final baseline. See Table 5.2 for an example scenario, where the project started in 2021 (thus requiring a 6-year historical baseline look-back period, starting with 2015 data), where two annual AE values needed to be replaced, and where 2017 exhibited the highest annual AE during the remaining years included in the historical baseline look-back period.

Table 5.2. Example of Replacement of Initial AE_{BLy} Values to Recalculate Static Baseline

Initial Baseline Years Used to Calculate the Mean	Exceeds 2 Standard Deviations below the Mean	*Initial baseline years replaced by year with highest* AE_{BLy} *(2017)*	Baseline Years Represented in Recalculated Baseline
2015	No		2015
2016	Yes	――――――――→	2017
2017	No		2017
2018	Yes	――――――――→	2017
2019	No		2019
2020	No		2020

[23] Direct measurements of the N_2O concentration in the off gas and the flow rate (F) of the off gas shall be made using a continuous emission monitoring system (CEMS); see Section 6 for complete information.

Equation 5.3. Static Baseline N_2O Abatement Efficiency

$$AE_{BL,S} = \left(\frac{\sum AE_{BLy}}{z}\right)$$

Where, Units

$AE_{BL,S}$	=	Static average baseline N_2O abatement efficiency	%
z	=	Total number of annual N_2O abatement efficiency rates included in calculation. *z* will always be >= 5 years	years

And,

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

Where, Units

AE_{BLy}	=	N_2O abatement efficiency rate in each baseline year *BLy* represented in the baseline look-back period	x%
$RE_{BLy,N2O}$	=	Measured amount of N_2O reduced and/or destroyed by the existing N_2O emission control unit in baseline year *BLy* of the baseline look-back period, see Equation 5.5	tN_2O
$TE_{BLy,N2O}$	=	Measured total N_2O emissions in off gas during baseline year *BLy* in the baseline look-back period before any emissions control treatment (e.g., destruction), see Equation 5.4	tN_2O

Equation 5.4 is used to determine the total N_2O emissions directly measured in off gas during the current reporting period ($TE_{RP,N2O}$ in Equation 5.2) and during each year, *BLy*, of the baseline look-back period ($TE_{BLy,N2O}$ in Equation 5.3) to determine the total amount of N_2O produced before any N_2O emissions are destroyed. Direct measurement results can be distorted before and after periods of downtime or malfunction of the monitoring system. To eliminate such extremes and to ensure that data during the baseline period are representative of standard operating conditions, the following statistical valuation is to be applied to the data series of N_2O concentration ($N_2O_{y,conc,cu}$ and $N_2O_{y,conc,ncu}$) and gas volume flow in the off gas ($F_{y,cu}$ and $F_{y,ncu}$) when calculating the baseline. Operating hours are not adjusted.

1. Calculate the sample means (x)
2. Calculate the sample standard deviations
3. Calculate the 95% confidence intervals (equal to 1.96 times the standard deviations)
4. Eliminate all data that lie outside the 95% confidence intervals
5. Calculate the new sample means from the remaining values (volume flow rate in the off gas ($F_{y,cu}$ and $F_{y,ncu}$), and N_2O concentration in the off gas ($N_2O_{y,conc,cu}$ and $N_2O_{y,conc,ncu}$))

Note that 'operating hours' are defined to include any period of time where there is any production of adipic acid and/or N_2O. Any periods where there is production of either, would need to remain in the dataset.

Equation 5.4. Total Annual N_2O Emissions Before any Emissions Control Treatment

$$TE_{y,N_2O} = \sum_{cu}(F_{y,cu} \times N_2O_{y,conc,cu} \times OH_{y,cu}) + \sum_{ncu}(F_{y,ncu} \times N_2O_{y,conc,ncu} \times OH_{y,ncu})$$

Where,			Units
$TE_{y,N2O}$	=	Measured total N_2O emissions in off gas during the current reporting period *RP* or the year *BLy* of the baseline look-back period before any emissions control treatment (e.g., destruction)	tN_2O
$F_{y,cu}$	=	Volume flow rate in the off gas during the current reporting period *RP* or the year *BLy* of the baseline look-back period to the N_2O control unit, *cu*	m^3/hour
$F_{y,ncu}$	=	Volume flow rate in the off gas during the current reporting period *RP* or the year *BLy* of the baseline look-back period to the non-N_2O control unit, *ncu*	m^3/hour
$N_2O_{y,conc,cu}$	=	N_2O concentration in the off gas during the current reporting period *RP* or the year *BLy* of the baseline look-back period to the N_2O control unit, *cu*	tN_2O/m^3
$N_2O_{y,conc,ncu}$	=	N_2O concentration in the off gas during the current reporting period *RP* or the year *BLy* of the baseline look-back period to the non-N_2O control unit, *ncu*	tN_2O/m^3
$OH_{y,cu}$	=	Operating hours in the current reporting period *RP* or the year *BLy* of the baseline look-back period by N_2O control unit, *cu*	hours
$OH_{y,ncu}$	=	Operating hours in the current reporting period *RP* or the year *BLy* of the baseline look-back period by non-N_2O control unit, *ncu*	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, *BLy*, in the static baseline look-back period, Equation 5.5 measures the amount of off gas directed to each control unit and multiplies it by the efficiency of the respective N_2O control unit. $N_2O_{y,conc,cu}$ and $F_{y,cu}$ following the elimination of outliers must be used, as described above for Equation 5.4.

Equation 5.5. Annual Abated Baseline N_2O Emissions

$$RE_{BLy,N_2O} = \sum_{cu} (F_{BLy,cu} \times N_2O_{BLy,conc,cu} \times OH_{BLy,cu}) \times E_{cu}$$

Where,			Units
$RE_{BLy,N2O}$	=	Total N_2O reduced and destroyed by the N_2O emission control unit in year *BLy* of the baseline look-back period	tN_2O
$F_{BLy,cu}$	=	Volume flow rate in the off gas flowing into the N_2O control unit during year *BLy* of the baseline look-back period	m^3/hour
$N_2O_{BLy,conc,cu}$	=	N_2O concentration in the off gas flowing into the N_2O control unit during year *BLy* of the baseline look-back period	tN_2O/m^3
$OH_{BLy,cu}$	=	Operating hours in year *BLy* of the baseline look-back period of the N_2O control unit	hours
E_{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)	

5.1.2 Dynamic Baseline Approach

To follow the dynamic baseline approach, project developers *must* submit data for review and approval by the Reserve before a dynamic baseline N_2O AE can be employed in the calculation of emission reductions. Once the dynamic AE regression has been developed and approved by the Reserve, it will be fixed for the duration or remainder of the initial crediting period. If a project developer wishes to apply for a second crediting period, the project must meet the baseline requirements of the most current version of this protocol, applied as of the project start date

This protocol utilizes a baseline look-back period defined as *at least* the five most recent calendar years of operation prior to the project start date. Due to significant structural changes in the U.S. adipic acid production industry, it is not appropriate to use data prior to 2015. Therefore, if a project was to start in 2020, the project must use a 5-year historical baseline look-back period, starting in 2015. If a project was to start in 2021, the project must use a 6-year historical baseline look-back period, starting in 2015, etc.

To set the dynamic baseline, the project developer must establish quarterly AE values using all available measurements of N_2O abatement and adipic acid production during the given quarter, in order to establish an AAP-specific N_2O abatement and adipic acid production trend (e.g., lower levels of N_2O abatement with greater levels of adipic acid production).

Equation 5.4 and Equation 5.5 must be used to calculate *Total Quarterly Baseline N_2O Emissions Before any Emissions Control Treatment* and *Quarterly Abated Baseline N_2O Emissions,* respectively, but in the case of the dynamic baseline each will be calculated for every quarter of the historical baseline period (instead of the annual calculations used for the static approach). Just as in calculations for the static baseline, extreme values must be removed according to the guidance preceding Equation 5.4.

The quarterly baseline AE represents the percent of the AAP's N_2O emissions that are destroyed by the N_2O emission control unit measured daily during each quarter within the historical baseline look-back period. Each quarterly baseline AE must be calculated using the full amount of N_2O produced (following the elimination of extreme values as set out in Section

5.1.1 above, using the guidance preceding Equation 5.4) during each quarter of the dynamic baseline look-back period prior to any destruction (using Equation 5.4 above, and substituting each quarter of data for years in that equation) and the amount of N_2O reduced and/or destroyed in the given period of time of the dynamic baseline look back period (using Equation 5.5 above, and substituting each quarter of data for years in that equation).[24]

The Reserve will be looking for a regression with an adjusted R-squared value of at least 0.8, but encourages project developers to reach out during the development of such regressions to ensure that the dynamic baseline will be acceptable.

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 AAP-specific baseline abatement efficiency ($AE_{BL,D}$), derived from the Reserve-approved regression) must be multiplied by total N_2O emissions in a given reporting period prior to any abatement (TE_{N2O} using Equation 5.4 above, substituting reporting period data for the annual data used in that equation). However, the correct AE_{BL} value to use in the calculation of baseline emissions (Equation 5.2) is dependent on the results of a Reserve-approved regression analysis using the following:[25]

- Maximum and minimum periodic baseline N_2O abatement efficiencies ($AE_{t,MAX}$[26] and $AE_{t,MIN}$, respectively) over the dynamic baseline look-back period;
- Maximum and minimum periodic baseline amounts of adipic production ($AA_{t,MAX}$ and $AA_{t,MIN}$, respectively) over the dynamic baseline look-back period; and
- The amount of adipic acid produced in a project reporting period (AA_{RP})

The project developer must calculate the AE for each quarter, *t*, of the dynamic baseline look-back period and identify the periodic maximum abatement efficiency ($AE_{t,MAX}$) and periodic minimum abatement efficiency ($AE_{t,MIN}$) obtained over the dynamic baseline look-back period. The project developer must also identify the maximum amount of adipic acid ($AA_{t,MAX}$) and minimum amount of adipic acid ($AA_{t,MIN}$) produced during any given quarter within the dynamic baseline look-back period, which may or may not be from the same quarter, *t*, (e.g., day) as the maximum and minimum abatement efficiencies; i.e., baseline N_2O abatement efficiency levels are decoupled from baseline adipic acid production values. There are also a few other important conditions that apply, as listed below:

- Each quarterly AE value is always lower bound by $AE_{t,MIN}$
- Each quarterly $AE_{t,MAX}$ must be equal > 90%

The $AE_{t,MIN}$, as calculated during the baseline look-back period shall be fixed as the minimum of the dynamic AE for the duration of the project. In no instances shall the dynamic baseline utilize an AE below $AE_{t,MIN}$, even If production increases to a level such that the dynamic baseline correlation line would be extrapolated below $AE_{t,MIN}$, thus ensuring AE values are more conservative.

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[24] Direct measurements of the N_2O concentration in the off gas and the flow rate (*F*) of the off gas shall be made using a continuous emission monitoring system (CEMS); see Section 6 for complete information.
[25] This protocol assumes that the NO_x/N_2O abatement trade-off faced by U.S. AAPs would continue in the absence of the project, and thus the inverse general trend of decreasing N_2O abatement with increasing adipic acid production would also continue in the absence of the project (Section 2.1).
[26] This protocol assumes that each AAP is *capable* of achieving their $AE_{t,MAX}$ in any given period of time, but is not always able to do so due to financial constraints, the NO_x/N_2O abatement trade-off (Section 2.1), and/or other constraints that make it impracticable to fully utilize the existing technology and achieve $AE_{t,MAX}$ day after day.

5.1.3 Baseline Nitric Acid Recovery Ratio

Equation 5.6 shows the calculation to quantify the impact of lower "virgin" nitric acid (HNO_3) use as a function of N_2O conversion to NO, which is then converted to HNO_3 in the downstream process. This occurs when 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 the annual ratio of HNO_3 to 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 5.6. Nitric Acid Use Ratio

$$HNO_{3_{Ratio}} = avg\left(\frac{HNO_{3_y}}{AA_y}\right) - \frac{HNO_{3_{RP}}}{AA_{RP}}$$

Where,

			Units
$HNO_{3,Ratio}$	=	Ratio of nitric acid (HNO_3) to adipic acid	$tHNO_3/tAA$
HNO_{3y}	=	Annual tonnes of HNO_3 used as an input for adipic acid production in a given year during the baseline look-back period	t
AA_y	=	Annual tonnes adipic acid in a given year during the baseline look-back period	t
$HNO_{3,RP}$	=	HNO_3 used as an input for adipic acid production in project reporting period	t
AA_{RP}	=	Measured adipic acid production in the project reporting period	t

5.1.4 Mitigating Leakage

Secondary effects, i.e., leakage, may occur if an AAP with a Reserve adipic acid project begins to produce more adipic acid than it otherwise would because the value of the carbon offset creates an incentive to shift production to the respective AAP and/or to maintain and/or increase production at levels above market conditions. The most acute leakage risk may be if a given entity has multiple AAPs within their corporate group, and was able to shift production between facilities, to facilitate higher production at any given facility that was able to generate carbon offsets for emission reductions associated with N_2O abatement. For AAPs that are not a part of a corporate group controlling multiple AAPs, there may still be a threat of leakage if the single project AAP was to increase production to a statistically significant volume (or keep production at a volume above what market conditions would otherwise justify), due to a competitive advantage afforded to it in the form of carbon revenues. If leakage were to occur, a portion of the CRTs would not be representative of real GHG emission reductions.

For any AAP that is part of a corporate group that controls multiple AAP, anywhere in the world, the project must assess average annual factory loading of the project AAP (that is the percentage of facility-specific total production capacity that is being used) during the baseline look-back period, relative to the AAP factory loading during each reporting period. In any given reporting period, if factory loading decreases at other AAPs controlled by the group, whilst simultaneously increasing at the project AAP (or remaining steady at the project AAP, while decreasing elsewhere) by a statistically significant amount, leakage would have occurred.

If the project facility is not part of a corporate group that controls more than one AAP facility, then the project may seek Reserve approval for demonstrating the threat of leakage is minimal by using alternative means. An alternative assessment may be undertaken using data that is no more than 5 years old, and the Reserve may also accept an alternative assessment based on data spanning less than the full baseline look-back period, where data for the full baseline look-back period is lacking. Projects should seek out Reserve guidance as soon as possible when seeking to develop a suitable methodology for a leakage assessment for any given reporting period. Projects seeking to use this option must demonstrate, using publicly available market data and a reasonable explanation, that any increase in market share is not attributable to carbon offset revenue. Acceptance of an alternative leakage assessment in a given reporting period does not necessitate such method being accepted in any other future reporting period. Reserve staff will determine if reasonably satisfied the materials provided demonstrate a lack of statistically significant changes in production relative to production elsewhere, such that the threat of leakage is material or not. If the project is unable to demonstrate to the Reserve's satisfaction that leakage has not occurred in a given reporting period, then leakage will be taken to have occurred, and the project must mitigate such leakage.

Where the project facility is not part of a corporate group that controls more than one AAP facility, and the project is unable to secure Reserve approval for an alternative method for demonstrating no leakage has occurred, then adipic acid production must not exceed the AAP's CAA Title V permitted production levels as at the project start date.

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 5.7. Project Emissions

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

Where,			Units
PE	=	Total project emissions during the reporting period	tCO_2e
PE_{N2O}	=	Measured N_2O emissions in the off gas from project N_2O control units during the reporting period (Equation 5.8)	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 5.9)	tCO_2e
PE_{EE}	=	GHG emissions from external energy used to reheat the off gas during the reporting period (Equation 5.12)	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, using Equation 5.8 below. In the calculation of N_2O emissions during the reporting period projects must remove extreme values following the guidance as set out in Section 5.1.1, using the guidance preceding Equation 5.4.

Equation 5.8. Project N_2O Emissions in the Off Gas Routed from Emissions Control Units

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

Where,

			Units
PE_{N2O}	=	Measured N_2O emissions in the off gas from project control units during the reporting period	tCO_2e
$F_{RP,cu}$	=	Volume flow rate in the off gas during the reporting period to/from (as appropriate) the N_2O control unit	m^3/hour
$F_{RP,ncu}$	=	Volume flow rate in the off gas during the reporting period to/from (as appropriate) 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/from (as appropriate) 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/from (as appropriate) 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, see Table 5.1	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 produces the same amount of emissions from baseline N_2O control technology hydrocarbon usage or reduces emissions from hydrocarbon use over baseline N_2O control technology hydrocarbon usage, project developers may assert zero project emissions from hydrocarbon use.

Equation 5.9. 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 5.10)	tCO_2e
CH_{4HC}	=	Net GHG emissions as CH_4 from hydrocarbon use during the reporting period (Equation 5.11)	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). When hydrocarbons are combusted, they produce heat, steam, and CO_2. For calculation of the GHG emissions related to hydrocarbons, this protocol assumes all hydrocarbons other than CH_4 are completely converted to CO_2 (Equation 5.10) and all CH_4 in the fuel or reducing agent is emitted directly as CH_4 to the atmosphere and is not converted to CO_2 (Equation 5.11). In Equation 5.10, 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.[27]

Equation 5.10. Project Carbon Dioxide Emissions from Hydrocarbon Use

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

Where,

			Units
CO_{2HC}	=	Net GHG emissions as CO_2 from converted hydrocarbon during the reporting period	tCO_2e
ρ_{HC}	=	Hydrocarbon density	t/m^3
$Q_{HC,avg}$	=	Historical average annual quantity of hydrocarbon, with two or more molecules of carbon (i.e., not methane), during the static, baseline look-back period	m^3
$Q_{HC,RP}$	=	Quantity of hydrocarbon, with two or more molecules of carbon (i.e., not methane), input during the reporting period	m^3
$EF_{HC,avg}$	=	Historical average annual carbon emission factor of hydrocarbon, with two or more molecules of carbon, from use during the static, 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)	

[27] 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 5.11. Project Methane Emissions from Hydrocarbon Use

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

Where,			Units
CH_{4HC}	=	Net GHG emissions as CH_4 from unconverted hydrocarbon (methane) during the reporting period	tCO_2e
ρ_{CH4}	=	Methane density	t/m^3
$Q_{CH4,RP}$	=	Quantity of methane used during the reporting period	m^3
$Q_{CH4,avg}$	=	Historical average annual quantity of methane used during the baseline look-back period	m^3
GWP_{CH4}	=	Global warming potential of CH_4, see Table 5.1	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 Increased External Energy Use

If an external energy source is used in greater amounts compared to baseline usage (e.g., from adjusting off gas temperatures at the inlet of the N_2O, increasing the utilization rate of the N_2O abatement technology, the use of the newly installed technology and/or enhancement, etc.), 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 5.12. Project Emissions from Increased External Energy Use

$$PE_{EE} = SE + OGU + OGH + CO_{2,net}$$

Where,			Units
PE_{EE}	=	Project emissions from external energy during the reporting period. If result is <0, use a value of 0	tCO_2e
SE	=	Emissions from net change in steam export during the reporting period (Equation 5.13)	tCO_2e
OGU	=	Emissions from net change in off gas utilization during the reporting period (Equation 5.14)	tCO_2e
OGH	=	Emissions from net change in off gas heating during the reporting period (Equation 5.15)	tCO_2e
$CO_{2,net}$	=	Net increase in CO_2 emissions from increased fossil fuel and/or electricity use due to project activity (Equation 5.16)	tCO_2

In practice, project developers shall account for the emissions from the operation of any new N_2O abatement technology or enhancement of an existing one for the purpose of implementing the project. Project developers may use Equation 5.13 to Equation 5.16 below to calculate the net increase in GHG emissions for any *applicable* external energy source (i.e., steam, off gas, fossil fuel, or electricity), or if they can demonstrate during verification that project GHG emissions are estimated to be equal to or less than 5% of the total baseline emissions from these sources, then the project developer may estimate baseline and project GHG emissions from these sources. If an estimation method is used, verifiers shall confirm based on professional judgment that project GHG emissions are equal to or less than 5% of the total baseline emissions based on documentation and the estimation methodology provided by the project developer. If emissions cannot be confirmed to be below 5%, then Equation 5.13 to

Equation 5.16 shall be used as necessary. Regardless of the method used, all estimates or calculations of GHG emissions within the GHG Assessment Boundary must be verified and included in emission reduction calculations.[28]

If calculations or estimates indicate that the project results in a net decrease in GHG emissions from external energy use, then for quantification purposes the increase in these emissions must be specified as zero for PE_{EE}.

Equation 5.13. Project Emissions from Steam Export

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

Where, Units

SE	=	Emissions from net change in steam export during the reporting period	tCO_2e
ST_{avg}	=	Average annual steam export during the baseline look-back 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 5.14. Project Emissions from Off Gas Utilization

$$OGU = \left[\frac{(EE_{avg} - EE_{RP}) \times OH_{RP}}{\eta_{r}}\right] \times EF_{r}$$

Where, Units

OGU	=	Emissions from net change in off gas utilization during the reporting period	tCO_2e
EE_{avg}	=	Average annual energy export from off gas utilization during the baseline look-back 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 5.15. 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 compared to the average annual amount of off gas heating	MWh
η_{OGH}	=	Efficiency of additional off gas heating	fraction
EF_{OGH}	=	Emission factor for additional off gas heating	tCO_2e / MW

[28] This is consistent with guidance in WRI's GHG Protocol regarding the treatment of significant secondary effects.

Equation 5.16 below calculates the net increase in carbon dioxide emissions resulting from the project activity. The quantities of electricity and fossil fuel consumed must be taken from operational records such as utility bills.

Equation 5.16. Project Emissions from Fossil Fuel and Electricity Use

$$\boldsymbol{CO_{2,net} = PE_{CO_2,EL,FF} - BE_{CO_2,EL,FF}}$$

Where,			Units
$CO_{2,net}$	=	Net increase in CO_2 emissions from increased fossil fuel and/or electricity use due to project activity	tCO_2
$BE_{CO2,EL,FF}$	=	Average baseline CO_2 emissions from fossil fuel and/or electricity use from operation of N_2O abatement technology during the baseline look-back (see equation below)	tCO_2
$PE_{CO2,EL,FF}$	=	Total project CO_2 emissions from fossil fuel and/or electricity use from operation of N_2O abatement technology during the reporting period (see equation below)	tCO_2

All CO_2 emissions associated with fossil fuel and/or electricity consumption from operation of N_2O abatement technology are calculated using the equation:

$$\boldsymbol{CO_{2,EL,FF} = \left(QE_{avg} \times EF_{CO_2,E}\right) + \left[\left(QF_{avg} \times EF_{CO_2,F}\right) \times 0.001\right]}$$

Where,			Units
$CO_{2,EL,FF}$	=	CO_2 emissions from fossil fuel and/or electricity consumption from operation of N_2O abatement technology	tCO_2
QE_{avg}	=	Quantity of grid-connected electricity consumed from operation of N_2O abatement technology; average amount during each year, *BLy*, of the baseline look-back period or annual amount during the reporting period	MWh
$EF_{CO2,E}$	=	CO_2 emission factor for electricity used[29]	tCO_2/MWh
QF_{avg}	=	Quantity of fossil fuel consumed from operation of N_2O abatement technology; average amount during each year, *BLy*, of the baseline look-back period or annual amount during the reporting period	MMBtu or gallons
$EF_{CO2,F}$	=	Fuel-specific emission factor *f* from Appendix C	kg CO_2/MMBtu or kg CO_2/gallon
0.001	=	Conversion factor from kg to metric tons	

[29] Refer to the version of the U.S. EPA eGRID most closely corresponding to the time period during which the electricity was used. Projects shall use the annual total output emission rates for the subregion where the project is located, not the annual non-baseload output emission rates. The eGRID tables are available from the U.S. EPA website: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

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 6.2 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 quality assurance/quality control (QA/QC) activities; the role of individuals performing each specific monitoring activity; and a detailed project diagram. The Monitoring Plan must 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 75 as indicated in protocol Sections 6.1 - 6.3. Part 75 provides guidance on the standards of performance for continuous emission monitoring systems (CEMS) for NO_X emission testing, which is also applicable to N_2O emission testing at AAPs.

Direct measurements of the N_2O concentration in the off gas and the flow rate of the 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.[30] Elements of a CEMS include a platform and sample probe within the stack to withdraw a sample of the off 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 off gas, and a flow meter within the stack to measure the flow rate of the off gas. The emissions are calculated from the concentration of N_2O in the off gas and the flow rate of the 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.[31]

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).

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.

[30] 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.
[31] 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.

6.1 Initial Monitoring Requirements

Both newly installed CEMS for the adipic acid project and 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 meet all of the initial monitoring requirements specified in 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. Project developers must include the CEMS installation and initial certification report to the Monitoring Plan for ease of review by the verification body and the verification body must ensure adherence to the requirements, as summarized in the remainder of Section 6.1.

6.1.1 System Installation and Certification

The project developer shall follow the requirements for CEMS installation and initial certification detailed in 40 CFR Appendix A to Part 75 – Specifications and Test Procedures. 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.

The following initial certification requirements are summarized from 40 CFR Appendix A to Part 75: section 3 Performance Specifications, section 4 Data Acquisition and Handling Systems, and section 6 Certification Tests and Procedures. Please refer to those sections for complete 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 (section 3.1 and 6.3 of 40 CFR Appendix A to Part 75; protocol Section 6.1.2).
- 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 (section 3.2 and 6.2 of 40 CFR Appendix A to Part 75; protocol Section 6.1.2).
- 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 (section 3.3 and 6.5 of 40 CFR Appendix A to Part 75; protocol Section 6.1.3).[32]
- Bias test to ensure that the monitoring system is not biased low with respect to the reference method, based on RATA results (section 3.4 and 6.5 of 40 CFR Appendix A to Part 75; protocol Section 6.1.3).
- 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 (section 3.5 and 6.4 of 40 CFR Appendix A to Part 75).[33]
- 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 (section 4 of 40 CFR Appendix A to Part 75).

[32] 40 CFR Part 75, Appendix A, section 6.1.2(a).
[33] 40 CFR Part 60, 60.13(e)(2).

6.1.2 Calibration

The initial certification calibration procedures from 40 CFR Appendix A to Part 75 for NO_x and flow monitors shall be followed for CEMS measuring N_2O emissions and flow under this protocol. Calibration test procedures are outlined in sections 6.3.1 and 6.3.2 of 40 CFR Appendix A to Part 75. The performance specifications for the 7-day calibration error test and linearity check are described in sections 3.1 and 3.2 of 40 CFR Appendix A to Part 75.

6.1.3 Accuracy Testing

The initial certification relative accuracy and RATA procedures from sections 3.3.4, 3.3.7, and 6.5 of 40 CFR Appendix A to Part 75 shall be followed for CEMS measuring N_2O emissions and flow in adipic acid projects. The guidance for NO_X CEMS shall be used for N_2O emission monitoring where the CEMS relative accuracy (RA) shall not exceed 10% at any operating level at which a RATA is performed.[34]

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[35] for the measurement of vapor phase organic and inorganic emissions by extractive FTIR spectroscopy[36]
- ASTM D6348-03 method for the determination of gaseous compound by extractive direct interface FTIR spectroscopy[37]
- ISO/DIS 21258 stationary source emissions determination of the mass concentration of N_2O reference method for NDIR[38]
- Other NDIR methods used in AM0034 or AM0028, or performance specification-based reference method such as EPA method 7E[39]

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.[40] For details on RATA sampling, see the relative accuracy test procedures and performance specifications in sections 3.3 and 6.5 of 40 CFR Appendix A to Part 75.

6.2 Ongoing Monitoring and 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 to Part 75 – Quality Assurance and Quality Control Procedures (see Section 7 of this protocol for further record-keeping requirements). Per Appendix B of 40 CFR to Part 75, AAPs must develop and implement a QA/QC program for the CEMS that at a minimum, includes a written plan that

[34] 40 CFR Part 75, Appendix A, section 3.3.4(a).
[35] EPA Air Emission Measurement Center (EMC), Method 320 - Vapor Phase Organic and Inorganic Emissions by Extractive FTIR
[36] 40 CFR Part 63, Appendix A; 40 CFR Part 98.54 – Subpart E. Adipic Acid Production.
[37] 40 CFR Part 60, 60.17(a)(82); 40 CFR Part 98.54 – Subpart E. Adipic Acid Production.
[38] ISO 21258:2010, Stationary source emissions -- Determination of the mass concentration of dinitrogen monoxide (N_2O) -- Reference method: Non-dispersive infrared method.
[39] EPA Air Emission Measurement Center (EMC), Method 7E - Nitrogen Oxide - Instrumental Analyzer
[40] 40 CFR Part 60, Appendix B, section 8.4.4

describes in detail (or that refers to separate documents containing) complete, step-by-step procedures and operations for the following:

- 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

Project developers shall include the AAP's written plan for its CEMS' ongoing QA/QC program, and any referenced supporting documentation, as required to be developed and implemented per Appendix B of 40 CFR to Part 75, to the project Monitoring Plan for ease of review by the verification body. The verification body shall review the QA/QC written plan and ensure successful implementation of all CEMS QA/QC requirements as summarized in the remainder of Section 6.2.

6.2.1 Frequency of Testing

The schedule for the frequency of testing required for CEMS is prescribed in section 2, Appendix B of 40 CFR Part 75. 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 below 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. At a minimum, the following schedule, as summarized in Table 6.1, must be followed for tests relevant to N_2O analysis using CEMS:

Daily (operating days only) 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 (section 6.3.1 of 40 CFR Appendix A to Part 75)
- Calibration error test for flow meter (section 6.3.2 of 40 CFR Appendix A to Part 75)
- Calibration adjustments for N_2O analyzer and flow meter (section 2.1.3 of 40 CFR Appendix B to Part 75)
- Data validation (section 2.1.4 of 40 CFR Appendix B to Part 75)
- Quality assurance (section 2.1.5 of 40 CFR Appendix B to Part 75)
- Data recording (section 2.1.6 of 40 CFR Appendix B to Part 75)

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

- Linearity check in quarters for which there is no RATA (section 6.2 of 40 CFR Appendix A to Part 75)
- Leak check for CEMS utilizing differential pressure (DP) flow meters (section 2.2.2 of 40 CFR Appendix B to Part 75)
- Data validation (section 2.2.3 of 40 CFR Appendix B to Part 75)
- Linearity and leak check grace period (section 2.2.4 of 40 CFR Appendix B to Part 75)

Semiannual[41] and annual assessments apply as of the calendar quarter following the calendar quarter in which the CEMS is provisionally certified:

- RATA (sections 6.5 – section 6.5.2.2 of 40 CFR Appendix A to Part 75; sections 2.3.1.3 – 2.3.1.4 of 40 CFR Appendix B to Part 75). If the RA is less than 7.5%, annual RATAs can be performed, if the RA is equal to or greater than 7.5% and less than or equal to 10%, the RATAs can be performed semi-annually
- Data validation (section 2.3.2 of 40 CFR Appendix B to Part 75)
- RATA grace period (section 2.3.3 of 40 CFR Appendix B to Part 75)
- Bias adjustment factor applied if a monitor fails the bias test (section 2.3.4 of 40 CFR Appendix B to Part 75; section 7.6 of 40 CFR Appendix A to Part 75)

Table 6.1. Quality Assurance Test Frequency Requirements

Test	Frequency		
	Daily[42]	Quarterly[43]	Semiannual or Annual[44]
Calibration Error Test (N_2O, flow)	X		
Interference Check (flow)	X		
Flow-to-Load Ratio		X	
Leak Check (DP flow monitors)		X	
Linearity Check		X	
RATA (N_2O, flow)[45]			X

If the daily calibration error tests reveal accuracy outside of a +/- 5% threshold for the N_2O analyzer or +/- 6% threshold for the flow meter,[46] calibration by the manufacturer or a certified service provider is required for the N_2O analyzer or flow meter accordingly. For the interval between the last successful calibration error test and the calibration error test that revealed accuracy outside +/- 5% or +/- 6% threshold, respectively, conservativeness will determine what flow meter data are used in emission reduction calculations. 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 40 CFR Appendix B to Part 75 and include the following items.[47]

[41] "Semiannual" means once every two successive operating quarters.
[42] "Daily" means operating days only.
[43] "Quarterly" means once every operating quarter.
[44] "Annual" means once every four operating quarters.
[45] Conduct RATA annually rather than semiannually if monitor meets accuracy requirements to qualify for less frequent testing.
[46] 40 CFR Appendix B to Part 75, Section 2.1.4.
[47] 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.

- 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 may have occurred, 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.

Projects should consider including a narrative in their Monitoring Report describing any statistically significant data inconsistencies, and be prepared to answer questions from verifiers, and Reserve staff regarding the same.

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.[48]

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 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 6.2.

[48] 40 CFR Part 75, 75.33, Standard missing data procedures for SO_2, NO_X, Hg, and flow rate.

Table 6.2. 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		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.
Equation 5.1	*ER*	Emission reductions for the reporting period	tCO_2e	c	Per reporting period	
Equation 5.2; Equation 5.6	AA_{RP}	Measured adipic acid production during the reporting period	t	m	Measured daily, totaled for the reporting period	
Equation 5.2; Equation 5.8	GWP_{N2O}	Global warming potential of N_2O	tCO_2e / tN_2O	r	Per reporting period	
Equation 5.2	*ld*	The proportion of adipic acid production in the reporting period assessed as being due to leakage into the project facility	%	c	Per reporting period	Leakage deduction calculated using one of the methods prescribed in Section 5.1.4, and applied each reporting period (where relevant).
Equation 5.4; Equation 5.5; Equation 5.8	*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	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Equation 5.4; Equation 5.8	*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	
Equation 5.11	GWP_{CH4}	Global warming potential of CH_4	tCO_2e / tCH_4	r	Per reporting period	
Equation 5.16	$EF_{CO2,E}$	Carbon dioxide (CO_2) emission factor for electricity used	MWh	r	Each verification	Refer to the version of the U.S. EPA eGRID most closely corresponding to the time period during which the electricity was used. Projects shall use the annual total output emission rates for the subregion where the project is located, not the annual non-baseload output emission rates. The eGRID tables are available from the U.S. EPA website: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html
Equation 5.16	$EF_{CO2,F}$	Fuel-specific emission factor f from Appendix C	MMBtu or gallons	r	Each verification	Appendix C
Baseline Calculation Parameters						
Equation 5.1; Equation 5.2	*BE*	Baseline emissions for the reporting period	tCO_2e	c	Each reporting period	Emissions that would have occurred in the absence of the project activity.

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Equation 5.2; Equation 5.3; Equation 5.4	$TE_{y,N2O}$	Measured total N_2O emissions in off gas during year *y* of the reporting period (*RP*) or the baseline look-back period (*BL*) before any emissions control treatment (e.g., destruction)	tN_2O	c	Once	
Equation 5.2	AE_{BL}	Baseline N_2O abatement efficiency – either static, $AE_{BL,S}$, or dynamic, $AE_{BL,D}$	%	c	Each reporting period	
Equation 5.2; Equation 5.6	HNO_{3Ratio}	Ratio of nitric acid (HNO_3) to adipic acid	$tHNO_3$ / tAA	c	Per reporting period	
Equation 5.3	$AE_{BL,S}$	Static average baseline N_2O abatement efficiency	%	c	Once	
Equation 5.3	AE_{BLy}	Abatement efficiency rate in year *y* of the baseline look-back period	%	c	Once	
Equation 5.3	*z*	Total number of annual N_2O abatement efficiency rates included in calculation	years	c	Once	*z* will always be >= 5 years.
Equation 5.3; Equation 5.5	$RE_{BLy,N2O}$	Measured N_2O reduced and/or destroyed by the N_2O emission control unit in year *y* of the baseline look-back period	tN_2O	c	Once	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Equation 5.4; Equation 5.5	$F_{y,cu}$	Volume flow rate in the off gas during year *y* of the reporting period (*RP*) or the baseline look-back period (*BL*) to the N_2O control unit, *cu*	m^3 / hour	m, o	Measured continuously and recorded at least hourly or totalized for year *y* in the baseline look-back period	Note that this measurement is taken in the off gas prior to entering any control equipment.
Equation 5.4; Equation 5.5	$N_2O_{y,conc,cu}$	N_2O concentration in the off gas during year *y* of the reporting period (*RP*) or the baseline look-back period (*BL*) to the N_2O control unit, *cu*	tN_2O / m^3	m, o	Measured continuously and recorded at least hourly or totalized for year *y* in the baseline look-back period	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 any control equipment.
Equation 5.4; Equation 5.5	$OH_{y,cu}$	Operating hours in year *y* of the reporting period (*RP*) or the baseline look-back period (*BL*) by N_2O control unit, *cu*	hours	m, o	Totaled once for each year *y* in the baseline look-back period	
Equation 5.4	$F_{y,ncu}$	Volume flow rate in the off gas during year *y* of the reporting period (*RP*) or the baseline look-back period (*BL*) to the non-N_2O control unit, *ncu*	m^3 / hour	m, o	Measured continuously and recorded at least hourly or totalized for year *y* in the baseline look-back period	Note this measurement is taken in the off gas prior to entering any non-control equipment.

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Equation 5.4	$N_2O_{y,conc,ncu}$	N_2O concentration in the off gas during year *y* of the reporting period (*RP*) or the baseline look-back period (*BL*) to the N_2O control unit, *ncu*	tN_2O / m^3	m, o	Measured continuously and recorded at least hourly or totalized for year *y* in the baseline look-back period	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 any non-control equipment.
Equation 5.4	$OH_{y,ncu}$	Operating hours in year *y* of the reporting period (*RP*) or the baseline look-back period (*BL*) by N_2O control unit, *ncu*	hours	m, o	Totaled once for each year *y* in the baseline look-back period	
Equation 5.5	E_{cu}	N_2O destruction efficiency, expressed as a fraction of total N_2O destroyed, of the N_2O emissions control unit, *cu*		o	Once	
Equation 5.6	HNO_{3y}	Annual tonnes HNO_3 in year *y* of the baseline look-back period	$tHNO_3$	o	Once	
Equation 5.6	AA_y	Annual tonnes adipic acid in year *y* of the baseline look-back period	t adipic acid	o	Once	
Equation 5.6	HNO_{3RP}	Measured HNO_3 production in reporting period	$tHNO_3$	m	Daily, totaled for the reporting period	

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Equation 5.16	$BE_{CO2,EL,FF}$	Average baseline CO_2 emissions from fossil fuel and/or electricity use from operation of N_2O abatement technology during the baseline look-back period	tCO_2	c	Once	
Equation 5.16	QE_{avg}	Average quantity of grid-connected electricity consumed from operation of N_2O abatement technology during the baseline look-back period or annual amount during the reporting period	MWh	o	Once	
Equation 5.16	QF_{avg}	Average quantity of fossil fuel consumed from operation of N_2O abatement technology during the baseline look-back period or annual amount during the reporting period	MMBtu or gallons	o	Once	
Project Calculation Parameters						
Equation 5.1; Equation 5.7	PE	Project emissions during the reporting period	tCO_2e	c	Per reporting period	Emissions resulting from project activities.
Equation 5.7; Equation 5.8	PE_{N2O}	Measured N_2O emissions in the off gas to project N_2O control units 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
Equation 5.7; Equation 5.9	PE_{HC}	GHG emissions from use of hydrocarbons as a reducing agent or to reheat off gas during the reporting period	tCO_2e	c	Per reporting period	
Equation 5.7; Equation 5.12	PE_{EE}	GHG emissions from external energy used to reheat the off gas during the reporting period	tCO_2e	c	Per reporting period	
Equation 5.8	$F_{RP,cu}$	Volume flow rate in the off gas during the reporting period to the N_2O control unit	m^3 / hour	m	Every one minute of the reporting period	Note this measurement is taken in the off gas prior to entering any control equipment.
Equation 5.8	$N_2O_{RP,conc,cu}$	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 of the reporting period	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 any control equipment.
Equation 5.8	$OH_{RP,cu}$	Operating hours in reporting period by N_2O control unit	hours	o	Totaled once for the reporting period	
Equation 5.8	$F_{RP,ncu}$	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 of the reporting period	Note this measurement is taken in the off gas prior to entering any non-control equipment.

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Equation 5.8	$N_2O_{RP,conc,ncu}$	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 of the reporting period	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 any non-control equipment.
Equation 5.8	$OH_{RP,ncu}$	Operating hours in reporting period by non-N_2O control unit	hours	o	Totaled once for the reporting period	
Equation 5.9; Equation 5.10	CO_{2HC}	Net GHG emissions as CO_2 from hydrocarbon use during the reporting period	tCO_2e	c	Per reporting period	
Equation 5.9; Equation 5.11	CH_{4HC}	Net GHG emissions as CH_4 from hydrocarbon use during the reporting period	tCO_2e	c	Per reporting period	
Equation 5.10	ρ_{HC}	Hydrocarbon density	t / m^3	m	Per reporting period	
Equation 5.10	$Q_{HC,RP}$	Quantity of hydrocarbon, with two or more molecules of carbon (i.e., not methane, input during the reporting period)	m^3	o	Daily during the reporting period	
Equation 5.10	$EF_{HC,RP}$	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 CO_2 and the chemical reaction when hydrocarbons are converted.

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Equation 5.10	$Q_{HC,avg}$	Historical average annual quantity of hydrocarbon, with two or more molecules of carbon, during the baseline look-back period	m^3	o	Once	
Equation 5.10	$EF_{HC,avg}$	Historical average annual GHG emissions as CH_4 from hydrocarbon use during the baseline look-back period	tCO_2e / tHC	c	Once	Given by the molecular weight of the hydrocarbon and CO_2 and the chemical reaction when hydrocarbons are converted.
Equation 5.11	ρ_{CH4}	Methane density	t / m^3	m	Per reporting period	
Equation 5.11	$Q_{CH4,RP}$	Quantity of methane used during the reporting period	m^3	o	Daily per reporting period	
Equation 5.11	$Q_{CH4,avg}$	Historical average annual quantity of methane used during the period predating the project	m^3	o	Once	
Equation 5.12; Equation 5.13	*SE*	Emissions from net change in steam export during the reporting period	tCO_2e	c	Per reporting period	
Equation 5.12; Equation 5.14	*OGU*	Emissions from net change in off gas utilization during the reporting period	tCO_2e	c	Per reporting period	
Equation 5.12; Equation 5.15	*OGH*	Emissions from net change in 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
Equation 5.12; Equation 5.16	$CO_{2,net}$	Net increase in CO_2 emissions from increased fossil fuel and/or electricity use due to project activity. If result is <0, use a value of 0	tCO_2	c	Per reporting period	
Equation 5.13	ST_{avg}	Baseline steam export during a reporting period	MW	c	Once	
Equation 5.13	ST_{RP}	Project steam export during the reporting period	MW	c	Once	
Equation 5.13; Equation 5.14	OH_{RP}	Operating hours in reporting period	hours	o	Totaled once for the reporting period	
Equation 5.13	η_{ST}	Efficiency of steam generation	fraction	c	Once	Manufacturer supplied information.
Equation 5.13	EF_{ST}	Fuel emission factor for steam generation	tCO_2e / MWh	r	Per reporting period	From fuel supplier certificate or default value.
Equation 5.14	EE_{avg}	Baseline energy export from off gas utilization during a reporting period	MW	c	Once	
Equation 5.14	EE_{RP}	Project energy export from off gas utilization during the reporting period	MW	c	Once	
Equation 5.14	η_r	Efficiency of replaced technology	fraction	c	Once	Manufacturer supplied information.
Equation 5.14	EF_r	Fuel emission factor for replaced technology	tCO_2e / MWh	r	Per reporting period	From fuel supplier certificate or default value.
Equation 5.15	EI_{OGH}	Energy input for additional off gas heating during the reporting period	MWh	m or c	Monthly	
Equation 5.15	η_{OGH}	Efficiency of additional off gas heating	fraction	c or r	Once	Manufacturer supplied information.

Eq. #	Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Equation 5.15	EF_{OGH}	Emission factor for additional off gas heating	tCO_2e / MW	r	Once	From fuel supplier certificate or default value.
Equation 5.16	$PE_{CO2,EL,FF}$	CO_2 emissions from fossil fuel and/or electricity use from operation of N_2O abatement technology during the reporting period	tCO_2	c	Per reporting period	

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 must 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 must 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 each reporting period 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). One site visit is required each reporting period at a minimum.

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. For periods where no adipic acid is being produced, all requisite data must still be recorded, and full datasets made available to verifiers upon request.

To meet the reporting period 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 may exceed 12 months, and only in such circumstances can more than 12 months of emission reductions be verified at once.

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:

- Reserve Offset Program Manual
- Climate Action Reserve Verification Program Manual
- Climate Action Reserve Adipic Acid Production Protocol (this document)

The Reserve Offset Program Manual, Verification Program Manual, and 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. 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 Protocol (this document), the Reserve Offset 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 6.2 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 Production 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?
2.2	Verify that the project meets the definition of an adipic acid project	No
2.2	Verify whether the AAP is existing, upgraded, relocated, or restarted	No
2.3	Verify ownership of the reductions by reviewing the Attestation of Title	No
3.1	Verify that the project only consists of activities at a single AAP operating within the U.S. or its territories	No
3.2	Verify project start date	No
3.3	Verify that project is within its 10-year crediting period	No
3.4.1	Verify that the project meets the technology-specific threshold for the performance standard test	No
3.4.2	Confirm execution of the Attestation of Voluntary Implementation form to demonstrate eligibility under the Legal Requirement Test	No
3.4.2	Confirm that neither the Title V nor PSD permit for the AAP includes language requiring installation of N_2O control technology	Yes
3.4.2	Verify that the Monitoring Plan contains procedures for ascertaining and demonstrating that the project passes the Legal Requirement Test at all times	Yes
3.5	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
6	Verify that the project has documented and implemented a Monitoring Plan	No
6	Verify that monitoring meets the requirements of the protocol. If it does not, verify that a variance has been approved for monitoring variations	No
6.1	Verify that installation and initial certification of the N_2O CEMS were completed according to manufacturer specifications and the requirements of this protocol	No
6.1.2; 6.2	Verify that the calibration test procedures were properly followed, including the calibration error test and linearity check	No
6.1.3; 6.2	Verify that the relative accuracy test audits were completed according to the required procedure and schedule	No
6.2	Verify that the QA/QC activities meet the protocol's QA/QC requirements	No
6.3	If used, verify that data substitution methodology was properly applied	No
	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?
4	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	No
4	Verify that all SSRs in the GHG Assessment Boundary are accounted for	No
5.1	Verify that the baseline emissions are properly aggregated	No
5.1	Verify that the correct value for AE_{BL} is used in the calculation of baseline emissions	No
5.1	Verify that the project developer received Reserve approval for using the dynamic baseline approach, if applicable	No
5.1.1	Verify that the project developer correctly calculated and applied $AE_{BL,S}$, *if applicable*	No
5.1.2	Verify that the project developer correctly calculated and applied $AE_{BL,D}$, *if applicable*	No
5.1.3	Verify that the project developer correctly calculated the nitric acid recovery ratio	No
5.2	Verify that the project emissions were calculated according to the protocol with the appropriate data	No
5.2.1	Verify that the project developer correctly accounted for N_2O emissions at the inlet and/or outlet of the control system for the project, as applicable	No
5.2.2	Verify that the project developer correctly quantified hydrocarbon use for the project, *if applicable*	No
5.2.3	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, *if applicable*	Yes
5.2.3	Verify that the project developer correctly monitored, quantified, and aggregated electricity use, *if applicable*	Yes
5.2.3	Verify that the project developer correctly monitored, quantified, and aggregated fossil fuel use, *if applicable*	Yes
5.2.3	Verify that the project developer applied the correct emission factors for fossil fuel combustion and grid-delivered electricity, *if applicable*	No
5	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
5	Verify that the appropriate calculations were performed by the project developer and quantification and equation processes were followed	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.

Note that regulatory requirements are extensive, particularly with respect to system installation, certification, calibration, accuracy testing and sampling, as are manufacturer recommendations for the same. Whilst a verifier should not ignore any instances they observe where such requirements have not been met (for instance where equipment is being operated in a manner inconsistent with manufacturer recommendations), these requirements should be taken as an input into verification risk analysis, and verifiers should use their professional judgement to determine to what extent they feel the project-specific risk justifies them inspecting compliance with specific requirements. A verifier may determine that a sampling-based approach is appropriate in certain circumstances.

Table 8.4. Risk Assessment Verification Items

Protocol Section	Item that Informs Risk Assessment	Apply Professional Judgment
6	Verify that the project Monitoring Plan is sufficiently rigorous to support the requirements of the protocol and proper operation of the project	Yes
6	Verify that appropriate monitoring equipment is in place to meet the requirements of the protocol.	Yes
6	Verify that the individual or team responsible for managing and reporting project activities are qualified to perform this function	Yes
6	Verify that appropriate training was provided to personnel assigned to GHG reporting duties	Yes
6	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
6, 7.2	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.
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: September 30, 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 25, 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.).
Nitrous oxide (N_2O)	A potent GHG with a GWP of 298, consisting of two nitrogen atoms and one oxygen atom.
Off gas	All gases (e.g., NO_x and N_2O) produced during and post adipic acid production that are emitted to the atmosphere; also referred to as “tail gas.”
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.[49]

The most appropriate type of control technology can be highly facility specific. Among the two existing adipic acid plants (AAPs) in the United States, the Ascend AAP has a Thermal Reduction Unit (TRU) installed, which abated approximately 75.3% of the facility's N_2O emissions[50] in 2018, 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.[51,52] Because adipic acid production is so emissions intensive, even after abating the majority of their emissions, these two facilities still released 10.3 million tCO_2e in 2018,[53] and thus have substantial opportunity for additional emission reductions.

With only two AAPs currently operating in the U.S., it's not possible to establish a performance benchmark for the U.S. industry for the individual AAPs to meet and/or exceed in order to pass a performance standard test. However, both the installation of a new N_2O abatement technology and the enhancement of an existing one come with high implementation costs. For example, new investment costs estimated to range from roughly 10.6 million USD to 17.25 million USD and increased operating costs estimated to range from roughly 1.33 to 2.0 million USD per year.[54,55] Therefore, the Reserve found it most appropriate to hold projects to this financial barrier test as a means of demonstrating additional performance. An overview of the potential controls and project activities that come with the increased CAPEX and OPEX are discussed in the following subsections.

[49] 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.
[50] United States Environmental Protection Agency, "Ascend - Cantonment, FL, GHG Facility Details." October 3, 2019. https://ghgdata.epa.gov/ghgp/service/facilityDetail/2018?id=1004962&ds=E&et=&popup=true
[51] United States Environmental Protection Agency, "Invista - Victoria, TV, GHG Facility Details." October 3, 2019. https://ghgdata.epa.gov/ghgp/service/facilityDetail/2018?id=1001781&ds=E&et=&popup=true Note, the 2018 INVISTA report states 0% abatement.
[52] 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."
[53] U.S. Environmental Protection Agency (2019a). Greenhouse Gas Reporting Program (GHGRP) Facility Level Information on GHGs Tool (FLIGHT). Washington, D.C., October 3, 2019. Available at: https://ghgdata.epa.gov/ghgp/main.do#
[54] Schneider et al., 2010. Industrial N_2O Projects Under the CDM: Adipic Acid – A Case of Carbon Leakage? Stockholm Environment Institute. October 9, 2010.
[55] All currencies were converted from EURs to 2010 U.S. Dollars (USD) with an annual average conversion factor of 1.33 https://www.x-rates.com/average/?from=EUR&to=USD&amount=1&year=2010.

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.

Table A.1. Review of Potential Control Technologies at Adipic Acid Plants[56]

Abatement Type	Description	Example Equipment
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 using flame burners with pre-mixed CH_4 or natural gas	Thermal Reduction Units (TRUs)
Recycle to Nitric Acid	Recycle N_2O to create nitric acid by burning the gas at high temperatures with steam	Nitrogen recycling adiabatic reactor
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

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.[57] Facilities can send their off gas to the TRU, which reduces N_2O[58] 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.

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[56] 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.

[57] 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, "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). 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.

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

Appendix B Evaluation of Leakage Potential

Unintended secondary effects, i.e., carbon leakage, may occur if an adipic acid plant (AAP) begins to over-produce their product because the value of carbon offset creates a perverse incentive ("product gaming"). If leakage occurs, a portion of the offsets would not represent real emission reductions nor be additional, and the activity could shift production away from other AAPs worldwide. This occurred in early Clean Development Mechanism (CDM)[59] adipic acid projects. According to the Stockholm Environmental Institute (SEI),[60] there were two primary carbon leakage drivers:

1. The protocol set the baseline N_2O abatement emissions level at 0% (i.e., no abatement); *– and –*
2. The value of the certified emission reductions (CERs)[61] created through abatement technology exceeded the value of the adipic acid itself, creating perverse incentives

To provide an example of the economic incentives that created secondary effects in early CDM projects, SEI compared the financials of early CDM projects with later Joint Implementation (JI) projects[62]. According to SEI, JI projects had baseline historical abatement levels around 90%.[63] By only crediting the incremental emissions beyond individual facility's abatement levels, the economic incentives for JI projects remained attractive but did not appear to create the same highly skewed incentive structure as CDM projects (Table B.1).

[59] The Clean Development Mechanism (CDM) allows a country with an emission reduction/limitation commitment under the Kyoto Protocol to implement an emission reduction project in developing countries.
[60] Schneider, Lambert, Michael Lazarus, and Anja Kollmus. 2010. Industrial N_2O Projects Under the CDM: Adipic Acid – A Case of Carbon Leakage? Stockholm Environment Institute. October 9, 2010.
[61] CDM projects can earn saleable certified emission reduction (CER) credits, each equal to 1 tCO_2e, which can be counted towards meeting Kyoto targets.
[62] Joint Implementation (JI) is a mechanism that allows a developed country with an emission reduction/limitation commitment under the Kyoto Protocol to earn emission reduction units (ERUs) from an emission reduction or emission removal project in another developed country. JI offers countries a flexible and cost-efficient means of fulfilling a part of their Kyoto commitments, while the host country benefits from foreign investment and technology transfer.
[63] Schneider et al., 2010.

Table B.1. Reference Cases for the Costs and Economic Incentives for CDM and JI Projects[64]

	Unit	CDM	JI
Technology	-	Single catalytic/thermal decomposition	Redundant catalytic/thermal decomposition[65]
Adipic Acid Production	Kiloton/year	150	150
Revenues from CERs or ERUs			
Baseline emission factor	kg N_2O/t adipic acid	270	30
Project emission factor	kg N_2O/t adipic acid	4	0
Other emissions	tCO_2/t adipic acid	0.1	0.1
CERs or ERUs	CERs or ERUs/t adipic acid	82.4	9.2
Price for CERs or ERUs	USD	$17.25	$17.25
Revenues from CERs or ERUs	USD/t adipic acid	$1,421.29	$159.25
CDM / JI Transaction Costs	USD/CER or ERU	$0.76	$0.50
Abatement Costs			
Investment Costs	Million USD	$10.62	$17.25
Operational Costs	Million USD/year	$1.33	$1.99
Technical Lifetime	Years	20	20
Required Return on Investment	-	15%	15%
Net Profits from CDM or JI	USD/t adipic acid	$1,339.01	$122.09

All currencies were converted from EURs to 2010 U.S. Dollars (USD) with an annual average conversion factor of 1.33[66]

SEI's evaluation demonstrated a considerable difference in profit between CDM projects and JI projects ($1,339 per metric ton adipic acid versus $122 per metric ton adipic acid), largely due to differences in baseline setting.

In general, the Reserve believes there is low risk for this scenario to occur in the United States (U.S.) with the Adipic Acid Production Protocol for the following reasons:

1. The protocol only generates credits for the incremental emission reductions above a historical and facility-specific baseline level of N_2O abatement (Section 5.1). As a result, U.S.-based projects would not achieve the same volume of credits as created under the CDM on a per-unit adipic acid produced basis, which had a baseline N_2O abatement emissions level of 0%;
2. Over-production of adipic acid is especially costly in the U.S. as, per the Clean Air Act (CAA), AAPs would need to abate the associated increasing amounts of NO_x emissions and would face financial penalties should their production exceed their maximum allowable production limits in their Title V permits; – *and* –
3. The historical average and most up-to-date (as of the time of this publication) average value of voluntary carbon offsets in North America are lower than the historical CDM

[64] Adapted from Table 6 in Schneider et al., 2010.
[65] "Redundant" refers to the installation of a second, additional catalytic or thermal decomposition unit at an AAP.
[66] https://www.x-rates.com/average/?from=EUR&to=USD&amount=1&year=2010

CER level when product gaming occurred (average of \$2.40 \$/tCO_2e in quarter 1 2018[67] compared to over \$17.25 USD/tCO_2e[68]). Figure B.1 below displays the historical average voluntary carbon credit prices for globally-located projects, U.S./North America-based projects, and global industrial N_2O projects, as well as the average price for CERs and ERUs (Table B.1) at the time of CDM project leakage. All data were retrieved from *State of the Voluntary Carbon Market* reports from 2007 – 2019, as published by Ecosystem Marketplace, A Forest Trends Initiative.[69] In addition to showing that U.S. averages have stayed well under the 2010 CER value, Figure B.1 also shows that the value for credits from industrial N_2O projects has either stayed at the same or below the global and U.S. averages.

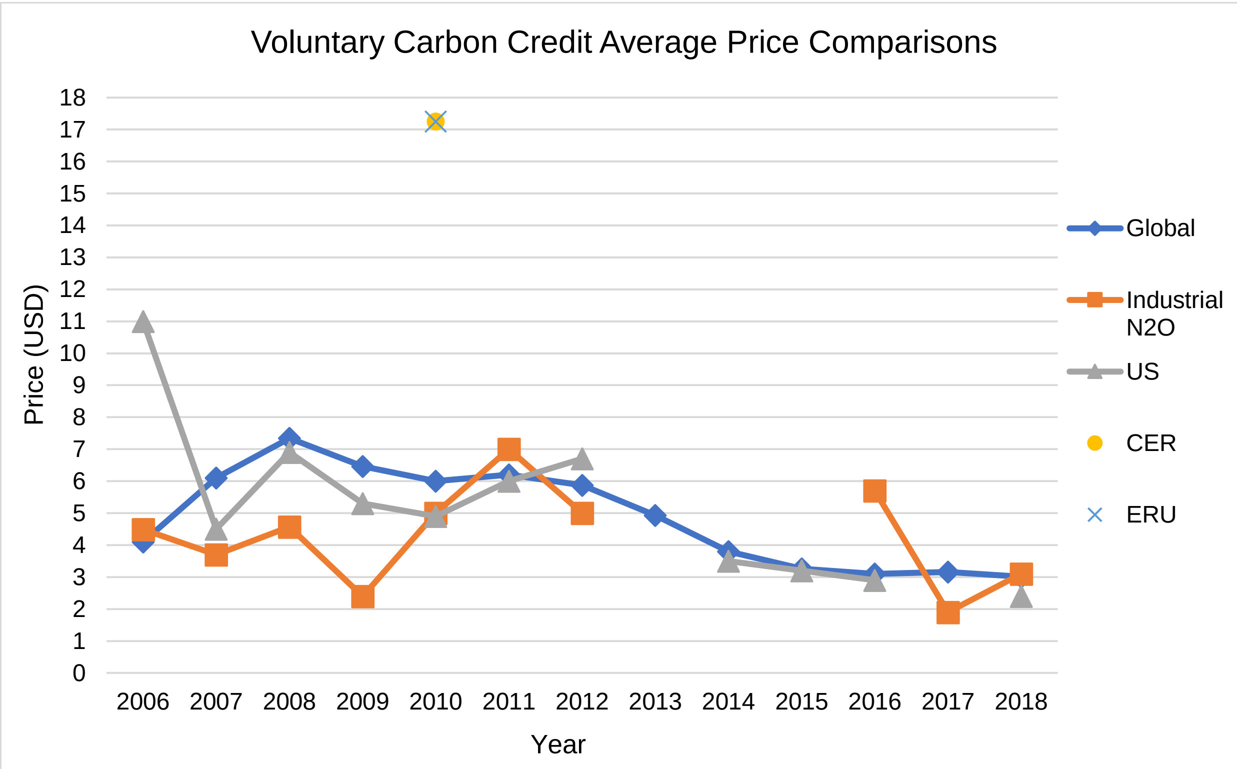

Figure B.1. Voluntary Carbon Credit Average Price Comparisons

The above graph shows the voluntary carbon credit average price comparisons among global averages (all project types), global industrial N_2O projects, projects located in the U.S./North America (all project types), and the average CER and ERU price at the time of international leakage (i.e., 2010).

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[67] Kelley Hamrick and Melissa Gallant, "Voluntary Carbon Market Insights: 2018 Outlook and First-Quarter Trends" (Ecosystem Marketplace, August 2018), https://www.forest-trends.org/wp-content/uploads/2018/09/VCM-Q1-Report_Full-Version-2.pdf.
[68] Schneider, Lazarus, and Kollmuss, "Industrial N_2O Projects Under the CDM: Adipic Acid - A Case of Carbon Leakage?"
[69]Note, data collected and presented, as well as project categorizations, in each State of the Voluntary Carbon Market report are not consistent from year to year. Specifically, Industrial N_2O projects represent data categorized as "Geological Sequestration and Industrial Gas" in 2006 and 2009, "Industrial Gas" in 2007 and 2008, "N_2O" in 2010 through 2012, "Gases" in 2016, and "Chemical Processes / Industrial Manufacturing" in 2017 and 2018. No average price data were available on this project type for 2013 through 2015. Also, the U.S. average price values from 2006 through 2010 are specifically for the U.S., while 2011 and 2012, and 2014 through 2018, are inclusive of all projects in North America. No regional data for the U.S. or North America were available in 2013.

Furthermore, at the time of this publication the most recent rolling six-month average value for adipic acid is just over $1,100 USD per tonne adipic acid.[70]

Although an offset project may be financially attractive in the U.S., the above factors all indicate that the project alone should not bring an AAP high enough value to justify increasing production exclusively for the carbon offset value; should adipic acid production increase beyond business as usual rates, it's likely to be for the value of adipic acid itself. Even if U.S.-based voluntary credits rise in value to a level comparable to early CDM CER levels, the Reserve believes that the decrease in credit issuance with a tighter baseline requirement would still protect against leakage incentives.

[70] Adipic acid price analysis data was obtained over December 2019 and January 2020 from Echemi at the following address: https://www.echemi.com/productsInformation/pd20150901270-adipic-acid.html.

Appendix C Emission Factor Tables

Table C.1. CO_2 Emission Factors for Fossil Fuel Use[71]

Fuel Type	Heat Content	CO_2 Emission Factor (Per Unit Energy)	CO_2 Emission Factor (Per Unit Mass or Volume)
Coal and Coke	**MMBtu / Short ton**	**kg CO_2 / MMBtu**	**kg CO_2 / Short ton**
Anthracite Coal	25.09	103.62	2,602
Bituminous Coal	24.93	93.46	2,325
Sub-bituminous Coal	17.25	97.17	1,676
Lignite	14.21	97.72	1,389
Mixed (Commercial Sector)	21.39	94.27	2,016
Mixed (Electric Power Sector)	19.73	95.52	1,885
Mixed (Industrial Cooking)	26.28	93.90	2,468
Mixed (Industrial Sector)	22.35	94.67	2,116
Coal Coke	24.80	113.67	2,819
Other Fuels - Solid	**MMBtu / Short ton**	**kg CO_2 / MMBtu**	**kg CO_2 / Short ton**
Municipal Waste	9.95	90.70	902
Petroleum Coke (Solid)	30.00	102.41	3,072
Plastics	38.00	75.00	2,850
Tires	28.00	85.97	2,407
Biomass Fuels - Solid	**MMBtu / Short ton**	**kg CO_2 / MMBtu**	**kg CO_2 / Short ton**
Agricultural Byproducts	8.25	118.17	975
Peat	8.00	111.84	895
Solid Byproducts	10.39	105.51	1,096
Wood and Wood Residuals	17.48	93.80	1,640
Natural Gas	**MMBtu / scf**	**kg CO_2 / MMBtu**	**kg CO_2 / scf**
Natural Gas	0.001026	53.06	0.05444
Other Fuels - Gaseous	**MMBtu / scf**	**kg CO_2 / MMBtu**	**kg CO_2 / scf**
Blast Furnace Gas	0.000092	274.32	0.02524
Coke Oven Gas	0.000599	46.85	0.02806
Fuel Gas	0.001388	59.00	0.08189
Propane Gas	0.002516	61.46	0.15463

[71] EPA Center for Corporate Climate Leadership. "Emission Factors for Greenhouse Gas Inventories, Table 1. Stationary Combustion." 9 March 2018. Available at: https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf.

Fuel Type	Heat Content	CO_2 Emission Factor (Per Unit Energy)	CO_2 Emission Factor (Per Unit Mass or Volume)
Biomass Fuels - Gaseous	**MMBtu / scf**	**kg CO_2 / MMBtu**	**kg CO_2 / scf**
Landfill Gas	0.000485	52.07	0.025254
Other Biomass Gases	0.000655	52.07	0.034106
Petroleum Products	**MMBtu / gallon**	**kg CO_2 / MMBtu**	**kg CO_2 / gallon**
Asphalt and Road Oil	0.158	75.36	11.91
Aviation Gasoline	0.120	69.25	8.31
Butane	0.103	64.77	6.67
Butylene	0.105	68.72	7.22
Crude Oil	0.138	74.54	10.29
Distillate Fuel Oil No. 1 (diesel)	0.139	73.25	10.18
Distillate Fuel Oil No. 2 (diesel)	0.138	73.96	10.21
Distillate Fuel Oil No. 4 (diesel)	0.146	75.04	10.96
Ethane	0.068	59.60	4.05
Ethylene	0.058	65.96	3.83
Heavy Gas Oils	0.148	74.92	11.09
Isobutane	0.099	64.94	6.43
Isobutylene	0.103	68.86	7.09
Kerosene	0.135	75.20	10.15
Kerosene-Type Jet Fuel	0.135	72.22	9.75
Liquified Petroleum Gases (LPG)	0.092	61.71	5.68
Lubricants	0.144	74.27	10.69
Motor Gasoline	0.125	70.22	8.78
Naptha (<401 deg F)	0.125	68.02	8.50
Natural Gasoline	0.110	66.88	7.36
Other Oil (>401 deg F)	0.139	76.22	10.59
Pentane Plus	0.110	70.02	7.70
Petrochemical Feedstocks	0.125	71.02	8.88
Petroleum Coke	0.143	102.41	14.64
Propane	0.091	62.87	5.72
Propylene	0.091	67.77	6.17
Residual Fuel Oil No. 5	0.140	72.93	10.21
Residual Fuel Oil No. 6	0.150	75.10	11.27
Special Naphtha	0.125	72.34	9.04

Fuel Type	**Heat Content**	**CO_2 Emission Factor** (Per Unit Energy)	**CO_2 Emission Factor** (Per Unit Mass or Volume)
Unfinished Oils	0.139	74.54	10.36
Used Oil	0.138	74.00	10.21
Biomass Fuels - Liquid	**MMBtu / gallon**	**kg CO_2 / MMBtu**	**kg CO_2 / gallon**
Biodiesel (100%)	0.128	73.84	9.45
Ethanol (100%)	0.084	68.44	5.75
Rendered Animal Fat	0.125	71.06	8.88
Vegetable Oil	0.120	81.55	9.79
Biomass Fuels - Kraft Pulping Liquor, by Wood Furnish	**MMBtu / gallon**	**kg CO_2 / MMBtu**	**kg CO_2 / gallon**
North American Softwood	-	94.40	-
North American Hardwood	-	93.70	-
Bagasse	-	95.50	-
Bamboo	-	93.70	-
Straw	-	95.10	-