ADIPIC ACID PRODUCTION

PROJECT PROTOCOL

Proposed Protocol

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Adipic Acid Production Project Protocol

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This proposed protocol, initially developed by ClimeCo Corporation, is for use by the Climate Action Reserve in the development and evaluation process for a standardized offset project protocol reducing N_2O emissions from adipic acid production.

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1. Introduction

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

The 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.[1] 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 production facilities use this document to 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 annual, 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 and section 8 of this protocol.

This protocol is designed to ensure the complete, consistent, transparent, accurate, and conservative quantification and verification of GHG emission reductions associated with a N_2O abatement project at an adipic acid plant.[2]

[1] The online registry may be accessed from the Reserve homepage at: www.climateactionreserve.org.
[2] See the WRI/WBCSD GHG Protocol for Project Accounting (Part I, Chapter 4) for a description of GHG reduction project accounting principles.

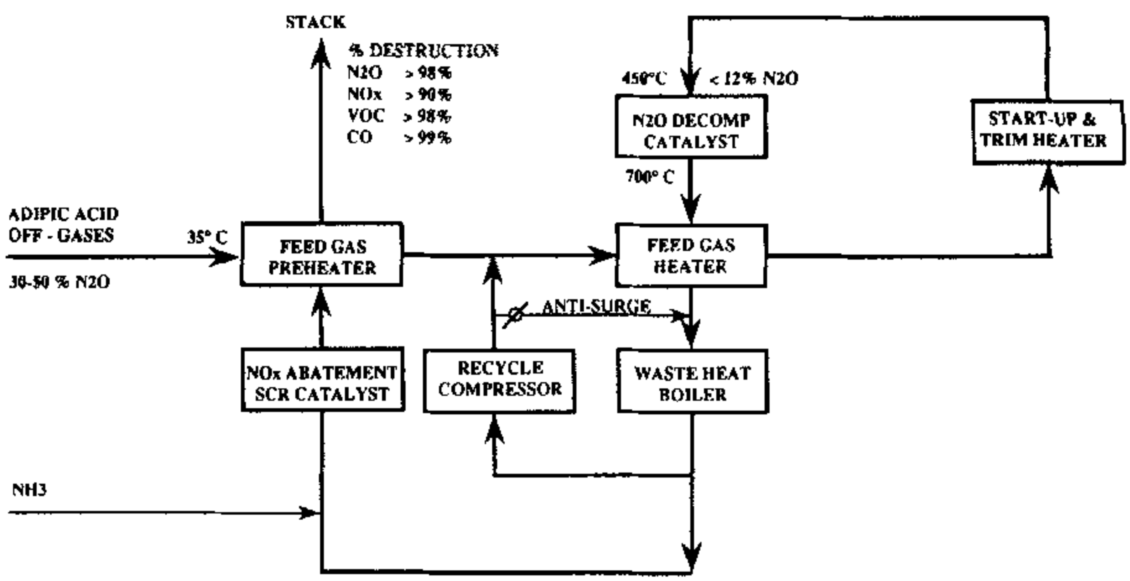
2. The GHG Reduction Project

2.1. Background

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

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

Figure 2.1. Typical process flowsheet for catalytic decomposition of N_2O



Reimeri et al. (1994)

[3] The Human Metabolomics Database, "Metabocard for Adipic Acid (HMDB0000448)," accessed September 12, 2019, http://www.hmdb.ca/metabolites/HMDB0000448#references.

[4] Castellan, A., Bart, J. C. J., & Cavallaro, S. (1991). Industrial production and use of adipic acid. *Catalysis Today*, *9*(3), 237-254.

2.2. Project Definition

For the purposes of this protocol, a GHG reduction project is defined as the installation and operation of a N_2O control technology, or the enhancement of an existing control technology, at a single AAP that results in the reduction of N_2O emissions that would otherwise have been vented to the atmosphere. Projects may only be implemented at existing, relocated, or upgraded AAPs.

The protocol does not apply to new AAPs constructed on or after January 1, 2020, with the exception of new AAPs for which a permit application for construction was submitted to the appropriate regulating authorities prior to January 1, 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.[5] 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.

[5] Attestation of Title form available on the Reserve's website.

3. Eligibility Rules

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

Table 3.1. General Eligibility Rules

Eligibility Rule I:	Location	→	United States, its territories and tribal lands
Eligibility Rule II:	Project Start Date	→	No more than six months prior to project submission
Eligibility Rule III:	Project Crediting Period	→	Maximum of two, ten-year crediting periods
Eligibility Rule IV:	Additionality	→	Exceed legal requirements
		→	Meet performance standard
Eligibility Rule V:	Regulatory Compliance	→	Compliance with all applicable laws

3.1. Location

Under this protocol, only projects located at adipic acid production facilities in the United States and its territories are eligible to register with the Reserve.[6]

3.2. Project Start Date

The project start date is defined as the date on which production first commences after the installation of specific N_2O control technology, as defined in section 3.4.2. For the purposes of this protocol, a project is eligible if N_2O control technology exists at the adipic acid plant prior to the project start date, but the replacement, upgrade, or expansion of the N_2O control facility is better than prior practice. Projects such as these will recognize the delta in emissions benefits.

To be eligible, the project must be submitted for listing on the Reserve no more than six months after the project start date.[7] Projects may always be submitted for listing by the Reserve prior to their start date.

3.3. Project Crediting Period

The crediting period for projects under this protocol is ten years. If a project developer wishes to apply for eligibility under a second crediting period, they must do so within the final six months of the initial crediting period. However, the Reserve will cease to issue CRTs for GHG reductions if at any point in the future N_2O abatement becomes legally required at the project site or the project otherwise fails the Legal Requirement Test (Section 3.4.1). 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 project activity is required by law, whichever comes first. Section 3.4.1 defines the conditions under which a project is considered legally required, and Section 3.4.2 describes the requirements to qualify for a second crediting period.

[6] The Reserve anticipates that this protocol could be applied throughout North America and internationally. To expand its applicability, data and analysis supporting an appropriate performance standard for other countries would have to be conducted accordingly.

[7] Projects are considered submitted for listing when the project developer has fully completed and filed the appropriate submittal documents, which include the Project Submittal form (available on the Reserve's website) and a project diagram.

3.4. Additionality

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

Projects must satisfy the following tests to be considered additional:

1. The Legal Requirement Test
2. The Performance Standard Test

3.4.1. The Legal Requirement Test

All projects are subject to a Legal Requirement Test to ensure that the GHG reductions achieved by a project would not otherwise have occurred due to federal, state or local regulations, or other legally binding mandates. A project passes the Legal Requirement Test when there are no laws, statutes, rules, regulations, ordinances, court orders, governmental agency actions, enforcement actions, environmental mitigation agreements, permitting conditions, permits or other legally binding mandates requiring the abatement of N_2O at the project site. To satisfy the Legal Requirement Test, project developers must submit a signed Attestation of Voluntary Implementation form[8] 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 adipic acid plants to abate N_2O emissions.[9] 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. If the adipic acid plant's N_2O emissions are included under an emissions cap (e.g. under a state or federal cap-and-trade program), emission reductions may likewise be reported to the Reserve until the date that the emissions cap takes effect.

[8] Attestation of Voluntary Implementation form available on the Reserve's website.

[9] 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 production facilities 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.

3.4.1.1. 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").[10] 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, "MT") of CO_2e emissions per year were required to obtain Title V operating permits for GHG emissions. Additionally, facilities were required to obtain Prevention of Significant Deterioration ("PSD") permits that address GHG emissions for (1) new source construction with emissions of 100,000 tons CO2e per year or more and (2) major facility modifications resulting in GHG emission increases of 75,000 tons (approximately 68,000 MT) of CO_2e per year or more.[11]

However, in 2014, the Supreme Court struck down the Title V provision of the Tailoring Rule[12]; 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 carbon offset 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-installed N_2O abatement projects should continue to be eligible for carbon offsets for the remainder of a project's crediting period(s). Verifiers will need to review PSD permits to ensure that projects are able to pass the Legal Requirement Test.

3.4.2. The Performance Standard Test

Project activities that are not legally required may still be non-additional if they would have been implemented for other reasons, including, for example, because they are attractive investments irrespective of the value of their carbon reductions. Performance Standard Tests are intended to screen out this potential set of project activities. Standards are specified such that the large majority of mitigation projects that meet the standard are unlikely to have been implemented due to financial, economic, social, and technical or technological drivers. In other words, incentives created by the carbon market are likely to have played a critical role in decisions to implement project activities that meet the Performance Standard Test.

Projects pass the Performance Standard Test by meeting a program-wide performance threshold (i.e., a standard of performance applicable to all N_2O abatement projects) established on an *ex-ante* basis by

[10] 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

[11] 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.

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

this protocol. The performance threshold represents installation of a better than business-as-usual N_2O control system. The performance standard defines those technologies that the Reserve has determined will exceed common practice in the nitric and adipic acid sectors and therefore generate additional GHG reductions.

By installing one of the following N_2O control technologies, the project passes the Performance Standard Test:

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

For existing AAPs, the Performance Standard Test is passed with the installation of one of the previously listed N_2O control technologies and improved N_2O destruction by the replacement, improvement, or expansion of the N_2O destruction facility.

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 future versions of the protocol or the Performance Standard Test 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.

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.

3.5. Regulatory Compliance

As a final eligibility requirement, project developers must attest that the project activities and project AAP are in material compliance with all applicable laws (e.g. air, water quality, safety, etc.) prior to verification activities commencing each time a project is verified. Project developers are required to disclose in writing to the verifier any and all instances of non-compliance of the project with any law. If a verifier finds that a project is in a state of recurrent non-compliance or non-compliance that is the result of negligence or intent, then CRTs will not be issued for GHG reductions that occurred during the period of non-compliance. Non-compliance solely due to administrative or reporting issues, or due to "acts of nature," will not affect CRT crediting. As part of this eligibility requirement, project developers must submit a signed Attestation of Regulatory Compliance form[13] prior to the commencement of verification activities each time the project is verified.

[13] Attestation of Regulatory Compliance form available on the Reserve's website.

4. GHG Assessment Boundary

The GHG Assessment Boundary delineates the GHG sources, sinks, and reservoirs (SSRs) that shall be assessed by project developers in order to determine the total net change in GHG emissions caused by an AAP 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 provides an illustration of the GHG Assessment Boundary for projects, indicating which SSRs are included or excluded from the boundary.

Table 4.1 provides greater detail on each SSR and provides justification for all SSRs and gases that are included or excluded from the GHG Assessment Boundary.

Figure 4.1. Illustration of GHG Assessment Boundary for Projects

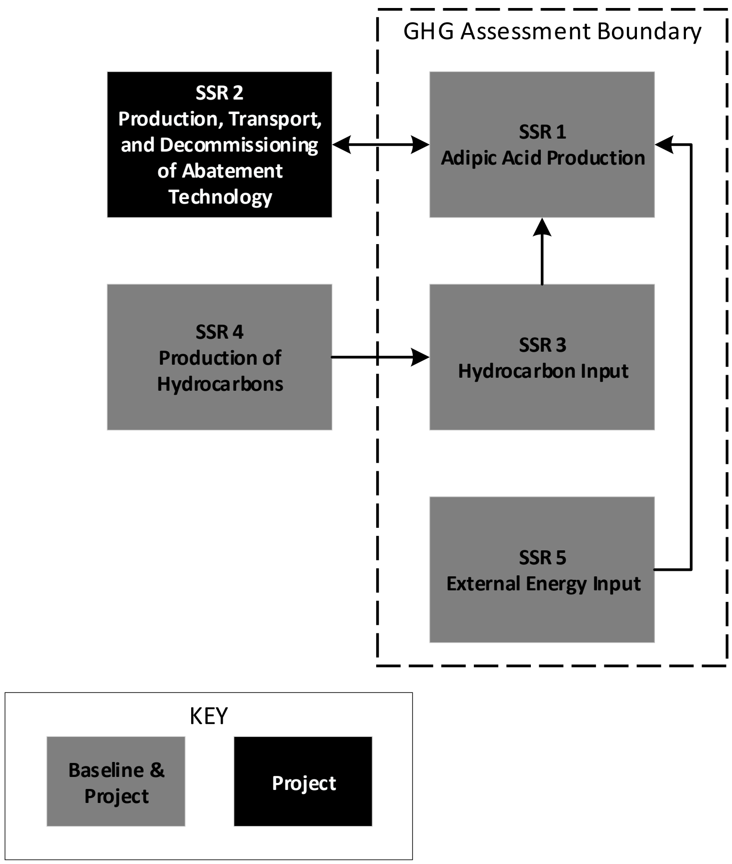


Table 4.1. Summary of Identified Sources, Sinks, and Reservoirs for Projects

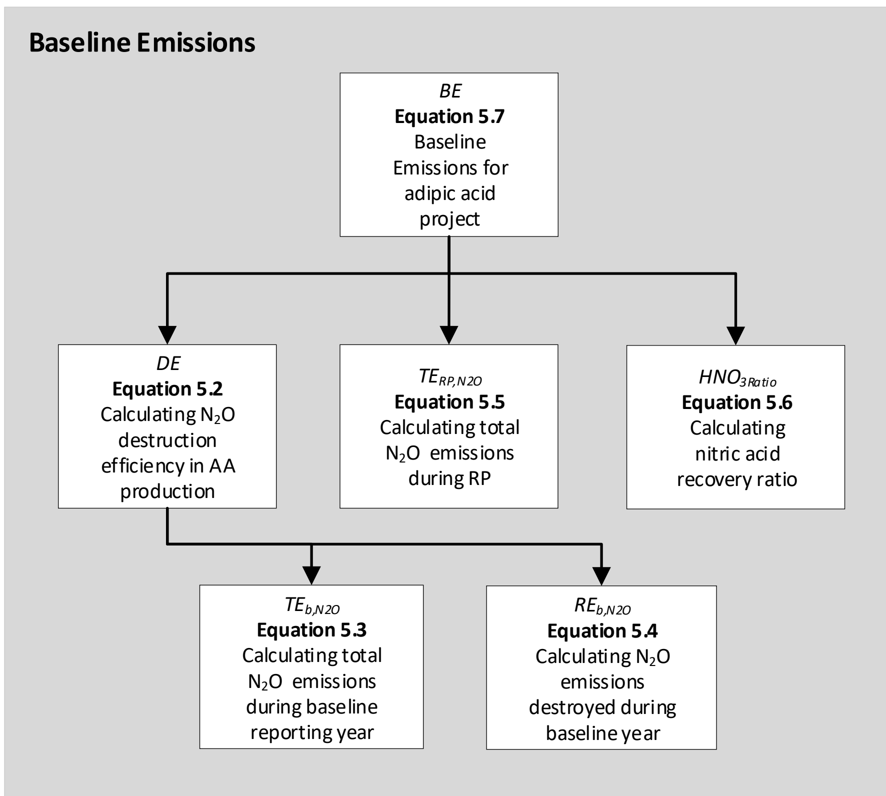
SSR	GHG Source	Source Description	GHG	Included / Excluded	Quantification Method	Relevant to Baseline (B) or Project (P)	Explanation
1	Adipic Acid Production	Adipic acid process unit (burner inlet to stack)	CO_2	Excluded	N/A	B, P	Excluded, as project activity is unlikely to impact emissions relative to baseline activity.
			CH_4	Excluded	N/A	B, P	Excluded, as project activity is unlikely to impact emissions relative to baseline activity.
			N_2O	Included	N_2O sampled before and after destruction	B, P	N_2O from production reaction is a primary effect and a major emission source.
2	N_2O abatement device	Emissions from production, transport, and decommissioning of the abatement device	CO_2, CH_4, N_2O	Excluded	N/A	P	Considered insignificant, upstream and downstream secondary GHG effects.
3	Hydrocarbon Input	Hydrocarbon used as reducing agent, reheating the off gas, or combustion fuel for thermal treatment units.	CO_2 and/or CH_4	Included	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.
4	Production of Hydrocarbons	Emissions related to the production of hydrocarbon	CO_2, CH_4, N_2O	Excluded	N/A	B, P	GHG emissions related to the production of hydrocarbons used as reducing agent are insignificant.
5	External Energy to Reheat Off Gas	May be used to reheat the off gas before entering N2O abatement units.	CO_2, CH_4, N_2O	Included	GHG emissions based on additional amounts of energy used during the project	B, P	If additional energy is used to reheat off gas and that energy is not recovered and used within the system, additional GHG emissions from the project activity will occur.

5. Quantifying GHG Emission Reductions

The GHG reduction calculations provided in this protocol are derived from internationally accepted methodologies.[14] Project developers shall use the calculation method provided in this protocol to quantify baseline and project GHG emissions in order to determine emission reductions. Figure 5.1 displays the relationships between various equations used in this section.

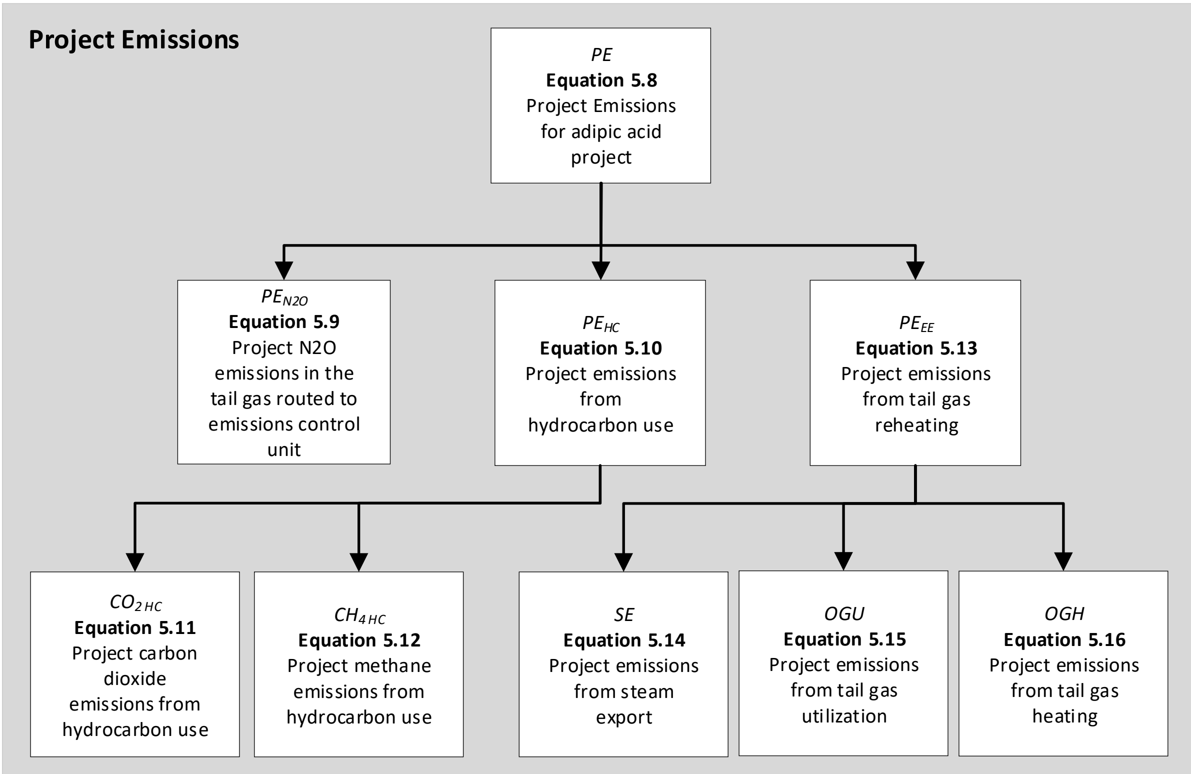
GHG emission reductions must be quantified and verified on at least an annual basis. The length of time over which GHG emission reductions are quantified and verified is called the "reporting period." The length of time over which GHG reductions are verified is called a "verification period."

Figure 5.1. Organizational Chart of Equations for Baseline Emissions of Adipic Acid Projects



[14] The Reserve's GHG reduction calculation method for N_2O abatement projects at adipic acid plants is adapted from the Kyoto Protocol's Clean Development Mechanism (AM0021 V.3.0).

Figure 5.2. Organizational Chart of Equations for Project Emissions of Adipic Acid Projects



Equation 5.1. Emission reductions for an Adipic Acid Project

$$ER = BE - PE$$

Where,			Units
ER	=	*Emission reductions during the reporting period*	tCO_2e
BE	=	*Baseline emissions during the reporting period (Equation 5.7)*	tCO_2e
PE	=	*Project emissions during the reporting period (Equation 5.8)*	tCO_2e

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 GHG reduction project (Equation 5.1). Baseline GHG emissions are based on the quantity of N_2O in the off gas[15] before it enters the project abatement technology.

For projects where N_2O destruction is already occurring prior to the project by control technology, projects must establish a Baseline Destruction Efficiency (DE) (Equation 5.2). This is accomplished by identifying the portion of the total N_2O destroyed in maximum adipic acid production year over the last five years.

Equation 5.2. Calculating N_2O destruction efficiency in Adipic Acid production

$$DE = \frac{RE_{b,N_2O}}{TE_{b,N_2O}}$$

Where,			Units
DE	=	*Baseline N_2O destruction efficiency for Adipic Acid production*	-
RE_{b,N_2O}	=	*Measured N_2O reduced and destroyed by the N_2O emission control unit in the baseline reporting year (b)*	tN_2O
TE_{b,N_2O}	=	*Measured total N_2O emissions during the baseline reporting year (b) before any emissions control treatment (e.g., destruction)*	tN_2O
b	=	*Year of the historical maximum annual total output of Adipic Acid production during the 5-year period predating the project*	-

[15] For the purposes of quantification, "off gas" is generally referring to gas that is created during the adipic acid production process, which includes pollutants such as N_2O, before it has entered any control equipment, such as a Thermal Reduction Unit (TRU) or a Selective Catalytic Reduction (SCR) units.

The DE represents the percent of the Adipic Acid plant's N_2O emissions that are destroyed by the N_2O emission control unit in the baseline reporting year. To make this calculation, the full amount of N_2O produced in the baseline reporting year prior to any destruction is calculated through

Equation 5.3, which uses direct measurements of the off gas flow.

Equation 5.3. Calculating total N_2O emission during the baseline reporting year before any emissions control treatment

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

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

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

Equation 5.4. Calculating N_2O emission destroyed during the baseline reporting year

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

Where,

			Units
RE_{b,N_2O}	=	*Total N_2O reduced and destroyed by the N_2O emission control unit in the baseline reporting period*	*tCO_2e*
$F_{b,cu}$	=	*Volume flow rate in the off gas flowing into the N_2O control unit during the baseline reporting year (b)*	*m^3 / hour*
$N_2O_{b,conc,cu}$	=	*N_2O concentration in the off gas flowing into the N2O control unit during the baseline reporting year (b)*	*tN_2O / m^3*
$OH_{b,cu}$	=	*Operating hours in the baseline reporting year (b) 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)*	-

In order for the baseline to be dynamically tied to the amount of actual N_2O emissions created by an Adipic Acid plant in the reporting period, the DE must be multiplied by actual reporting year emissions. Equation 5.5 utilizes direct measurements taken in reporting year to determine the total amount of N_2O produced before any N_2O emissions are destroyed.

Equation 5.5. Calculating total N_2O emission during the reporting period before any emissions control treatment

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

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

Equation 5.6 shows the calculation for the recovery of HNO_3 as a function of N_2O conversion to NO, which is then converted to HNO_3 in the downstream process. This applies to technologies that convert a portion of the N_2O in the exhaust to beneficial byproducts rather than simply oxidizing the N_2O to N_2 and O_2 (conventional technology). The calculation establishes a ratio of HNO_3 to adipic acid as an average of HNO_3 to an average of adipic acid over the five previous years. This ratio is then compared to the ratio of HNO_3 to adipic acid in the reporting period.

Equation 5.6. Calculating nitric acid recovery ratio

$$HNO_{3\,Ratio} = \frac{HNO_{3\,Hist}}{AA_{Hist}} - \frac{HNO_{3\,RP}}{AA_{RP}}$$

Where,			Units
$HNO_{3\,Ratio}$	=	*Ratio of HNO_3 to AA*	*$tHNO_3$ / tAA*
$HNO_{3\,Hist}$	=	*Average annual tons HNO_3 during the 5-year period predating the project*	*$tHNO_3$*
AA_{Hist}	=	*Average annual tons AA during the 5-year period predating the project*	*tAA*
$HNO_{3\,RP}$	=	*Tons HNO_3 in reporting period*	*$tHNO_3$*
AA_{RP}	=	*Tons AA in reporting period*	*tAA*

In **Error! Not a valid bookmark self-reference.**, adipic acid production, the determined N_2O destruction efficiency, the project emissions prior to destruction in the reporting period, and nitric acid recovery ratios from the previous equations are used to calculate baseline emissions.

Equation 5.7. Baseline emissions

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

Where,			Units
BE	=	*Baseline emissions during the reporting period*	*tCO_2e*
TE_{RP,N_2O}	=	*Measured total N_2O emissions during the reporting period before any emissions control treatment (e.g., destruction) (Equation 5.5)*	*tN_2O*
DE	=	*Baseline N_2O destruction efficiency (Equation 5.2)*	-
$HNO_{3\,Ratio}$	=	*Ratio of HNO_3 to AA (Equation 5.6)*	*$tHNO_3$ / tAA*
EF_{N2O}	=	*IPCC emission factor for N_2O emissions per HNO_3 production = 0.0025*	*tN_2O / $tHNO_3$*
GWP_{N2O}	=	*Global warming potential of N_2O*	*tCO_2e / tN_2O*

5.2. Quantifying Project Emissions

Project emissions are comprised of potentially multiple sources, and may include N_2O emissions in the gas that bypasses a N_2O-specific control technology and is vented into the atmosphere, or any N_2O emissions remaining after the off gas is process by an installed N_2O control system.

Equation 5.8. Project emissions

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

Where,

			Units
PE	=	*Project emissions during the reporting period*	*tCO_2e*
PE_{N_2O}	=	*GHG emissions from N_2O in the tail gas[16] during the reporting period (Equation 5.6)*	*tCO_2e*
PE_{HC}	=	*GHG emissions from the use of hydrocarbons as a reducing agent or to reheat off gas during the reporting period (Equation 5.8)*	*tCO_2e*
PE_{EE}	=	*GHG emissions from external energy used to reheat the off gas during the reporting period (Equation 5.11)*	*tCO_2e*

[16] For the purpose of quantification, "tail gas" is generally referring to gas after it exits the control equipment. There may be situations where gas exits a control unit and is recycled or used elsewhere, and thus not vented out of a physical stack immediately. Such gas should still be included in this quantification. The intension of these equations is to quantify the amount of N_2O emissions that is not fully destroyed by the control equipment, regardless of precise terminology.

5.2.1. Calculating Project N2O Emissions in the Tail Gas

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

Equation 5.9. Project N_2O emissions in the tail gas of the emissions control units

$$PE_{N_2O} = \left[\sum_{cu}(F_{sg,cu} \times N_2O_{sg,conc,cu} \times OH_{RP,cu}) + \sum_{ncu}(F_{ncu} \times N_2O_{RP,conc,ncu} \times OH_{RP,ncu})\right] \times GWP_{N2O}$$

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

Note: Depending on the type of N_2O control technology employed by a control system or unit, monitoring may occur at the inlet or outlet based on operating parameters and prohibitive direct measurement environments. Project developers are to use best judgment in the location and installation of direct measurement equipment for project monitoring and reference section 6 of this protocol.

5.2.2. Calculating emissions from hydrocarbon use

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

Equation 5.10. 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 tail gas during the reporting period*	tCO_2e
$CO_{2_{HC}}$	=	*Net GHG emissions as CO_2 from hydrocarbon use during the reporting period (Equation 5.11)*	tCO_2e
$CH_{4_{HC}}$	=	*Net GHG emissions as CH_4 from hydrocarbon use during the reporting period (Equation 5.12)*	tCO_2e

Hydrocarbons (organic compounds made up of carbon and hydrogen) are used primarily as a combustible fuel source (e.g. natural gas, which is mostly methane, propane, and butane). For calculation of the GHG emissions related to hydrocarbons, those that are combusted to produce heat and/or steam are completely converted to CO_2 (Equation 5.11) while CH_4 in fuel or reducing agent is emitted directly to the atmosphere as CH_4 (Equation 5.12) and is not converted to CO_2. In Equation 5.12, 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.[17]

Equation 5.11. Project carbon dioxide emissions from hydrocarbon use

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

Where,			Units
$CO_{2_{HC}}$	=	*Net GHG emissions as CO_2 from converted hydrocarbon during the reporting period*	tCO_2e
ρ_{HC}	=	*Hydrocarbon density*	t / m^3
$Q_{HC,b}$	=	*Historical average annual quantity of hydrocarbon, with two or more molecules of carbon, during the 5-year period predating the project (i.e. not methane)*	m^3
$Q_{HC,p}$	=	*Quantity of hydrocarbon, with two or more molecules of carbon, input during the reporting period (i.e. not methane)*	m^3
$EF_{HC,b}$	=	*Historical average annual carbon emission factor of hydrocarbon, with two or more molecules of carbon, from use during the 5-year period predating the project*	tCO_2e / tHC
$EF_{HC,p}$	=	*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)*	-

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

Equation 5.12. Project methane emissions from hydrocarbon use

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

Where,

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

5.2.3. Calculating Project Emissions from Tail Gas Reheating

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

Equation 5.13. Project emissions from tail gas reheating

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

Where,

			Units
PE_{EE}	=	*Project emissions from external energy during the reporting period*	tCO_2e
SE	=	*Emissions from net change in steam export during the reporting period (Equation 5.14)*	tCO_2e
OGU	=	*Emissions from net change in tail gas utilization during the reporting period (Equation 5.15)*	tCO_2e
OGH	=	*Emissions from net change in tail gas heating during the reporting period (Equation 5.16)*	tCO_2e

Equation 5.14. Project emissions from steam export

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

Where, Units

SE	=	*Emissions from net change in steam export during the reporting period*	tCO_2e
ST_b	=	*Baseline steam export during a reporting period*	*MW*
ST_p	=	*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 5.15. Project emissions from tail gas utilization

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

Where, Units

OGU	=	*Emissions from net change in tail gas utilization during the reporting period*	tCO_2e
EE_b	=	*Baseline energy export from tail gas utilization during a reporting period*	*MW*
EE_p	=	*Project energy export from tail 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 5.16. Project emissions from tail gas heating

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

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

6. Project Monitoring

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

At a minimum, the Monitoring Plan shall stipulate the frequency of data acquisition, a record keeping plan, the frequency of instrument field check and calibration activities, the role of individuals performing each specific monitoring activity, as well as quality assurance/quality control (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 3.4.1).

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

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

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

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

6.1. Monitoring Requirements

Direct measurements of the N_2O concentration in the tail gas/off gas and the flow rate of the tail gas/off gas shall be made using a continuous emission monitoring system. CEMS is the most accurate monitoring method because N_2O emissions are measured continuously from a specific source.[18] Elements of a CEMS include a platform and sample probe within the stack to withdraw a sample of the tail gas, an analyzer to measure the concentration of the N_2O (typically a non-dispersive infrared sensor (NDIR) or Fourier transform infrared (FTIR) spectroscopy) in the tail gas, and a flow meter within the stack to measure the flow rate of the tail gas. The emissions are calculated from the concentration of N_2O in the tail gas/off gas and the flow rate of the tail gas/off gas. A CEMS continuously withdraws and analyzes a sample of the gas and continuously measures the N_2O concentration and flow rate of the gas.[19]

6.1.1. System Installation and Certification

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

Projects utilizing a CEMS that was initially installed for a purpose other than the monitoring of a N_2O abatement project (e.g. to monitor NO_X abatement) must still meet all of the requirements of this section. If any of the required tests listed below were not conducted or the requirements were not met at the time of initial installation and certification, the project developer must conduct the tests and ensure that the requirements are met prior to the project start date.

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

- 7-day calibration error test to evaluate the accuracy and stability of a gas analyzer's or flow monitor's calibration over a period of unit operation.
- Linearity check to determine whether the response of the N_2O concentration monitor is linear across its range by challenging CEMS with three different levels of calibration gas concentrations.
- Relative Accuracy Test Audit (RATA) to determine the accuracy of the system by comparing N_2O emissions data recorded by the CEMS to data collected concurrently with an emission reference test method. All RATA of CEMS must be conducted by a testing body conforming to the requirements of ASTM D7036-04.[20]

[18] 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.
[19] 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.
[20] 40 CFR Part 75, Appendix A, section 6.1.2(a).

- Bias test to ensure that the monitoring system is not biased low with respect to the reference method, based on RATA results.
- Cycle time test to ensure that the monitoring system is capable of completing at least one cycle of sampling, analyzing, and data recording every 15 minutes.[21]
- 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.

6.1.2. Calibration

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

6.1.3. Accuracy Testing

The relative accuracy and RATA procedures from Appendix A and B (Performance Specification 2) of 40 CFR Part 60 and Appendix A of 40 CFR Part 75 shall be followed for CEMS used in Adipic Acid Production projects. The guidance for NO_X CEMS shall be used for N_2O emission monitoring where the CEMS relative accuracy shall not exceed 10% at any operating level at which a RATA is performed.[22]

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[23] for the measurement of vapor phase organic and inorganic emissions by extractive FTIR spectroscopy[24]
- ASTM D6348-03 method for the determination of gaseous compound by extractive direct interface FTIR spectroscopy[25]
- ISO/DIS 21258 stationary source emissions determination of the mass concentration of N_2O reference method for NDIR[26]
- Other NDIR methods used in AM0034 or AM0028, or performance specification-based reference method such as EPA method 7E.[27]

[21] 40 CFR Part 60, 60.13(e)(2).
[22] 40 CFR Part 75, Appendix A, section 3.3.4(a).
[23] EPA Air Emission Measurement Center (EMC), Method 320 - Vapor Phase Organic and Inorganic Emissions by Extractive FTIR
[24] 40 CFR Part 63, Appendix A.
[25] 40 CFR Part 60, 60.17(a)(82).
[26] ISO 21258:2010, Stationary source emissions -- Determination of the mass concentration of dinitrogen monoxide (N_2O) -- Reference method: Non-dispersive infrared method
[27] EPA Air Emission Measurement Center (EMC), Method 7E - Nitrogen Oxide - Instrumental Analyzer

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.[28] For details on RATA sampling, see the relative accuracy test procedures and performance specifications in Performance Specification 2, Appendix B of 40 CFR Part 60 and Appendix A of 40 CFR Part 75.

6.2. QA/QC Requirements

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

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

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

6.2.1. Frequency of Testing

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

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

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

[28] 40 CFR Part 60, Appendix B, section 8.4.4

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

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

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

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

For CEMS that were installed and certified for NO_X abatement prior to implementation of the N_2O abatement project, the daily, quarterly, semi-annual, and annual assessments detailed above only need to be performed, documented, and verified as of the project start date, not as of the date when the CEMS originally completed certification testing for NO_X abatement. For CEMS that were installed specifically for N_2O abatement project implementation, assessments must be performed, documented, and verified as of the date that the CEMS was certified.

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

6.2.2. Data Management

Data management procedures are an important component of a comprehensive QA/QC plan. Data management procedures are described throughout Appendix B of 40 CFR Part 75 and include the following items.[29]

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

6.3. Missing Data Substitution

In situations where the N_2O CEMS is missing data, the project developer shall follow the missing data substitution procedures for NO_X CEMS found in section 75.33 of 40 CFR Part 75. In summary, missing data from the operation of the CEMS may be replaced with substitute data to determine the N_2O emissions during the period for which CEMS data are missing. The owner or operator of the CEMS can substitute for missing N_2O concentration data using the procedures specified in section 75.33.[30]

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 6.1.

[29] 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.
[30] 40 CFR75, 75.33, Standard missing data procedures for SO_2, NO_X, Hg, and flow rate.

Table 6.1. Monitoring Parameters for Projects

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
General Project Parameters						
	Regulations	Project developer attestation of regulatory compliance with legal requirements relating to the project	All applicable regulations	N/A	Each verification	Information used to: 1) 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, and 2) Demonstrate compliance with all applicable regulations, e.g. criteria pollutant emission standards, health and safety, etc.
	ER	Emission reductions for the reporting period	tCO_2e	C	Per reporting period	
5.7, 5.9	GWP_{N2O}	Global warming potential of N_2O	tCO_2e/tN_2O	R	Per reporting period	
5.12	GWP_{CH_4}	Global warming potential of CH_4	tCO_2e / tCH_4	R	Per reporting period	

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.3, 5.4, 5.5, 5.9,5.11,5.12	*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	
5.3, 5.5, 5.9	*ncu*	Each installed non-N_2O emissions control unit (e.g. selective catalytic reduction unit or other non- N_2O abating device), inclusive of any bypassed and direct venting of N_2O emissions	All applicable units	O	Each verification	
Baseline Calculation Parameters						
5.1, 5.7	*BE*	Baseline emissions for the reporting period	tCO_2e	C	Per reporting period	Emissions that would have occurred in the absence of the project activity
5.2, 5.7	DE	Baseline N_2O destruction efficiency for Adipic Acid production	-	C	Once	
5.2, 5.3	TE_{b,N_2O}	Measured total N_2O emissions during the baseline reporting year before any emissions control treatment (e.g., destruction)	tN_2O	C	Once	

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.2, 5.4	RE_{b,N_2O}	Total N_2O reduced and destroyed by the N_2O emission control unit in the baseline reporting period	tN_2O	C	Once	
5.3, 5.4	$F_{b,cu}$	Volume flow rate in the off gas during the baseline reporting year to the N_2O control unit	m^3 / hour	M		Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
5.3	$F_{b,ncu}$	Volume flow rate in the off gas during the baseline reporting year to the non-N_2O control unit	m^3 / hour	M		Note this measurement is taken in the off gas prior to entering the any control or non-control equipment

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.3, 5.4	$N_2O_{b,conc,cu}$	N_2O concentration in the off gas during the baseline reporting year to the N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the off gas prior to entering the any control or non-control equipment

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.3	$N_2O_{b,conc,ncu}$	N_2O concentration in the off gas during the baseline reporting year to the non- N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
5.3, 5.4	$OH_{b,cu}$	Operating hours in baseline reporting year by N_2O control unit	Hours	M	Totaled once for the reporting period	
5.3	$OH_{b,ncu}$	Operating hours in baseline reporting year by non- N_2O control unit	Hours	M	Totaled once for the reporting period	`

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.4	E_{cu}	N_2O destruction efficiency, expressed as a fraction of total N_2O destroyed, of the N_2O emissions control unit	-	O	Once	
5.5, 5.7	TE_{RP,N_2O}	Measured total N_2O emissions during the reporting period before any emissions control treatment (e.g., destruction)	tCO_2e	C	Totaled once for the reporting period	
5.5	$F_{RP,cu}$	Volume flow rate in the off gas during the reporting period to the N_2O control unit	m^3 / hour	M	Every one minute	Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
5.5, 5.9	$F_{RP,ncu}$	Volume flow rate in the off gas during the reporting period to the non-N_2O control unit	m^3 / hour	M	Every one minute	Note this measurement is taken in the off gas prior to entering the any control or non-control equipment

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.5	$N_2O_{RP,conc,cu}$	N_2O concentration in the off gas during the reporting period to the N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the off gas prior to entering the any control or non-control equipment

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.5, 5.9	$N_2O_{RP,conc,ncu}$	N_2O concentration in the off gas during the reporting period to the non- N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
5.6, 5.9	$OH_{RP,cu}$	Operating hours in reporting period by N_2O control unit	Hours	O	Totaled once for the reporting period	
5.6, 5.9	$OH_{RP,ncu}$	Operating hours in reporting period by non- N_2O control unit	Hours	O	Totaled once for the reporting period	
5.6, 5.7	$HNO_{3\ Ratio}$	Ratio of HNO_3 to AA	$tHNO_3$ / tAA	C	Per reporting period	

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.6	$HNO_{3\ Hist}$	Average annual tons HNO_3 during the 5-year period predating the project	$tHNO_3$	O	Once	
5.6	AA_{Hist}	Average annual tons AA during the 5-year period predating the project	tAA	O	Once	
5.6	$HNO_{3\ RP}$	Tons HNO_3 in reporting period	$tHNO_3$	M	Daily, totaled for the reporting period	
5.6, 5.7	AA_{RP}	Tons AA in reporting period	tAA	M	Daily, totaled for the reporting period	
5.7	EF_{N2O}	IPCC emission factor for N_2O emissions per HNO_3 production = 0.0025	tN_2O / $tHNO_3$	R	Per reporting period	
5.11	ρ_{HC}	Hydrocarbon density	t / m^3	m	Per reporting period	
5.11	$Q_{HC,b}$	Historical average annual quantity of hydrocarbon, with two or more molecules of carbon, during the 5-year period predating the project (i.e. not methane)	m^3	O	Once	

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.11	$EF_{HC,b}$	Historical average annual GHG emissions as CH_4 from hydrocarbon use during the 5-year period predating the project	tCO_2e / tHC	C	Once	Given by the molecular weight of the hydrocarbon and CO_2 and the chemical reaction when hydrocarbons are converted
5.12	ρ_{CH_4}	Methane density	t / m^3	M	Per reporting period	
5.12	$Q_{CH_{4,b}}$	Historical average annual quantity of methane used during the 5-year period predating the project	m^3	O	Once	
5.14	ST_b	Baseline steam export during a reporting period	MW	C	Once	
5.15	EE_b	Baseline energy export from off gas utilization during a reporting period	MW	C	Once	
Project Calculation Parameters						
5.8	PE	Project emissions during the reporting period	tCO_2e	C	Per reporting period	Emissions resulting from project activities
5.8, 5.9	PE_{N_2O}	Measured project N_2O emissions in the off gas to project N_2O control units during the reporting period (Equation 5.9)	tCO_2e	C	Per reporting period	

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.8, 5.10	PE_{HC}	Net GHG emissions from the use of hydrocarbons as a reducing agent or to reheat otail gas during the reporting period (Equation 5.10)	tCO_2e	C	Per reporting period	
5.8, 5.13	PE_{EE}	GHG emissions from external energy used to reheat the tail gas during the reporting period (Equation 5.13)	tCO_2e	C	Per reporting period	
5.9	$F_{sg,cu}$	Volume flow rate in the tail gas during the reporting period by N_2O control unit	m^3 / hour	M	Every one minute	Data collected using a gas volume flow meter and processed using appropriate software programs. The meter will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the tail gas after exiting the control equipment.

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.5, 5.9	$F_{RP,ncu}$	Volume flow rate in the off gas during the reporting period to the non-N_2O control unit	m^3 / hour	M	Every one minute	Note this measurement is taken in the off gas prior to entering the any control or non-control equipment
5.9	$N_2O_{sg,conc,cu}$	N_2O concentration in the tail gas during the reporting period to the N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards. Note this measurement is taken in the tail gas after exiting the control equipment.

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.6, 5.9	$N_2O_{RP,conc,ncu}$	N2O concentration in the off gas during the reporting period to the non - N_2O control unit	tN_2O / m^3	M	Every one minute	Data collected using a gas analyzer and processed using appropriate software programs. The analyzer will be calibrated according to manufacturer specification and recognized industry standards.
5.5, 5.9	$OH_{RP,cu}$	Operating hours in reporting period by N_2O control unit	Hours	O	Totaled once for the reporting period	
5.5 5.9	$OH_{RP,ncu}$	Operating hours in reporting period by non- N_2O control unit	Hours	O	Totaled once for the reporting period	
5.10, 5.11	$CO_{2_{HC}}$	Net GHG emissions as CO_2 from hydrocarbon use during the reporting period (Equation 5.11)	tCO_2e	C	Per reporting period	
5.10, 5.12	$CH_{4_{HC}}$	Net GHG emissions as CH_4 from hydrocarbon use during the reporting period (Equation 5.12)	tCO_2e	C	Per reporting period	

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.11	ρ_{HC}	Hydrocarbon density	t / m³	m	Per reporting period	
5.11	$Q_{HC,p}$	Quantity of hydrocarbon, with two or more molecules of carbon, input during the reporting period (i.e. not methane)	m³	O	Daily	
5.11	$EF_{HC,p}$	GHG emissions as CH_4 from hydrocarbon use during the reporting period	tCO_2e / tHC	C	Per reporting period	Given by the molecular weight of the hydrocarbon and CO2 and the chemical reaction when hydrocarbons are converted
5.12	ρ_{CH_4}	Methane density	t / m³	M	Per reporting period	
5.12	$Q_{CH_4,p}$	Quantity of methane used during the reporting period	m³	O	Daily	
5.13, 5.14	SE	Emissions from net change in steam export during the reporting period (Equation 5.14)	tCO_2e	C	Per reporting period	
5.13, 5.15	OGU	Emissions from net change in tail gas utilization during the reporting period (Equation 5.15)	tCO_2e	C	Per reporting period	

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.13, 5.16	OGH	Emissions from net change in tail gas heating during the reporting period (Equation 5.16)	tCO_2e	C	Per reporting period	
5.14	ST_p	Project steam export during the reporting period	MW	C	Once	
5.14	η_{ST}	Efficiency of steam generation	Fraction	C	Once	Manufacturer supplied information
5.14	EF_{ST}	Fuel emission factor for steam generation	tCO_2e / MWh	C	Per reporting period	From fuel supplier certificate or default value
5.14, 5.15	OH_{RP}	Operating hours in reporting period	Hours	O	Totaled once for the reporting period	
5.15	EE_p	Project energy export from tail gas utilization during the reporting period	MW	C	Once	
5.15	η_r	Efficiency of replaced technology	Fraction	C	Once	Manufacturer supplied information
5.15	EF_r	Fuel emission factor for replaced technology	tCO_2e / MWh	C	Per reporting period	From fuel supplier certificate or default value
5.16	EI_{OGH}	Energy input for additional tail gas heating during the reporting period	MWh	M or C	Monthly	

Eq.	Parameter	Description	Data Unit	Calculated (C), Measured (M), Referenced (R), Operating Records (O)	Measurement Frequency	Comment
5.16	η_{OGH}	Efficiency of additional tail gas heating	Fraction	C	Once	Manufacturer supplied information
5.16	EF_{OGH}	Emission factor for additional tail gas heating	tCO_2e / MW	C	Once	From fuel supplier certificate or default value

7. Reporting Parameters

This section provides 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 annually at a minimum.

7.1. Project Documentation

Project developers must provide the following documentation to the Reserve in order to register a project under this Protocol.

- Project Submittal form
- Project diagram (diagram of the AAP showing where the project is located within the AAP, as well as location of monitoring equipment)
- 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
- Signed Attestation of Title form
- Signed Attestation of Voluntary Implementation form
- Signed Attestation of Regulatory Compliance form

At a minimum, the above project documentation will be available to the public via the Reserve's online registry. Further disclosure and other documentation may be made available by the project developer on a voluntary basis.[31]

7.2. Record Keeping

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

System information the project developer should retain includes:

- All data inputs for the calculation of the project emission reductions, including all required sampled data

[31] Project submittal forms and project registration information can be found at the Reserve's website (http://www.climateactionreserve.org/).

- 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 3 years prior to the project start date, and for each subsequent year of project operation
- Project developer attestation of compliance with regulatory requirements relating to the N_2O abatement project
- 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 per reporting period and the number of operating hours
- CO_2e annual tonnage calculations
- Initial and annual verification records and results
- All maintenance records relevant to the N_2O control system and monitoring equipment

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

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

7.3. Reporting Period and Verification Cycle

Project developers must report GHG reductions resulting from project activities during each reporting period. A reporting period may not exceed 12 months in length, and no more than 12 months of emission reductions may be verified at once, except during a project's first verification, which may include historical emission reductions from prior years. 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.

8. Verification Guidance

This section provides verification bodies with guidance on verifying GHG emission reductions from projects developed to the standards of this protocol. This verification guidance supplements the Reserve's Verification Program Manual and describes verification activities in the context of reducing nitrous oxide emissions through abatement projects at adipic acid plants.

Verification bodies trained to verify adipic acid production projects must conduct verifications to the standards of the following documents:

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

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

In cases where the Program Manual and/or Verification Program Manual differ from the guidance in this protocol, this protocol takes precedent.

Only ISO-accredited verification bodies trained by the Reserve for this project type are eligible to verify adipic acid production project reports. Verification bodies approved under other project protocol types are not permitted to verify adipic acid production projects. Information about verification body accreditation and Reserve project verification training can be found in the Verification Program Manual.

8.1. Standard of Verification

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

8.2. Monitoring Plan

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

8.3. Verifying Eligibility Criteria

Verification bodies must affirm adipic acid production project eligibility according to the rules described in this protocol. The table below outlines the eligibility criteria for an adipic acid production project. This table does not represent all criteria for determining eligibility comprehensively; verification bodies must also look to Section 3 and the verification items lists in Section 8.5.

Table 8.1. Summary of Eligibility Criteria

Eligibility Rule	Eligibility Criteria	Frequency of Rule Application
Start Date	Start date may be no more than 6 months prior to project submittal	Once during first verification
Location	United States and its territories	Once during first verification
Performance Standard	Installation of an N_2O control technology at an adipic acid plant	Once during first verification
Legal Requirement Test	Signed Attestation of Voluntary Implementation form and monitoring procedures that lay out procedures for ascertaining and demonstrating that the project passes the Legal Requirement Test	Every verification
Regulatory Compliance Test	Signed Attestation of Regulatory Compliance attesting that project is in material compliance with all applicable laws	Every verification

8.4. Core Verification Activities

The Adipic Acid Production Project Protocol provides explicit requirements and guidance for quantifying 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 production project, but verification bodies shall 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
2. Reviewing GHG management systems and estimation methodologies
3. Verifying emission reduction estimates

8.4.1. Identifying emission sources, sinks, and reservoirs

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

8.4.2. Reviewing GHG management systems and estimation methodologies

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

8.4.3. 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 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 production project. The tables include references to the section in the protocol where requirements are further described. The tables also identify 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 should not be viewed as a comprehensive list or plan for verification activities, but rather guidance on areas specific to adipic acid production projects that must be addressed during verification.

8.5.1. Project Eligibility and CRT Issuance

Table 8.2 lists the criteria for reasonable assurance regarding eligibility and Climate Reserve Tonne (CRT) issuance for adipic acid production 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 one 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?
2.1– 2.1.3	Verify that the project meets the project definition and is properly defined	No
2.1	Verify whether the adipic acid plant is existing, upgraded, relocated or restarted	No
2.2	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 adipic acid facility operating within the U.S. or its territories	No
3.2	Verify eligibility of project start date	No
3.2	Verify accuracy of project start date based on operational records	Yes
3.3	Verify that project is within its 10-year crediting period	No
3.4.1	Verify that the project meets the appropriate Performance Standard Test for the project type	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	No
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 monitoring meets the requirements of the protocol. If it does not, verify that a variance has been approved for monitoring variations	No
6.1– 6.3	Verify that all components of the CEMS adhered to the field check and calibration schedule specified in the protocol. If they do not, verify that a variance has been approved for monitoring variations or that adjustments have been made to data per the protocol requirements	No
6.1.1	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	Verify that the calibration test procedures were properly followed, including the calibration error test and linearity check	No
6.1.3	Verify that the relative accuracy test audits were completed according to the required procedure and schedule	No
6.3	If used, verify that data substitution methodology was properly applied	No
n/a	If any variances were granted, verify that variance requirements were met and properly applied	Yes

8.5.2. Quantification of GHG Emission Reductions

Table 8.3 lists the items that verification bodies shall include in their risk assessment and recalculation of the project GHG emission reductions. These quantification items inform any determination as to whether there are material and/or immaterial misstatements in the project 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
5	Verify that the appropriate calculations were performed by the project developer and quantification and equation processes were followed.	No
5.1	Verify that the project developer correctly calculated and applied EF_{AA}	No
5.1	Verify that the project developer correctly calculated the nitric acid recover ratio, if applicable	No
5.2.1	Verify that the project developer correctly accounted for N2O emissions at the inlet and outlet of the control system for the project, as applicable	Yes
5.2.2	Verify that the project developer correctly quantified hydrocarbon use for the project	Yes
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	Yes
5.2	Verify that the project emissions calculations were calculated according to the protocol with the appropriate data	No

8.5.3. Risk Assessment

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

Table 8.4. Risk Assessment Verification Items

Protocol Section	Item that Informs Risk Assessment	Apply Professional Judgment
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	No
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 greenhouse gas reporting duties	Yes
6	Verify that all contractors are qualified for managing and reporting greenhouse gas 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

8.6. 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. List of Abbreviations and Acronyms

AA	Adipic acid
AAP	Adipic acid plant
ARB	Air Resources Board
ASTM	American Society for Testing and Material international
BACT	Best available control technology
CAA	Clean Air Act
CEMS	Continuous emission monitoring systems
CFR	Code of Federal Regulations
CO2e	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
lb	Pound
m	Meter
Mg	Megagram
MT	Metric ton
MW	Megawatt
MWh	Megawatt hour

NDIR	Non-dispersive infrared sensor
NOV	Notice of violation
NOVA	Notification of verification activities
PSD	Prevention of Significant Deterioration
QA/QC	Quality assurance and quality control
RATA	Relative accuracy test audit
SCR	Selective catalytic reduction
SSR	GHG sources, sinks, and reservoirs
SSRs	Sources, sinks, and reservoirs
t	Metric ton, equivalent to a Megagram

10. Glossary of Terms

Accredited verification body	A verification firm approved by the Registry to provide verification services for Project Developers.
Additionality	Manure management practices 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	Greenhouse gas emissions from sources that are owned or controlled by the reporting entity.
Emission factor	A unique value for determining an amount of a greenhouse gas 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.
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, over a 100-year horizon, as determined periodically by the IPCC and reported in the most recent Inventory of U.S. Greenhouse Gas Emissions and Sinks published annually by the EPA.
Greenhouse gas (GHG)	Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and other gasses that contribute to the greenhouse effect by absorbing infrared radiation.
Indirect emissions	Emissions that are a consequence of the actions of a reporting entity but are produced by sources owned or controlled by another entity.
Methane (CH_4)	A potent GHG consisting of a single carbon atom and four hydrogen atoms.
Metric ton (tonne, MT, Mg, t)	A common international measurement for the quantity of GHG emissions, equivalent to about 2204.6 pounds or 1.1 short tons.
Nitrogen Oxides (NO_x)	A group of compound gasses containing nitrogen and oxygen atoms that contribute to atmospheric pollution; includes nitrous oxide (N_2O), nitric oxide (NO) and dinitrogen dioxide (N_2O_2), dinitrogen trioxide (N_2O_3), nitrogen dioxide (NO_2) and dinitrogen tetroxide (N_2O_4), and dinitrogen pentoxide (N_2O_5).
Nitrous oxide (N_2O)	A GHG consisting of two nitrogen atoms and a single oxygen atom.
Project baseline	A business-as-usual GHG emission assessment against which GHG emission reductions from a specific GHG reduction activity are measured.
Stationary combustion source	A stationary source of emissions from the production of electricity, heat, or steam, resulting from combustion of fuels in boilers, furnaces, turbines, kilns, and other facility equipment.

Verification	The process used to ensure that a given participant's greenhouse gas emissions or emission reductions have met the minimum quality standard and complied with the Registry's procedures and protocols for calculating and reporting GHG emissions and emission reductions.
Verification body	An accredited firm that is able to render a verification opinion and provide verification services for operators subject to reporting under this Protocol.
Verification period	The period of time over which GHG reductions are verified.

11. References

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"U.S. Code of Federal Regulations (CFR). Title 40." n.d. https://www.ecfr.gov/cgi-bin/text-idx?SID=279f36b48682c8391859ad082975596b&mc=true&tpl=/ecfrbrowse/Title40/40cfr75_main_02.tpl.

Appendix A. Performance Standard Development

Emission Controls at Adipic Acid Plants

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 main body of protocol, Section 3.4.1 "The Legal Requirement Test"), all Western industrialized countries voluntarily installed abatement technology in the 1990s.[32]

The most appropriate type of control technology can be highly facility specific. Among the two existing adipic acid plants in the United States, the Ascend adipic acid plant has a Thermal Reduction Unit ("TRU") installed, which abated approximately 83% of the facility's N_2O emissions[33] in 2017, whereas the INVISTA adipic acid plant abates using specially designed boilers that generate steam from process-derived waste streams and N_2O-specific selective catalytic reduction ("SCR") systems, which achieved 97% abatement in 2017.[34,35] Because adipic acid production is so emissions intensive, even after abating the majority of their emissions, these two facilities still released 7.4 million tCO2e in 2017, and thus have substantial opportunity for additional emission reductions.

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.

[32] Heike Mainhardt and Dina Kruger, "N2O Emissions from Adipic Acid and Nitric Acid Production," accessed June 25, 2019, https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/3_2_Adipic_Acid_Nitric_Acid_Production.pdf.
[33] United States Environmental Protection Agency, "Ascend - Cantonment, FL, GHG Facility Details."
[34] United States Environmental Protection Agency, "Invista - Victoria, TV, GHG Facility Details."
[35] INVISTA's West Powerhouse ("WPH") Victoria plant has a comparably high abatement level because it was required to install GHG control technology as part of their Prevention of Significant Deterioration ("PSD") permitting under the Clean Air Act after a major source modification (40 CFR § 124.41). For more information, see Section 3.1 "Federal Regulations".

Table A.1. Review of potential control technologies at Adipic Acid plants.[36]

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

Existing facilities can reduce their emissions beyond a business-as-usual level in two ways. First, they could utilize their existing emissions control technology at a higher rate, or they could install new emissions abatement control technology. Increasing the use of existing abatement technology is particularly pertinent to U.S. adipic acid plants; 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.[37] Facilities can send their off gas to the TRU, which reduces N_2O[38] 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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[36] 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.

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

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