ADIPIC ACID PRODUCTION

ISSUE PAPER

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Adipic Acid Production Issue Paper

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This issue paper, 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

This Issue Paper reviews the potential to reduce GHG emissions and generate voluntary offset credits, or Climate Reserve Tonnes ("CRTs"), by creating an Adipic Acid Production Protocol through the Climate Action Reserve ("Reserve"). It summarizes the existing literature, data and quantification methodologies related to adipic acid emissions abatement and leverages lessons-learned from historical international projects. Because adipic acid production and GHG abatement technology closely mirrors the production and abatement of greenhouse gases ("GHGs") from nitric acid production, this Issue Paper will rely heavily on the Reserve's existing Nitric Acid Production Protocol ("Nitric Acid Protocol").[1]

1.1. Adipic Acid Production History and Market

Adipic Acid ($HOOC(CH_2)_4COOH$), also known as hexanedioic acid, is a chemical compound commonly used as a precursor to produce nylon 6,6 polyamide through its reaction with 1.6-hexamethylenediamine. In 2017 (the most recent date for which data are available), adipic acid facilities in the United States generated 7.4 million metric tons CO_2 equivalent ("tCO_2e").[2,3,4] Between 2012 and 2015, aggregate GHG emissions and production remained approximately steady, with some fluctuation.[5] In 2015, INVISTA shut down their Orange, Texas production facility, which had an annual capacity of 220,000 metric tons of adipic acid per year.[6] This resulted in a moderate decrease in aggregate U.S. production accompanied by a relative increase in emissions, indicating that local production shifted from

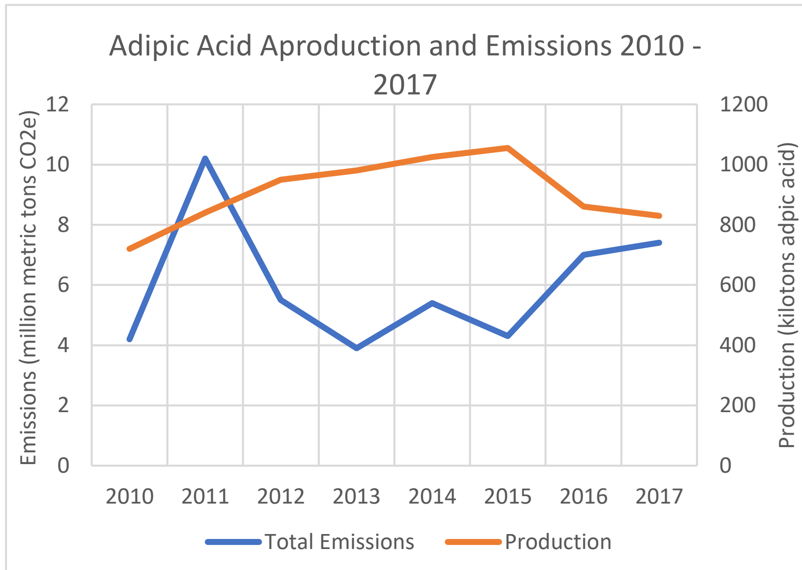

Figure 1. Emissions and production data for adipic acid facilities in the United States.

[1] Climate Action Reserve, "Nitric Acid Production Project Protocol Version 2.2," April 18, 2019, http://www.climateactionreserve.org/how/protocols/nitric-acid-production/.

[2] United States Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017," April 11, 2019, https://www.epa.gov/sites/production/files/2019-04/documents/us-ghg-inventory-2019-main-text.pdf.

[3] United States Environmental Protection Agency, "Ascend - Cantonment, FL 2014 GHG Facility Details," EPA Flight, accessed June 25, 2019, https://ghgdata.epa.gov/ghgp/service/html/2014?id=1004962&et=undefined.

[4] United States Environmental Protection Agency, "Invista - Victoria, TX 2017 GHG Facility Details," EPA Flight, accessed June 25, 2019, https://ghgdata.epa.gov/ghgp/service/html/2017?id=1001781&et=undefined.

[5] United States Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016."

[6] ICIS, "US INVISTA to Close Adipic Acid Plant in Texas," Icis, October 6, 2015, https://www.icis.com/explore/resources/news/2015/10/06/9930535/us-invista-to-close-adipic-acid-plant-in-texas.

the shuttered facility to an existing higher-emitting facility. Currently, only two adipic acid facilities remain active in the United States: The Ascend plant in Pensacola, Florida and the INVISTA plant in Victoria, Texas.

Adipic acid production in the United States represents a substantial source of GHG emissions from very few facilities. As such, the industry has an enormous potential to reduce emissions given the appropriate incentives to install control technologies.

1.2. Adipic Acid Manufacturing Process

There are two stages to adipic acid production. First, cyclohexane is air-oxidized to form a cyclohexanone/cyclohexanol mixture (Figure 2). In the second stage this mixture is chemically oxidized, creating N_2O, the GHG of concern, as an unavoidable byproduct that is emitted in the facility's off gas (Figure 3). Adipic acid and N_2O are created in proportional molar ratios (i.e., for every molecule of adipic acid produced, a molecule of N_2O is produced as a byproduct.) The process is represented by the following chemical reaction[7]:

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

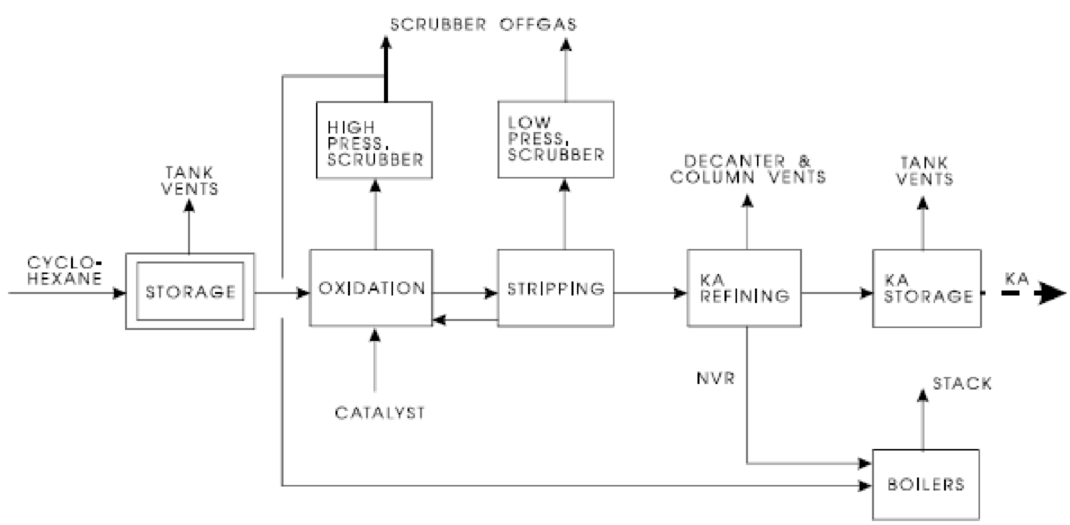

Figure 2. Diagram depicting the first step of the adipic acid production (Figure from U.S. EPA Adipic Acid Production report).[8]

[7] United States Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016."

[8] United States Environmental Protection Agency, "Adipic Acid Production," July 1994, https://www3.epa.gov/ttn/chief/ap42/ch06/bgdocs/b06s02.pdf.

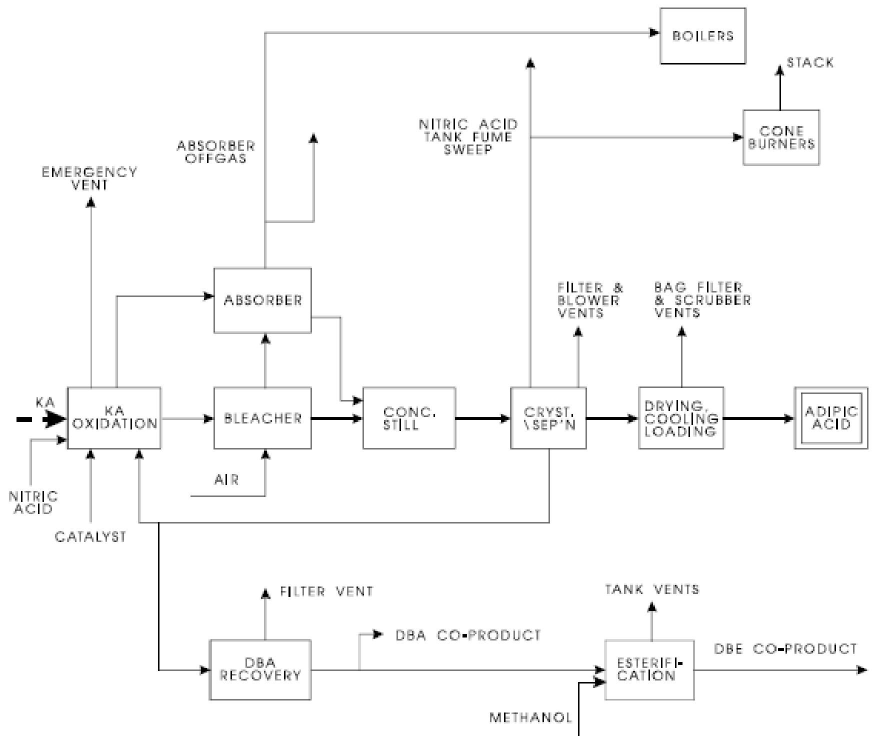

Figure 3. Diagram depicting the second step of the adipic acid production (Figure from U.S. EPA Adipic Acid Production report).[9]

The off gas from adipic acid plants contains several different molecules, many of which are detrimental to the environment (Table 1). One challenge facing the adipic acid industry is the trade-off between abating different types of pollutants in a cost-effective manner, which is discussed in detail later in this Issue Paper.

Table 1. Typical composition of the off gas created in adipic acid production.[10]

Chemical or Common Name	Chemical Formula	Molar Percent of Off Gas
Nitrous Oxide	N_2O	30.5%
Nitrogen Oxide	NO_x	0.7%
Carbon Dioxide	CO_2	6.0%
Carbon Monoxide	CO	0.03%
Ozone	O_2	3.9%
Water	H_2O	2.0%
Dinitrogen	N_2	57.0%
Volatile Organic Compounds ("VOCs")	Many	0.03%

[9] United States Environmental Protection Agency.
[10] R. A. Reimer et al., "Abatement of N2O Emissions Produced in the Adipic Acid Industry," *Environmental Progress* 13, no. 2 (1994): 134–37, https://doi.org/10.1002/ep.670130217.

2. Emission Controls at Adipic Acid Plants

2.1. Existing Controls

Currently, most adipic acid facilities are fitted with some N_2O abatement technology. Although there is no federal requirement to control N_2O emission in the United States (except under limited circumstances, see Section 4.1 "Federal Regulations"), all Western industrialized countries voluntarily installed abatement technology in the 1990s.[11]

The most appropriate type of control technology can be highly facility specific. The Ascend adipic acid plant has a Thermal Reduction Unit ("TRU") installed, which abated approximately 83% of the facility's N_2O emissions[12] 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.[13,14] Because adipic acid production is so emissions intensive, even after abating the majority of their emissions, these two facilities still released 7.4 million tCO_2e in 2017 (see Figure 1), and thus have substantial opportunity for additional emission reductions.

2.2. Potential Controls and Eligible Project Activities

Adipic acid N_2O abatement technology is similar to the abatement technology at nitric acid facilities. In the Reserve's Nitric Acid Protocol, abatement can either be secondary (abatement in the burner/ammonia oxidation reactor ["AOR"] where the reaction occurs) or tertiary (abatement of the waste off gas downstream of the AOR). However, unlike nitric acid production, adipic acid production cannot tolerate the associated pressure change with secondary abatement. As a result, abatement is limited to installing downstream technology to treat the facility's off gas. Control technology falls into four types of systems, outlined in Table 2.

[11] 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.
[12] United States Environmental Protection Agency, "Ascend - Cantonment, FL 2014 GHG Facility Details."
[13] United States Environmental Protection Agency, "Invista - Victoria, TX 2017 GHG Facility Details."
[14] 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 2. Review of potential control technologies at Adipic Acid plants.[15]

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 to produce other products.	Using N_2O off gas as an oxidant to produce phenol from benzene.
Recycle to Nitric Acid	Recycle N_2O to create nitric acid by burning the gas at high temperatures with steam.	Nitrogen recycling adiabatic reactor

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; as previously discussed, 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.[16] Facilities can send their off gas to the TRU, which reduces N_2O[17] 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 increase TRU utilization by reducing NO_x.

[15] 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.

[16] 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.

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

3. Evaluation of Additionality

3.1. Climate Action Reserve Additionality Tests

In this section, we evaluate how an adipic acid project passes the Reserve's thresholds for additionality. In general, the Reserve requires that a project passes a standardized additionality test considering either an emissions rate threshold, a practice or technology-based threshold, or other conditions or criteria.[18]

Both thresholds are potentially applicable to adipic acid GHG abatement projects in the U.S. However, the threshold for an emissions rate may be very difficult to evaluate with the limited number of plants in the U.S. Therefore, this Issue Paper will discuss the potential for a technology or practice-based threshold.

Although facilities have historically installed equipment to reduce GHG emissions, there is not a legal requirement to abate above-and-beyond current levels. Facilities have no incentive to make the often-substantial capital investment to increase their GHG abatement levels. However, there is still an enormous potential to abate incremental GHG emissions if a facility can either increase the utilization of existing technology or install more efficient GHG abating equipment.

Because existing facilities already utilize some GHG control technology, it is important to also ensure emissions reductions are incremental or additional to any existing practices. The Reserve acknowledges the challenges associated with a common practice or technology performance standard test in their Program Manual (emphasis added):

> "A common rule of thumb for establishing performance standards is that they should make eligible only technologies or practices that are not "common practice." However, "common practice" is often difficult to define. Instead of adopting a simple rule for defining "common practice" (as a threshold market penetration rate, for example) **the Reserve requires setting performance standards based on an overall assessment of the market for GHG reductions and the risk of crediting too many non-additional reductions**."

To comply with the Reserve's standard evaluation of additionality, we will therefore focus on the market for GHG reductions and the risk of over-crediting.

3.2. Risk of Over-Crediting and Secondary Effects

International adipic acid abatement projects have faced historical criticism for creating secondary effects, sometimes referred to as carbon leakage, and generating non-additional credits. The prominent think tank Stockholm Environmental Institute's 2010 assessment found that projects under first version of the Clean Development Mechanism ("CDM") adipic acid production protocol AM0021 (Version 1)[19] caused a

[18] Climate Action Reserve, "Program Manual," September 1, 2015.

[19] UNFCCC/CCNUCC, "Approved Baseline and Monitoring Methodology AM0021, 'Baseline Methodology for Decomposition of N2O from Existing Adipic Acid Production Plants' Version 03," February 27, 2009, https://cdm.unfccc.int/methodologies/DB/PC4EBQSJUB9IV2FS9TMQV8DFM3X6MZ.

substantial shift in worldwide adipic acid production, resulting in an estimated 20% non-additional Certified Emission Reductions ("CERs").[20]

According to SEI, there were two primary carbon leakage drivers:

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

These factors created an incentive for adipic acid production to shift from non-CDM projects to CDM projects, and for individual CDM projects to increase production of adipic acid for the value of the carbon credit rather than the actual adipic acid product.

Despite these issues, SEI acknowledged that CDM adipic acid abatement projects remained a largely effective mechanism to reduce emissions, stating, "[t]he carbon market provided incentives for adipic acid producers to abate N_2O emissions to an extent which had previously not been achieved and which had not been considered practical or feasible in the relevant technical literature."[21] In other words, although the original CDM protocol left room for systematic abuse, the protocol created incentives that allowed effective emission reduction equipment to be installed that would have otherwise been uneconomical. A more recent analysis by the German think tank Öko-Institut, in collaboration with SEI, argued that given an overall lack of incentive to abate GHG emissions for adipic acid projects, "this project type can be considered to be very likely additional. We recommend considering this project type as automatically additional, as long as no regulations require N_2O abatement."[22]

These reports acknowledge that none of the adipic acid plants would have installed abatement technologies in the absence of the incentives created by the carbon market. However, there is a risk of over-crediting that should be thoroughly evaluated. Both reports suggest secondary effects can be largely mitigated or completely avoided through careful protocol design.

SEI suggests that setting baselines based on emissions rates would be the most straightforward and efficient way to prevent secondary effects. This strategy was utilized in later Joint Implementation ("JI")[23] projects that had more stringent leakage protections and did not appear to have had any secondary effects or carbon leakage.

[20] Lambert Schneider, Michael Lazarus, and Anja Kollmuss, "Industrial N2O Projects Under the CDM: Adipic Acid - A Case of Carbon Leakage?," *Stockholm Environmental Institute*, October 9, 2010, 23.
[21] Schneider, Lazarus, and Kollmuss.
[22] Dr. Martin Cames et al., "How Additional Is the Clean Development Mechanism? Analysis of the Application of Current Tools and Proposed Alternatives," *Öko-Institut*, March 2019, https://ec.europa.eu/clima/sites/clima/files/ets/docs/clean_dev_mechanism_en.pdf.
[23] Joint Implementation is a project-based mechanism similar to the CDM established under the United Nations Framework Convention for Climate Change's Kyoto Protocol that is applicable in countries classified as "developed" at the time of the Kyoto Protocol.

In this Issue Paper, we will discuss why the incentive structures in the U.S. would not encourage secondary effects. After, we will discuss best practices to implement careful and conservative protocol design that would eliminate any risk of carbon leakage including setting a rigorous baseline.

3.2.1. Evaluation of Secondary Effect Potential in the United States

Secondary effects (carbon leakage) may occur if a facility begins to over-produce their product because the value of carbon offset creates a perverse incentive ("product gaming"). This occurred in early CDM adipic acid abatement projects. If secondary effects occur, a portion of the offsets would be non-additional and the activity could shift production away from other adipic acid production facilities worldwide. In general, we believe this scenario will not occur in the United States for the following reasons:

1. The value of voluntary carbon offsets in the United States is lower than historical CDM CER level when product gaming occurred (average of \$2.40 \$/tCO_2e in quarter 1 2018[24] compared to over \$18 USD/tCO_2e[25]).
2. The Reserve's protocol would only generate credits for the incremental emission reductions above a baseline (to be discussed in Section 3.2.2.). As a result, U.S.-based projects would not achieve nearly the same volume of CERs as created under the CDM on a per-unit adipic acid produced basis.
3. In the U.S., over-production is especially costly because the facility would need to increasingly abate its NO_x emissions.

Although an offset project may be financially attractive in the U.S., these factors all indicate that the project alone should not bring a facility high enough value to justify increasing production exclusively for the offset value. Even if U.S.-based voluntary credits rise in value to a level comparable to early CDM CER levels, we believe that the decrease in credit issuance with a tighter baseline requirement would still protect against leakage incentives.

To provide an example of the economic incentives that created secondary effects in early CDM projects, SEI compared the financials of early CDM projects with later JI projects. According to SEI, JI projects had baseline historical abatement levels around 90%.[26] By only crediting the incremental emissions beyond individual facility's abatement levels, the economic incentives for JI projects remained attractive but did not appear to create the same highly skewed incentive structure (Table 3).

[24] Kelley Hamrick and Melissa Gallant, "Voluntary Carbon Market Insights: 2018 Outlook and First-Quarter Trends" (Ecosystem Marketplace, August 2018), https://www.forest-trends.org/wp-content/uploads/2018/09/VCM-Q1-Report_Full-Version-2.pdf.

[25] Schneider, Lazarus, and Kollmuss, "Industrial N2O Projects Under the CDM: Adipic Acid - A Case of Carbon Leakage?"

[26] Schneider, Lazarus, and Kollmuss.

Table 3. Example value of hypothetical CDM and JI projects adapted from the Stockholm Environmental Institute.[27]

	Unit	**CDM**	**JI**
Technology	-	Single catalytic/thermal decomposition	Redundant catalytic/thermal decomposition
Adipic Acid Production	Kiloton/year	150	150
Revenues from CERs or ERUs			
Baseline emission factor	kg N_2O/MT adipic acid	270	30
Project emission factor	kg N_2O/MT adipic acid	4	0
Other emissions	tCO_2e/MT adipic acid	0.1	0.1
CERs or ERUs	CER or ERU/MT adipic acid	82.4	9.2
Price for CERs or ERUs	$	$18.07	$18.07
Revenues from CERs or ERUs	$/MT adipic acid	$1,489	$167
CDM / JI Transaction Costs	$/CER or ERU	$0.79	$0.53
Abatement Costs			
Investment Costs	Million $	$11.12	$18.07
Operational Costs	Million $/year	$1.39	$2.1
Technical Lifetime	Years	20	20
Required Return on Investment	-	15%	15%
Net Profits from CDM or JI	**$/MT adipic acid**	**$1,402**	**$128**

MT = metric ton. All currencies were converted from EURs to 2010 U.S. Dollars with a conversion factor of 1.39.[28]

SEI's evaluation demonstrated a considerable difference in profit between CDM projects and JI projects ($1,402 per metric ton adipic acid versus $128 per metric ton adipic acid), largely due to differences in baseline setting. Again, these final differences in net profits were based on a comparably higher value for CERs or ERUs that we would not expect in the U.S. voluntary market ($18 per unit versus $2.40 per unit, 650% higher).

3.2.2. Baseline Setting

As discussed earlier in the Issue Paper, a large amount of N_2O emissions are already abated from voluntarily installed abatement technology. However, significant N_2O emissions remain. A robust baseline must only consider incremental emissions above and beyond the business-as-usual abatement levels.

Incremental reduction limitations could be achieved in two ways. First, a quantification protocol could set a blanket average emissions reduction benchmark for which each facility could measure itself against. Alternatively, the protocol could set baselines based on individual, facility-level historical emissions.

[27] Schneider, Lazarus, and Kollmuss.
[28] X-RATES, "Exchange Rate Average (Euro, US Dollar)," accessed July 4, 2019, https://www.x-rates.com/average/?from=EUR&to=USD&amount=1&year=2010.

The blanket-average strategy is typical in several carbon policies; for example, the California cap-and-trade program utilizes sector-level emissions intensity benchmarks to determine free allowance allocation for certain industries.[29] This is also one strategy recommended by the SEI in their original evaluation of the CDM market. However, recent global changes mean that this strategy is unsuitable for adipic acid reduction projects; international baseline-setting data is insensitive to U.S.-specific technology and regulatory environment.

SEI originally argued that an international standard would level the playing field between facilities in different jurisdictions; however, price and carbon offset unit type (e.g., CDM credits vs. Reserve-issued CRTs) have become extremely divergent. Facilities in the U.S. creating Reserve-issued CRTs will expect a much different price compared to facilities generating CERs through the CDM. Although prices could stabilize internationally in the long-term, we expect that the price of carbon offsets between jurisdictions will remain divergent in the near future. For this reason, an apples-to-apples baseline does not achieve the goal of international carbon market parity.

Therefore, a facility-level evaluation of historical emissions levels appears to be the most appropriate and straightforward mechanism to set the baseline in the United States. Data for historical emissions levels should be readily available because of GHG emissions reporting requirements under other regulations in the U.S. We recommend setting the baseline emissions rate at the level achieved during the maximum adipic acid production level from the past five years (percent N_2O destroyed annually). This safeguard is in-line with current practices in the Nitric Acid Protocol[30]

We do not believe any new adipic acid facilities will be built in the near future. If this were to occur, new facilities could participate and generate carbon offsets with a default value baseline rather than a baseline derived from historical emissions data. Any default baseline value would need to be carefully calculated to acknowledge the well-established but voluntary nature of GHG abatement technology at existing adipic acid plants. If it becomes more likely that an adipic acid facility may be built, the Reserve could review options to calculate the default baseline and expand the Protocol.

3.2.3. Summary of Additionality

In the absence of regulatory requirements, there are no incentives to abate N_2O emissions at adipic acid plants in the United States. Despite historical criticism of CERs generated under the CDM through at adipic acid plants, we believe the risk of secondary effects in the U.S. would be extremely low; the incentive structure does not exist to create non-additional credits because the value and volume of the credits will be much lower. The Reserve's protocol should ensure any CRTs generated would be incremental to existing voluntary abatement levels by setting a baseline based on historical abatement levels. With these protections, we believe future CRTs from an eligible adipic acid abatement project will be completely additional.

[29] 17 California Code of Regulations § 95891

[30] Climate Action Reserve, "Nitric Acid Production Project Protocol Version 2.2."

4. Evaluation of Legal Requirements

Carbon offset credit must be for activities that are not currently required by regulation or covered under an existing carbon pricing regime. The following section evaluates existing or imminent regulations and regimes that could regulate N_2O emissions from adipic acid plants.

4.1. U.S. Regulations

Currently, there are no existing federal carbon pricing regulation (cap-and-trade or otherwise) in the United States. No adipic acid plants are located in jurisdictions with such regimes (e.g., California). We do not expect the current federal administration, headed by President Donald Trump, to pass any comprehensive GHG regulations in the near term. There may be regulations in the future pending the outcome of the 2020 presidential election; however, we believe it would be premature to speculate on the nature, coverage, or likelihood of any federal carbon pricing systems post-2020. Should comprehensive carbon regulations enter into-force during a Project crediting period, the Reserve would follow standard procedures and allow any Project to finish its respective crediting period but be ineligible for subsequent crediting period extensions.

Our regulatory review has determined that adipic acid plant N_2O emissions will fall under the same regulatory framework as nitric acid plant N_2O emissions (GHG emissions from major stationary sources). Accordingly, we are leveraging information from the Nitric Acid Protocol, which made the following findings:

1. There are no existing federal, state, or local regulations that requires nitric acid (or adipic acid) plants to abate N_2O emissions under typical circumstances.
2. If a facility triggers certain provisions under the Clean Air Act, they may be required to install some GHG abatement equipment. If this occurs, projects may become ineligible for offsets.

The following section, adapted directly from the Nitric Acid Protocol with some alterations, reviews the current status of GHG permitting under the Clean Air Act.

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").[31] 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

[31] 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

modifications resulting in GHG emission increases of 75,000 tons (approximately 68,000 MT) of CO_2e per year or more.[32]

However, in 2014, the Supreme Court struck down the Title V provision of the Tailoring Rule[33]; 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.

In 2012, an INVISTA adipic acid plant in Victoria, Texas was required to install GHG abatement technology following failure to procure appropriate PSD permits in 2004.[34] 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.

4.2. International Regulations

Although it may be possible to expand the protocol to Canada and Mexico in the future, both jurisdictions are undergoing substantial reviews of their national GHG emissions regulations, which may make it difficult to predict or evaluate the impact of emerging regulations on additionality and the legal requirements test. The first version of the Reserve's protocol will limit eligibility to the U.S.

5. Discussion of Protocol Composition

As previously discussed, the abatement measures for adipic acid production are extremely similar to those utilized in GHG abatement at nitric acid plants. Therefore, an Adipic Acid Protocol could be adapted directly from the existing Reserve-approved Nitric Acid Protocol.[35] We expect that the Reserve's existing best-practices for rigorous monitoring and quantification at nitric acid facilities to be similarly appropriate at adipic acid facilities.

The following protocol composition review shall therefore discuss the existing Nitric Acid Protocol, including any adaptive changes necessary for adipic acid facilities. In addition to the Nitric Acid Protocol,

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[32] 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.
[33] Utility Air Regulatory Group v. Environmental Protection Agency et. al., No. 12–1146 (Supreme Court of the United States June 23, 2019).
[34] "Greenhouse Gas Prevention of Significant Deterioration (PSD) Permit Application, INVISTA S.a.r.l. Victoria Plant," March 12, 2012, https://archive.epa.gov/region6/6pd/air/pd-r/ghg/web/pdf/invista_app.pdf.
[35] Climate Action Reserve, "Nitric Acid Production Project Protocol Version 2.2."

the CDM hosts an adipic-acid specific protocol (AM0021)[36], which will also be discussed to a lesser extent. Although AM0021 is directly relevant to adipic acid abatement, we believe it is most appropriate to utilize the existing methodologies that have already been approved by the Reserve.

5.1. Project Scope and Boundaries

5.1.1. Facility Age Eligibility

The Nitric Acid Production Protocol defines the project as the installation and operation of a N_2O abatement technology at a single Nitric Acid Plant ("NAP") that results in the reduction of N_2O emissions that would otherwise have been vented to the atmosphere. Projects are limited to existing, relocated or upgraded NAPs that can provide historical production levels and operating conditions so the project can meet the appropriate additionality constraints. We believe this project scope would be appropriate for Adipic Acid Plants ("AAPs").

The Reserve's Nitric Acid Protocol limits applicability to NAPs constructed before December 2nd, 2009 (corresponding to the publish date of the first version of the protocol), while the CDM adipic acid methodology limits applicability to AAPs that began commercial operation prior to December 31, 2004 (corresponding to the year prior to the methodology's first publication). We do not believe that the Adipic Acid Protocol should automatically make future facilities ineligible, because new facilities continue to lack any incentive to install control technology. However, new facilities would still be subject to the Legal Requirements Test and may be ineligible if they must abate GHGs under their Title V permit. The first version of the Protocol may limit eligibility to existing plants because more research would be necessary to establish an appropriate baseline for facilities with no emissions history.

5.1.2. Project Boundaries

The project boundary will be established in the protocol according to an evaluation of all sources, sinks and reservoirs (SSRs). This will be presented as a "GHG Assessment Boundary" figure and a table of all SSRs with details on each SSR, if they are included in or excluded from the project boundary, and if excluded, why. This figure and table should represent and include all elements that could potentially be a part of the project.

We believe the Adipic Acid Protocol will have the following SSRs included in the project boundary:

- N_2O from adipic acid production;
- CO_2 and/or CH_4 hydrocarbons used as reducing agents and/or reheating the off gas (project only); and
- CO_2, CH_4 and NO_2 for reheating the off gas before entering the tertiary catalyst or NSCR (project only).

Individual projects should have the opportunity to evaluate the project-specific suite of SSRs and exclude emissions if they can be proven to be de minimis or unchanged due to the project activity.

[36] UNFCCC/CCNUCC, "Approved Baseline and Monitoring Methodology AM0021, 'Baseline Methodology for Decomposition of N2O from Existing Adipic Acid Production Plants' Version 03."

We expect the following SSRs to be excluded from the Adipic Acid Protocol as in the Nitric Acid Protocol:

- Non-N_2O GHG emissions from adipic acid production (e.g., trace amounts of CO_2, CH_4);
- Emissions from production, transport, and de-commissioning eligible technologies and catalysts; and
- Emissions related to the production of hydrocarbons utilized in the project.

5.1.3. Geographical Boundaries

The first version of the adipic acid protocol would only apply to the United States. Expanding the protocol to Canada and Mexico may be permissible given additional research.

5.2. Quantifying GHG Emission Reductions

The amount of emissions reductions will be quantified by calculating the difference between the business as usual baseline and the emissions after the technologies have been put in place ("Project Emissions").

5.2.1. Standardized Baseline Calculations

Standardized baseline calculations could be adapted from the Nitric Acid Protocol and the CDM's AM0021. Baseline GHG emissions would be based on the existing quantity of N_2O in the off gas following currently installed N_2O abatement.

In order to ensure the baseline is conservative and represents only the incremental emissions reduced beyond historical levels, we also propose a Baseline Destruction Efficiency ("DE") that accounts for the destruction level prior to project implementation. As previously discussed in "Section 3.2.1 Baseline Setting", the DE would be the percent N_2O emissions destroyed during the year with the highest production levels in the past five years.

Additionally, the baseline will consider the average level of nitric acid (HNO_3), which is an input in the adipic acid production process, being recovered and recycled in the five years prior to the project start date. As discussed in Section 2.2, one potentially eligible technology would reduce virgin nitric acid input, which should be included as a project emission reduction. We expect the recycling rate to be zero in the baseline under most circumstances but recommend including a parameter to capture any facility-specific deviations and practices.

In general, baseline emissions reductions would be calculated using the following equation, with each parameter expanded and described in the full protocol:

$$BE = \left[\left(TE_{RP,N_2O} \times (1 - DE) \right) + (\mathrm{HNO}_{3\,Ratio} \times AA_{RP} \times EF_{N2O}) \right] \times GWP_{N2O}$$

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)*	*tN_2O*
DE	=	*Baseline N_2O destruction efficiency*	-
$HNO_{3\,Ratio}$	=	*Ratio of HNO_3 to AA*	*$tHNO_3$ / 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*

t = metric ton; AA = adipic acid

5.2.2. Project Emission Calculations

Project emissions come either from the off gas to an SCR de-NO_x unit and any emissions that were not destroyed by the eligible control technology. The project emissions will be characterized by the following equation, with each parameter expanded and described in the full protocol

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

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

5.2.3. Leakage

No leakage adjustment is included in the Nitric Acid Protocol. The CDM AM0021 includes a final leakage adjustment for steam produced outside of the project boundary and used at the AAP. Steam produced within the project boundary would already be captured in baseline and project calculations. We believe this adjustment will not be necessary in the U.S., as adipic acid plants rarely purchase steam.

6. Monitoring

Adipic acid facilities are already required to have a continuous emissions monitoring systems ("CEMS") for NO_x emissions testing under the Clean Air Act (40 CFR, Part 60). As in the Nitric Acid Protocol, the proposed Adipic Acid Protocol will apply 40 CFR Part 75 for added quality assurance / quality control and will implement CEMS upstream and downstream of N_2O abatement units to achieve real-time destruction efficiency data. CEMS are considered the industry standard for direct emissions monitoring and provide highly accurate and reliable data when installed and calibrated appropriately because they continuously measure a specific source.[37] CEMS are used in several Reserve-approved protocols; the Adipic Acid Protocol will include the same standard rigorous calibration, accuracy testing, and quality assurance/quality controls as the Nitric Acid Protocol.

As an example, the following items should be monitored and reported at the AAP:

- Metric tons of adipic acid produced
- Metric tons of nitric acid utilized and/or recycled
- Volume flow rate in the off gas during the reporting period by the control unit
- N_2O concentration in the off gas
- Operational hours in the reporting period
- Methane use

The final Protocol should include a comprehensive list of all reporting parameters and monitoring requirements based on detailed baseline and project calculations.

7. Environmental and Social Impacts

We do not expect an adipic acid GHG abatement project to have any direct or down-stream adverse environmental or social impacts. As discussed earlier in the paper, the abatement technology would neither increase secondary emissions, nor would it impact the production levels of the facility. The most likely secondary emission to be impacted by a project, NO_x, is already regulated under the CAA and facilities would face legal penalties for increasing above their emissions limit. As such, we expect projects to continue to run at a business-as-usual level, albeit with newly installed control technology.

[37] 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.

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