



**CLEAN DEVELOPMENT MECHANISM  
PROJECT DESIGN DOCUMENT FORM (CDM-PDD)  
Version 03 - in effect as of: 28 July 2006**

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**SECTION A. General description of project activity****A.1. Title of the project activity:**

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Title: N<sub>2</sub>O Abatement Project of Capro Corporation

Version: 1

Completion date: 19/10/2009

**A.2. Description of the project activity:**

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The proposed project is to reduce N<sub>2</sub>O emissions of the tail gas emitted from Caprolactam production process in Capro Corporation (hereinafter “Capro”) by installing catalytic N<sub>2</sub>O destruction system. The expected CERs from this project is approximately 665182(tCO<sub>2</sub>-eq./year). In Korea, there is no mandatory regulation related to N<sub>2</sub>O emission. Therefore, N<sub>2</sub>O emitted from Capro will be released continuously if the proposed project is not implemented.

The project site is owned by Capro, which is the only company in Republic of Korea that manufactures caprolactam, and it is used as a raw material for nylon fibers which is utilized in manufacture of clothing, tire cords, carpets, and engineering plastics to domestic market since 1974. There are three Plants manufacturing Caprolactam in Capro. However, only plant I and plant II are involved in the proposed project and commenced its commercial production from 4<sup>th</sup> May 1974 (Plant I) and 30<sup>th</sup> Dec 1988(Plant II) respectively (Commercial production is earlier than 31 December 2005). Existing production capacity of Capro is about 128609tons of caprolactam per year (Plant I: approximate 63271ton/yr, Plant II : approximate 65338tons/yr based on the maximum daily production and maximum operating days till 31 December 2005).

This project is developed by Hyosung Ebara Engineering Co., Ltd. (hereinafter “Hyosung”). Hyosung involves in this project as a project developer, an engineering company and co-financer as well. Hyosung has participated in environmental business, including water treatment, air pollution treatment and waste treatment since 1978. Especially, Hyosung under joint investment with Ebara Corporation, who is a leading company of the environmental field in Japan, has conducted R&D activities to lead the technological development in the Korean environmental industry. Recently, Hyosung has expanded its business areas to cover the advanced water purification facility, stream purification facility, denitrification & desphosphorization facility, plasma melting facility and VOCs & odor removal facility.

Nitrous oxide (N<sub>2</sub>O) in this project is generated by the side reaction of Ammonia oxidation reaction for producing Ammonium nitrite as a reagent for Hydroxylamine sulfate, one of intermediate products to prepare caprolactam, in Capro caprolactam production plant I and II.

NO<sub>x</sub> concentration in the tail gas emitted from Ammonium nitrite process has been reduced through NH<sub>3</sub> Selective Catalytic Reduction (NH<sub>3</sub>-SCR) technology even before this project, because NO<sub>x</sub> is one of the air pollutants under mandatory regulation in Korea. Therefore, Capro has been emitted N<sub>2</sub>O into atmosphere without any recovery and treatment, and has no plan to implement N<sub>2</sub>O abatement under such



situation if the proposed project would not be implemented as CDM. There is no economic incentive to recover and utilize or sell N<sub>2</sub>O as a product, technically and economically, except for CERs. In addition, there is no increase in the amount of production resulting from the proposed project. Therefore, without CERs, Capro will continue releasing N<sub>2</sub>O to the atmosphere under its normal operation (i.e., will continue the current practice).

For this project, the investigation is in process at present to seek the proper N<sub>2</sub>O abatement catalyst with at least 90% of high efficiency and longer-lasting effective lifetime. Therefore it is expected that advanced catalyst technology will be introduced to the Republic of Korea through this project.

N<sub>2</sub>O decomposition facility to load N<sub>2</sub>O abatement catalyst will be designed and equipped by Hyosung.

The financial benefits from the sale of CERs will be used to offset the capital and operating costs of the project to provide for its continued operation throughout the crediting period. Through the sale of CERs, Capro will also be able to improve its profitability, ensure employment and contribute to economic prosperity in the region. In these aspects, the project contributes to sustainable development.

### **A.3. Project participants:**

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<b>Name of Party involved(*) ((host) indicates a host Party)</b>	<b>Private and/or public entity(ies) Project participants(*) (as applicable)</b>	<b>Kindly indicate if the Party involved wishes to be considered as project participants (Yes/No)</b>
The Republic of Korea(host)	Capro Corporation Hyosung Ebara Engineering Co., Ltd.	No

(\*) In accordance with the CDM modalities and procedures, at the time of making the CDM PDD public at the stage of validation, a Party involved may or may not have provided its approval. At the time of requesting registration, the approval by the Party(ies) involved is required.

### **A.4. Technical description of the project activity:**

#### **A.4.1. Location of the project activity:**

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##### **A.4.1.1. Host Party(ies):**

&gt;&gt;

Republic of Korea

##### **A.4.1.2. Region/State/Province etc.:**

&gt;&gt;

Ulsan

##### **A.4.1.3. City/Town/Community etc.:**

&gt;&gt;

402-1, Bugok-dong, Nam-gu, Ulsan

**A.4.1.4. Details of physical location, including information allowing the unique identification of this project activity (maximum one page):**

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The geographic location of the Capro caprolactam production plant is shown in Figure 1. The plant is located in the south-eastern part of the Republic of Korea: the east longitude is about 129°19' and the north latitude is about 35°29'. The full address of this facility is 402-1, Bugok-dong, Nam-gu, Ulsan in Korea.



**Figure 1. The location of Capro caprolactam production plant**

**A.4.2. Category (ies) of project activity:**

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The project falls under UNFCCC sectoral scope 5: “Chemical industry”.

**A.4.3. Technology to be employed by the project activity:**

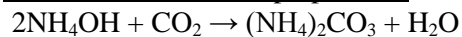
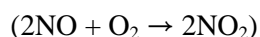
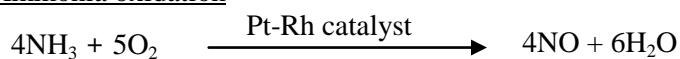
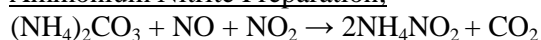
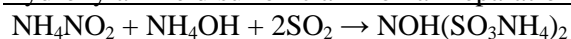
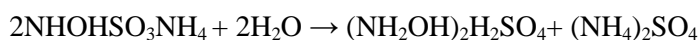
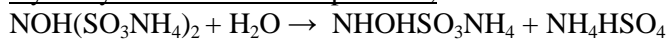
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Caprolactam is produced by cyclohexane, ammonia, and sulphur as its primary raw materials, and Ammonium sulfate comes out as a by-product, which is supplied as nitrogen fertilizer and a chemical feedstock for industrial uses.

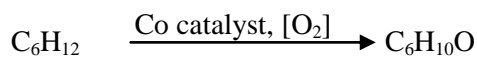
In Capro, the main process of caprolactam production is as follows:



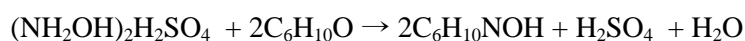
## 1. Hydroxylamine sulfate preparation ;

Ammonium carbonate preparationAmmonia oxidationAmmonium Nitrite Preparation:Hydroxylamine disulfonic ammonia Preparation:Hydroxylamine Sulfate Preparation:

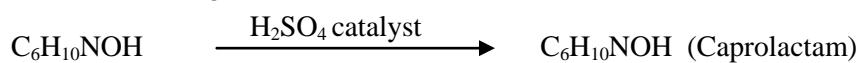
## 2. Cyclohexanone preparation



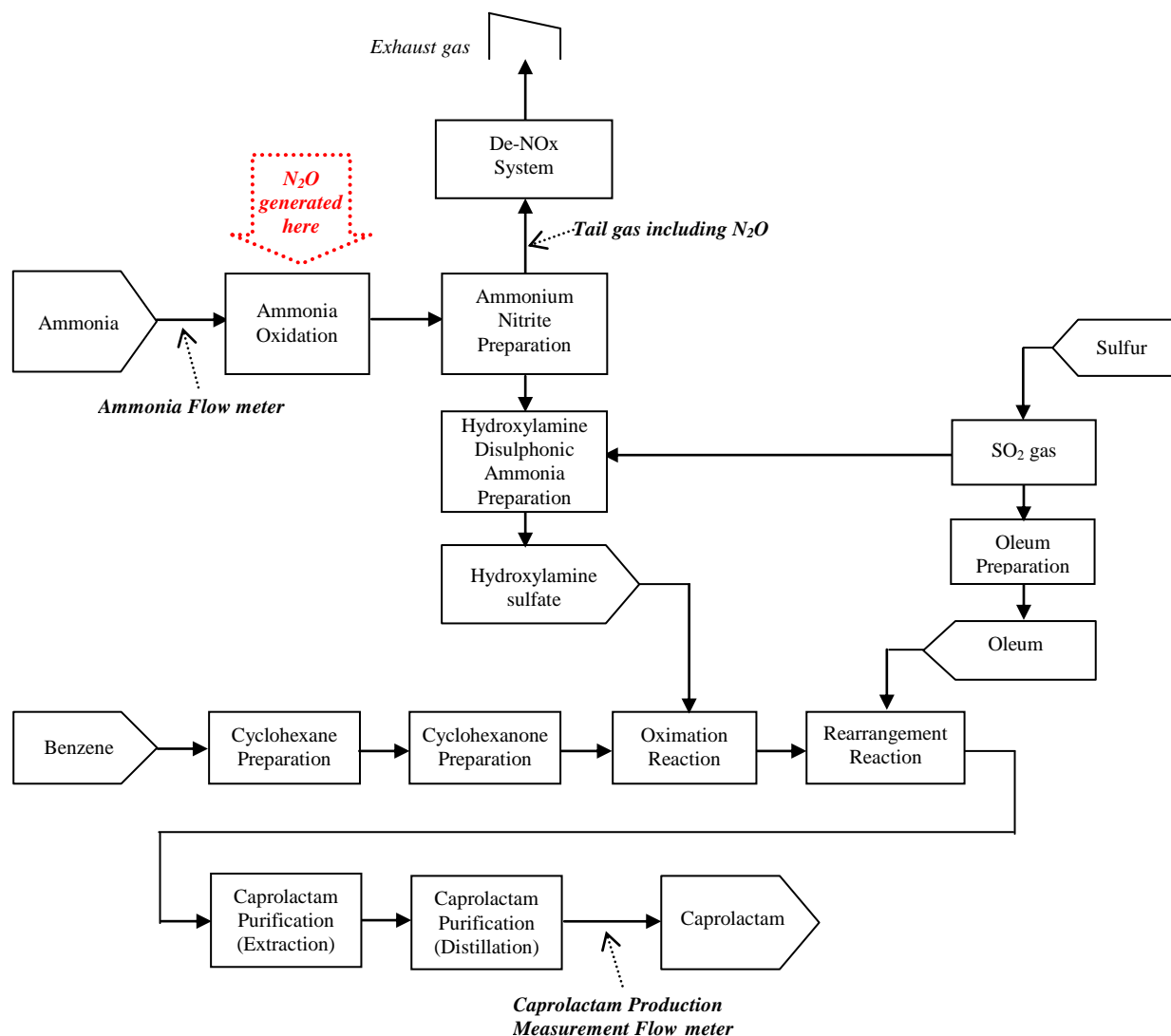
## 3. Oximation Reaction;



## 4. Beckmann rearrangement;



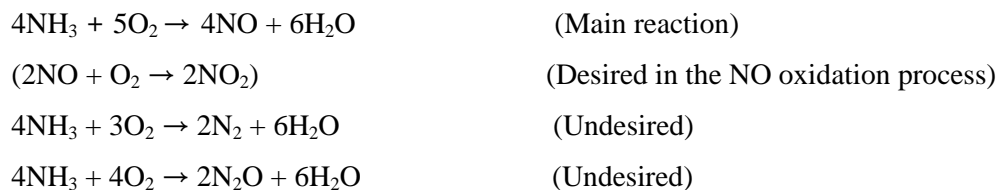
The block flow diagram for existed caprolactam production process of Capro is shown in Figure 2.



**Figure 2. Block flow diagram for caprolactam production process**

Nitrous oxide ( $N_2O$ ) is generated as an undesired by-product through side reaction of Ammonia oxidation. Ammonia oxidation reaction is originally for producing  $NO$  and  $NO_2$  to be reagents of Ammonium Nitrite, which is intermediate to derive Hydroxylamine sulphate preparation. Hydroxylamine sulphate is one of intermediate products to be a reagent for producing caprolactam.

Ammonia oxidation reaction to generates  $NO/NO_2$  gases and the side-reaction of Ammonia oxidation will be as follows:



There are two plants (Plant I, Plant II) involved in this project. As shown in Figure 3, each caprolactam production plant has two of AORs (Plant I: AOR-a, AOR-b, Plant II: AOR-c, AOR-d) in a parallel connection. In each plant, the total ammonia input flows through the one line with one flow meter, and that is supplied into both of two AORs equally. So, every plant has one flow meter for measuring ammonia input. The process of ammonia oxidizers for (a) Plant I, (b) Plant II is shown in Figure 3.

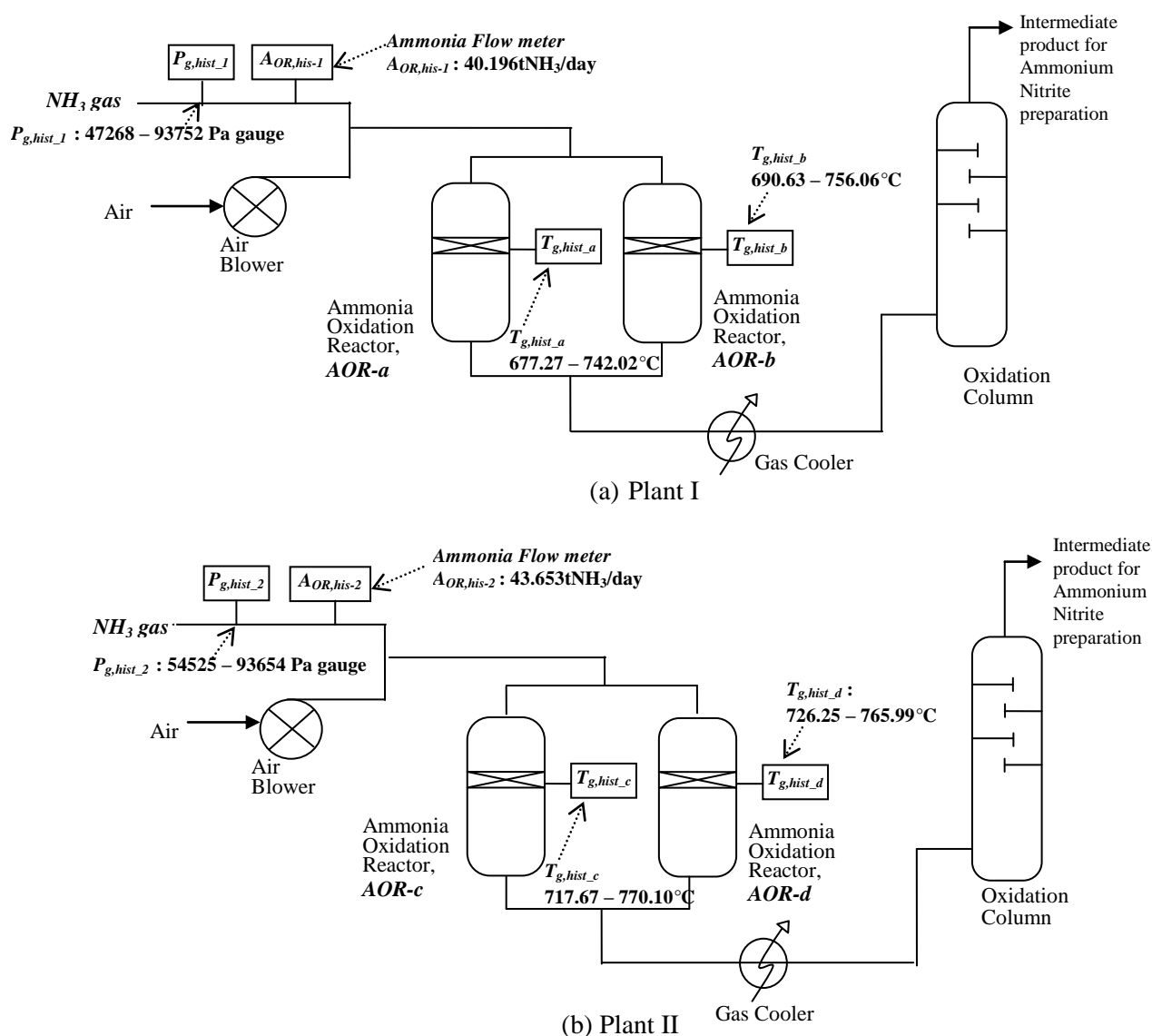
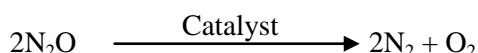


Figure 3. Overview of the process of ammonia oxidizer

Ammonium oxidation reaction is carried out by the reactor with Pt-Rh Catalyst gauze under the operating condition of about 47268~93752 Pa gauge and 677~770°C in Capro. More details of each operation temperature and pressure range of the ammonia oxidation reactors are shown in B.6.2 and Annex3 (: Baseline information).

According to plan for this project, tertiary type of the N<sub>2</sub>O abatement system will be installed to avoid any change in the existed production process of Capro. Also, no reductant input for N<sub>2</sub>O diminishing is technically intended. N<sub>2</sub>O will be catalytically decomposed on the De-N<sub>2</sub>O facility as follows:



The concept of N<sub>2</sub>O destruction facility designed by Hyosung is as shown in Figure 4. The same De-N<sub>2</sub>O process will be applied to Plant I and II. In order to save energy input, RTO (Regenerative Thermal Oxidizer) technology is adapted for the De-N<sub>2</sub>O reactor for this project. Therefore the De-N<sub>2</sub>O system can also function as a heat exchanger, not only as a degradation reactor. So, the N<sub>2</sub>O destruction facility designed by Hyosung is called “Regenerative Catalytic System”. Where, liquefied natural gas (LNG, hereafter “natural gas”) will be used as a re-heating the tail gas, not as a reductant.

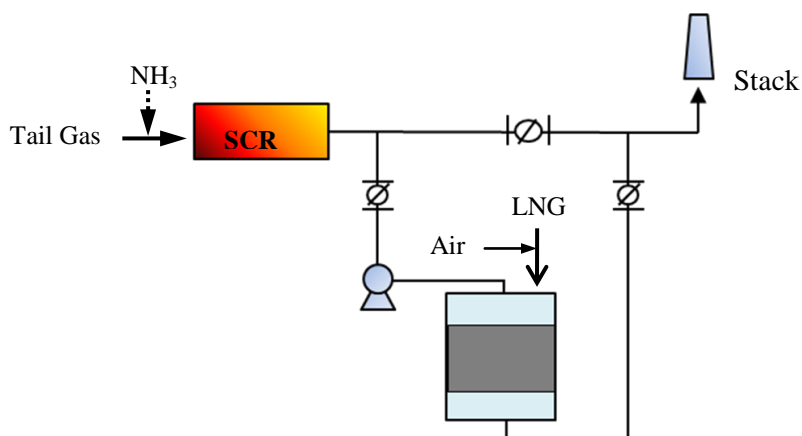


Figure 4. Overview of the De-N<sub>2</sub>O process in Plant I and II

**A.4.4. Estimated amount of emission reductions over the chosen crediting period:**

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Total ex-ante emissions reductions are estimated to be approximate 6651821 tonCO<sub>2</sub>e during ten-year crediting period. The annual emissions reductions are expected to be about 665182 tonCO<sub>2</sub>e. It is notable that the estimates of GHG emission reductions are made for reference purpose only and actual emissions reductions will be based on monitored data and may differ from this estimate. The estimated reductions during ten-year crediting period are shown in Table 1.





Table 1. Annual estimation of emission reductions

Years	Estimation of annual emission reductions in tonnes of CO <sub>2</sub> e
2010	665182
2011	665182
2012	665182
2013	665182
2014	665182
2015	665182
2016	665182
2017	665182
2018	665182
2019	665182
<b>Total estimated reductions</b>	<b>6651821 tCO<sub>2</sub>e/yr</b>
<b>Total number of crediting years</b>	<b>10 years</b>
<b>Annual average of the estimated reductions over the crediting period</b>	<b>665182 tCO<sub>2</sub>e/yr</b>

**A.4.5. Public funding of the project activity:**

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This project doesn't involve any public funding from Parties including in Annex 1.

**SECTION B. Application of a baseline and monitoring methodology****B.1. Title and reference of the approved baseline and monitoring methodology applied to the project activity:**

&gt;&gt;

Version 04.2 of AM0028 “Catalytic N<sub>2</sub>O destruction in the tail gas of Nitric Acid Plants or Caprolactam Production”

**B.2. Justification of the choice of the methodology and why it is applicable to the project activity:**

&gt;&gt;

AM0028(ver04.2) is applicable this proposed project activity, because the activity is to destroy N<sub>2</sub>O emission by catalytic decomposition of N<sub>2</sub>O in tail gas of caprolactam production plants including the ammonia oxidation reactor (AOR) where N<sub>2</sub>O is generated, and those plants of Capro satisfy the applicability conditions which is stipulated in AM0028(version 04.2).

The following sentences are to explain how the plants for proposed project activity meet each of 7 applicability conditions quoted in box.

**Applicability Condition 1**

The applicability is limited to the existing production capacity measured in tonnes of nitric acid or caprolactam, where the commercial production had began no later than 31 December 2005. Definition of “existing” production capacity is applied for the process with the existing ammonia oxidation reactor where N<sub>2</sub>O is generated and not for the process with new ammonia oxidizer. Existing production “capacity” is defined as the designed capacity, measured in tons of nitric acid or caprolactam per year.

The plant I and plant II in Capro have been operated to manufacture caprolactam as a product for market, since 4<sup>th</sup> May 1974 and 30<sup>th</sup> December 1988 respectively. Each plant has two ammonia oxidation reactors, which have been existed from the beginning installation for commercial production up to present. Therefore the existing production capacity of every plant (plant I and plant II in Capro) is equal to the product capacity measured until 31 December 2005.

In other words, the production capacity of every plant in this proposed project activity are considered as the existing production capacity and also as the designed capacity, because the opening date of each plant is no later than 31 December 2005 as mentioned at the provision of applicability condition, and all of ammonia oxidation reactors of these plants are keeping with the same as they were installed at the beginning. Therefore this proposed project activity meets “*Applicability condition 1*” of AM0028 (version 04.2).

Applicability Condition 2

Existing caprolactam plants are limited to those employing the Raschig process not using any external sources of nitrogen compounds other than feed ammonia.

The existing caprolactam plants for this proposed project activity employ Raschig process, which converts Ammonium carbonate to Ammonium nitrite through the reacting with Nitrogen oxide, and ammonium nitrite converted to hydroxylamine disulfonate and thence to hydroxylamine sulfate. And only feed ammonia is used as a nitrogen compound source in the Raschig process.

Therefore this proposed project activity satisfies the *Applicability Condition 2* of AM0028 (version 04.2).

Applicability Condition 3

The project activity will not result in shut down of an existing N<sub>2</sub>O destruction or abatement facility at the nitric acid or caprolactam production plant.

This proposed project activity will not result in shut down of existing N<sub>2</sub>O destruction or abatement facility at the caprolactam production plants in Capro, because there is no existing N<sub>2</sub>O destruction or abatement facility in Capro.

Consequently, this proposed project activity is not against *Applicability Condition 3* of AM0028 (version 04.2).

Applicability Condition 4

The project activity shall not affect the nitric acid or caprolactam production level.

The De-N<sub>2</sub>O technology for this project is specified for applying to tail gas treatment process in order to attain the goal without any effect on the caprolactam produce process. Accordingly the De-N<sub>2</sub>O treatment process for this proposed project activity should not be an immediate cause of the change in the caprolactam production level.

In addition, if caprolactam production capacity will be expanded in the future because of the growing demand for caprolactam, the variation of N<sub>2</sub>O reduction amount by increased production level shall not be accounted as a result of this proposed project activity.

It thus appears that this project activity corresponds to *Applicability Condition 4* of AM0028 (version 04.2).

Applicability Condition 5

The project activity will not cause an increase in NO<sub>x</sub> emissions.



The De-N<sub>2</sub>O equipments to be installed at the Plant I and Plant II in Capro are designed not to affect NO<sub>x</sub> emissions.

Moreover, the NO<sub>x</sub> amount emitted to the atmosphere from the stack shall be observed and controlled for the strong mandatory regulation for NO<sub>x</sub> restriction in Korea. So, even though the increase of NO<sub>x</sub> emission would be induced by the project activity, the NO<sub>x</sub> emission shall be adjusted until the permitted level as low as that before the project activity.

Accordingly, this project activity corresponds to *Applicability Condition 5* of AM0028 (version 04.2).

*Applicability Condition 6*

In case a De-NO<sub>x</sub> unit is already installed prior to the start of the project activity, the installed De-NO<sub>x</sub> is a Selective Catalytic Reduction (SCR) De-NO<sub>x</sub> unit.

De-NO<sub>x</sub> units are already installed at the all plants in Capro before the start of the project activity in order to observe the NO<sub>x</sub> regulation, and these units are applied with the Selective Catalytic Reduction system.

Therefore, the project activity condition related to De-NO<sub>x</sub> unit conforms to the *Applicability Condition 6* of AM0028 (version 04.2).

*Applicability Condition 7*

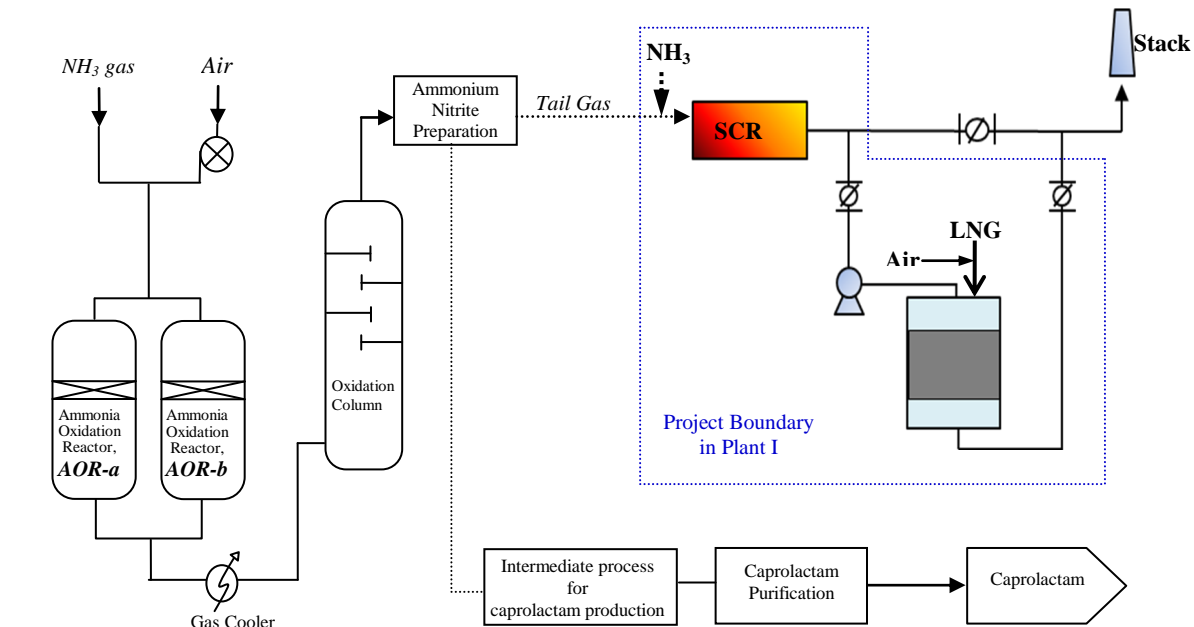
The N<sub>2</sub>O concentration in the flow at the inlet and the outlet of the catalytic N<sub>2</sub>O destruction facility is measurable.

The real time Automated Measuring Systems (AMS) are intended to be equipped at the points just before and after the De-N<sub>2</sub>O catalytic systems at the all plants in Capro for this proposed project activity, and so there are no facilities to generate N<sub>2</sub>O after De-N<sub>2</sub>O unit until stack.

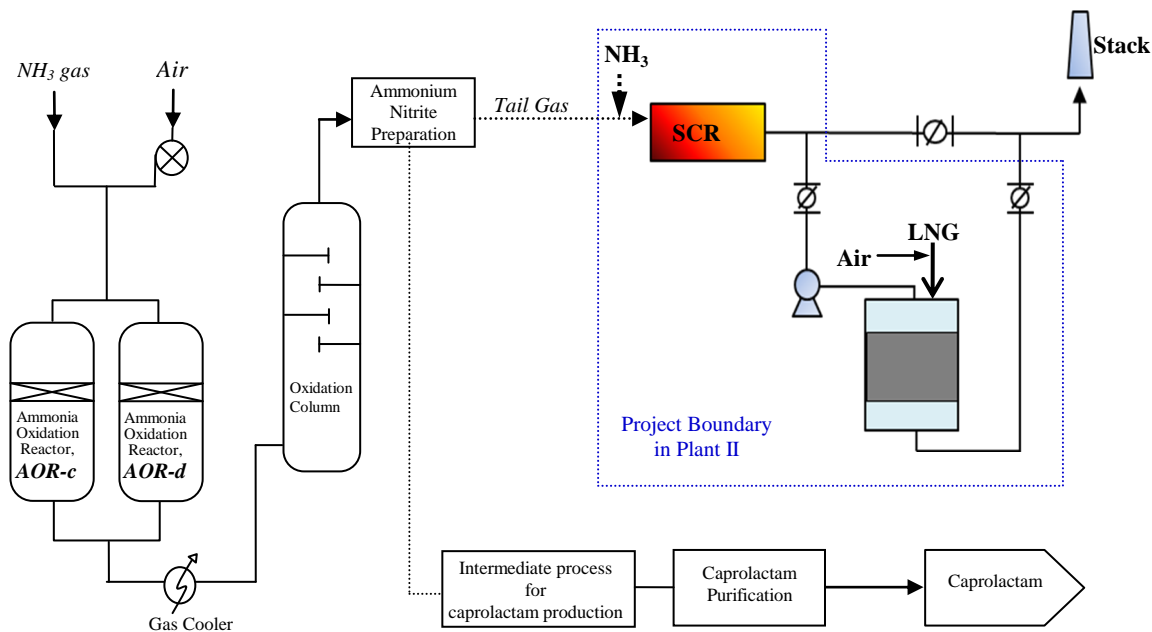
The *Applicability Condition 7* of AM0028 (version 04.2) is adequate for this proposed project activity.

**B.3. Description of the sources and gases included in the project boundary:**

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(a) Plant I



(b) Plant II

**Figure 5. The flow diagrams of the project boundary**



	Source	Gas	Included	Justification/ Explanation
Baseline	Emissions of N <sub>2</sub> O as a result of side reaction to the caprolactam production process	N <sub>2</sub> O	Included	Main emission source, taking national N <sub>2</sub> O emission regulations into account.
	Emissions related to the production of ammonia used for NO <sub>x</sub> reduction	CO <sub>2</sub> CH <sub>4</sub> N <sub>2</sub> O	Included	Since SCR De-NO <sub>x</sub> unit is already installed prior to the project start: ammonia input for SCR is considered to be of the same magnitude to project related ammonia input for NO <sub>x</sub> reduction. Baseline emissions and project emissions are similar and therefore not considered for calculation.
	N <sub>2</sub> O emissions from SCR De-NO <sub>x</sub> -unit	N <sub>2</sub> O	Excluded	The presence of an SCR De-NO <sub>x</sub> unit tends to increase the N <sub>2</sub> O emissions. Therefore the <i>ex-post</i> measurement of the baseline emissions at the inlet of the N <sub>2</sub> O destruction facility represents a conservative determination of the baseline N <sub>2</sub> O emissions.
Project Activity	Emissions of N <sub>2</sub> O as a result of side reaction to the caprolactam production process	N <sub>2</sub> O	Included	Main emission source, taking national N <sub>2</sub> O emission regulations into account.
	Emissions related to the production of ammonia used for NO <sub>x</sub> reduction	CO <sub>2</sub> CH <sub>4</sub> N <sub>2</sub> O	Included	Since SCR De-NO <sub>x</sub> unit is already installed prior to the project start, ammonia input for SCR is considered to be of the same magnitude to project related ammonia input for NO <sub>x</sub> reduction. Baseline emissions and project emissions are similar and therefore not considered for calculation.
	In case of N <sub>2</sub> O reduction process installed: Emissions at the project site resulting from hydrocarbons used as reducing agent and/or re-heating the tail gas	CH <sub>4</sub> and/or CO <sub>2</sub>	Included	Hydrocarbon as reducing agent does not used for this project activity Only Natural gas is additionally used as fuel to increase the temperature of tail gas to strengthen activity of the De-N <sub>2</sub> O catalyst. The unconverted methane fraction of Natural gas is counted.
	Emissions from electricity demand for equipment such as fans	CO <sub>2</sub> CH <sub>4</sub> N <sub>2</sub> O	Excluded	GHG emissions related to the electricity consumption are insignificant, and are excluded as monitoring would lead to unreasonable costs.
	Emissions related to the production of the hydrocarbons	CO <sub>2</sub> CH <sub>4</sub> N <sub>2</sub> O	Excluded	GHG emissions related to the production of hydrocarbons used as reducing agent represent less than 0.001% of expected emission reductions and will not be taken into account due to unreasonable costs for monitoring.

**B.4. Description of how the baseline scenario is identified and description of the identified baseline scenario:**

&gt;&gt;

The baseline scenario is identified in accordance in AM0028 (version 0.4) by steps as follows:

***Step 1: Identify technically feasible baseline scenario alternatives to the project activity***

***Step 1a: The baseline scenario alternatives should include all possible options that are technically feasible to handle N<sub>2</sub>O emissions. These options are, inter alia:***

- (1) Status quo: The continuation of the current situation, where there will be no installation of technology for the destruction or abatement of N<sub>2</sub>O;
- (2) Switch to alternative production method not involving ammonia oxidation process;
- (3) Alternative use of N<sub>2</sub>O such as:
  - o Recycling of N<sub>2</sub>O as a feedstock for the plant;
  - o The use of N<sub>2</sub>O for external purposes.
- (4) Installation of a Non-Selective Catalytic Reduction (NSCR) De-NO<sub>x</sub> unit
- (5) The installation of an N<sub>2</sub>O destruction or abatement technology:
  - o Tertiary measure for N<sub>2</sub>O destruction;
  - o Primary or secondary measures for N<sub>2</sub>O destruction or abatement.

All of these options subscribed as *step 1a* are *technically* feasible as alternatives for the baseline scenario.

***Step 1b: In addition to the baseline scenario alternatives of Step 1a, all possible options that are technically feasible to handle NO<sub>x</sub> emissions should be considered. The installation of a NSCR De-NO<sub>x</sub> unit could also cause N<sub>2</sub>O emission reduction. Therefore NO<sub>x</sub> emission regulations have to be taken into account in determining the baseline scenario. The respective options are, inter alia:***

- (6) The continuation of the current situation, where either a De-NO<sub>x</sub>-unit is installed or not;
- (7) Installation of a new Selective Catalytic Reduction (SCR) De-NO<sub>x</sub> unit;
- (8) Installation of a new Non-Selective Catalytic Reduction (NSCR) De-NO<sub>x</sub> unit;
- (9) Installation of a new tertiary measure that combines NO<sub>x</sub> and N<sub>2</sub>O emission reduction.

All of these options subscribed as *step 1b* are technically feasible as alternatives for the baseline scenario.

***Step 2: Eliminate baseline alternatives that do not comply with legal or regulatory requirements***

In the Republic of Korea, there are no regulations or legal requirements dealing with restricting N<sub>2</sub>O emissions and/or recycling N<sub>2</sub>O released from production process for the present. Therefore all nominated *technically* feasible alternatives subscribed as *step 1.a* are not against laws.

Even though strong legal limitation of NO<sub>x</sub> is existed in the Republic of Korea, there is no technical limitation for NO<sub>x</sub> treatment, and so the all *Step 1b*-options for handle NO<sub>x</sub> are fully under the legal requirement.

In conclusion, the all of technically feasible baseline options taken through “step 1” are not eliminated at *Step 2*.

***Step 3: Eliminate baseline alternatives that face prohibitive barriers (barrier analysis)***

***Sub-Step 3a: On the basis of the alternatives that are technically feasible and in compliance with all legal and regulatory requirements, the project participant should establish a complete list of barriers that would prevent alternatives to occur in the absence of CDM. Barriers should include, among others:***

- Investment barriers, *inter alia*:
  - o Debt funding is not available for this type of innovative project activity;
  - o No access to international capital markets due to real or perceived risks associated with domestic or foreign direct investment in the country where the project activity is to be implemented.
- Technological barriers, *inter alia*:
  - o Technical and operational risks of alternatives;
  - o Technical efficiency of alternatives (e.g. N<sub>2</sub>O destruction, abatement rate);
  - o Skilled and/or properly trained labour to operate and maintain the technology is not available and no education/training institution in the host country provides the needed skill, leading to equipment disrepair and malfunctioning;
  - o Lack of infrastructure for implementation of the technology.
- Barriers due to prevailing practice, *inter alia*:
  - o The project activity is the “first of its kind”: No project activity of this type is currently operational in the host country or region.





- Investment barriers, *inter alia*:

Considering that there is no profit but for CERs from N<sub>2</sub>O abatement activity at the caprolactam production plant, and that there is no mandatory regulation for N<sub>2</sub>O emission in the Republic of Korea, it is economically unreasonable and unnecessary that introducing N<sub>2</sub>O destruction or abatement technology, or replacing the existed production method to the new one. Because the considerable initial investment costs is required for such as large scale facilities, and/or the enormous economic loss form shutdown is also expected during installation for new production method. Therefore the *option (2)*: switch to alternative production method not involving ammonia oxidation process), and the *option (5)*: the installation of an N<sub>2</sub>O destruction or abatement technology) are eliminated, even if they are technically feasible.

N<sub>2</sub>O is not a component which can be used as a feedstock for producing caprolactam. Besides there is no legal enforcement of recycling N<sub>2</sub>O emitted from the caprolactam production process in the Republic of Korea. Therefore there is no reason to recover N<sub>2</sub>O without the economic gains by selling N<sub>2</sub>O for external purposes. However comparing with the expected profit from N<sub>2</sub>O market, excessive cost is required to recover concentrated enough N<sub>2</sub>O to be valuable from the highly diluted tail gas of the process. (It may be less than 0.2% volume that the concentration of N<sub>2</sub>O in the tail gas of caprolactam production plants in Capro.) Accordingly, it is so difficult to lead the investment to introduce technology for alternative use of N<sub>2</sub>O that the *option (3)* mentioned in step1 is eliminated.

Capro has already satisfied the legally permitted NO<sub>x</sub> emission level with SCR type De-NO<sub>x</sub> units before considering this proposed project. And the existed SCR type units in Capro are durable enough at present. Therefore it doesn't need to install new SCR unit for this proposed project. So, "Option (7): Installation of a new SCR De-NO<sub>x</sub> unit" is cancelled.

As for NSCR-type De-NO<sub>x</sub> unit, it is not necessary to replace the existed SCR type with NSCR-type for the purpose of NO<sub>x</sub> emission control, unless the existed SCR type unit is so much worse for working as that should be disposed, and at the same time NSCR type unit are economically feasible and technically reliable enough to be introduced. However the performance of existed SCR type De-NO<sub>x</sub> units is considered as good as the existed SCR units can be sustainable at least for the crediting period of the proposed project. In addition, NSCR type is not so much economically attractive as replace exist SCR units, because the initial cost for installing new NSCR-type De-NO<sub>x</sub> unit is huge. In operating NSCR-type De-NO<sub>x</sub> unit, larger amount of natural gas is required, thereby increasing CO<sub>2</sub> emission, than SCR type De-NO<sub>x</sub> units. As a result, there is no economically feasible reason to install new NSCR to replace the existed SCR unit. In other world, *option (4)* and *(8)* among the technically feasible options in Step 1 are eliminated.

From the economical feasibility of view, as mentioned above, there is no compulsory reason to install any units including tertiary type in order to reduce N<sub>2</sub>O emission. And it doesn't have to introduce a new installation, regardless of the type of units, for NO<sub>x</sub> emission reduction, because SCR De-NO<sub>x</sub> unit, kind of tertiary measure, is already existed for each involved plant to this project. Accordingly *option (9)* in *step 1* is removed from feasible baseline options.



***Sub-Step 3b: Show that the identified barriers would not prevent the implementation of at least one of the alternatives (except the proposed CDM project activity):***

It can be concluded that only the continuation of current practice such as option (1) and (6) is considered as feasible alternative to be baseline scenario, since it does not face any barriers.

***Step 4: Identify the most economically attractive baseline scenario alternative***

***Sub-Step 4a: Determine appropriate analysis method::***

Since, the continuation of current practice, remaining project alternative, generate no financial or economic benefits other than CDM related income, the simple cost analysis (Option I) is applied.

***Sub-Step 4b: Option I: Apply simple cost analysis:***

All alternatives including the proposed project activity but for the continuation of the current practice require substantial investment, and corresponding returns cannot be anticipated except for CER. The investment costs consist of the engineering, construction, shipping, erection, installation and commissioning of the De-N<sub>2</sub>O unit, *etc.* and thus continuation of current practice is apparently the most attractive course of action because other options need considerable investment.

***Sub-step 4c: Option II: Apply investment comparison analysis:***

Not applicable

***Sub-step 4d: Sensitivity analysis (only applicable to Option II)***

Not applicable

***Step 5: Re-assessment of Baseline Scenario in course of proposed project activity's lifetime***

At the start of a crediting period, a re-assessment of the baseline scenario due to new or modified NO<sub>x</sub> or N<sub>2</sub>O emission regulations should be executed as follows:

***Sub Step 5a: New or modified NO<sub>x</sub>-emission regulations***

If new or modified NO<sub>x</sub> emission regulations are introduced after the project start, determination of the



baseline scenario will be re-assessed at the start of a crediting period. Baseline scenario alternatives to be analyzed should include, *inter alia*:

- Selective Catalytic Reduction (SCR);
- Non-Selective Catalytic Reduction (NSCR);
- Tertiary measures incorporating a selective catalyst for destroying N<sub>2</sub>O and NO<sub>x</sub> emissions;
- Continuation of baseline scenario.

For the determination of the adjusted baseline scenario the project participant should re-assess the baseline scenario and shall apply baseline determination process as stipulated above (Steps 1 – 5).

***Sub Step 5b: New or modified N<sub>2</sub>O-emission regulations***

If legal regulations on N<sub>2</sub>O emissions are introduced or changed during the crediting period, the baseline emissions shall be adjusted at the time the legislation has to be legally implemented.

**B.5. Description of how the anthropogenic emissions of GHG by sources are reduced below those that would have occurred in the absence of the registered CDM project activity (assessment and demonstration of additionality):**

>>

The additionality of this proposed project activity is assessed and demonstrated using all of the steps indicated in the version 5.2 of “Tool for the demonstration and assessment of additionality (hereafter ‘Additionality Tool’)” in compliance with AM0028 (version 04.2) as follows ;

**Step 1 of the Additionality Tool  
: Identification of alternatives to the project activity consistent with current laws and regulations**

According to AM0028 (version 04.2), *step 1* of the ‘Additionality Tool’ can be ignored, because of the similarity of both approaches used to determine the baseline scenario and the additionality tool.

**Step 2 of the Additionality Tool  
: Investment analysis**

**Sub-step 2a: Determine appropriate analysis method**

Simple cost analysis (*Option I*) is applied, because this project activity doesn’t make any profit but CER, even though the installation of De-N<sub>2</sub>O unit is required considerable investment.

**Sub-step 2b: Option I. Apply simple cost analysis**

All alternatives including the proposed project activity including the proposed project activity but for the continuation of the current practice require substantial investment, and corresponding returns cannot be



anticipated except for CER. The investment costs consist of the engineering, construction, shipping, erection, installation and commissioning of the De-N<sub>2</sub>O unit, *etc.* and thus continuation of current practice is apparently the most attractive course of action because other options need considerable investment.

<b>Step 3 of the Additionality Tool</b> <b>: Barrier analysis</b>
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The assessment result of barrier analysis according to step 3 in ‘Additionality Tool’ is same as Step 3 of Section B.4.

<b>Step 4 of the Additionality Tool</b> <b>: Common practice analysis</b>
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**Sub-step 4a: Analyze other activities similar to the proposed project activity:**

There are no other activities similar to the proposed project activity (not under CDM). The caprolactam production facilities in Asian countries analyzed are listed below;

- Navoiyazot, Chirchik Plant in Uzbekistan
- Gujarat State Fertilizers, Baroda Plant in India
- Gujarat State Fertilizers, Vadodara Plant in India
- Fertilizers and Chemicals Travancore, Karala Plant in India
- China Petrochemical Development, Siaogang Plant in Taipei China
- China Petrochemical Development, Kaohsiung Plant in Taipei China
- Yingshan Petrochemical, Yueyang Plant in China
- Baling Petrochemical, Yueyang Plant in China
- DSM Nanjing Chemical, Nanjing Plant in China
- Heibei Northern Chemical, Shijiazhuang Plant in China

**Sub-step 4b: Discuss any similar Options that are occurring:**

There are no similar options occurring in the Republic of Korea, because Capro is only company to produce caprolactam in the Republic of Korea. Recently, the similar project to abate N<sub>2</sub>O emitted from caprolactam production plant is registered as a CDM project hosted by Thailand and thus this project is not a common practice.

In conclusion, this proposed project is estimated to be additional.

**B.6. Emission reductions:****B.6.1. Explanation of methodological choices:**

&gt;&gt;

**1. Project Emissions**

Project emissions are defined by the following equation:

$$PE_y = PE_{ND,y} + PE_{DF,y} \quad (1)$$

Where:

$PE_y$  : Project emissions in year y (tCO<sub>2</sub>e)

$PE_{ND,y}$  : Project emissions from N<sub>2</sub>O not destroyed in year y (tCO<sub>2</sub>e)

$PE_{DF,y}$  : Project emissions related to the operation of the destruction facility in year y (tCO<sub>2</sub>e)

The term of  $PE_{ND,y}$  is for a) the emissions of not destroyed N<sub>2</sub>O after passing through the catalytic abatement system, and the other term of  $PE_{ND,y}$  is for b) emissions from auxiliary ammonia and hydrocarbons input resulting from the operation of the N<sub>2</sub>O destruction facility.

**a) N<sub>2</sub>O emissions not destroyed by the project activity ( $PE_{ND,y}$ )**

The emissions of non destroyed N<sub>2</sub>O are given by:

$$\begin{aligned} PE_{ND,y} &= PE_{N2O,y} \times GWP_{N2O} \\ &= \left( \sum_i^n F_{TE,i} \times CO_{N2O,i} \times M_i \right) \times GWP_{N2O} \end{aligned} \quad (2)$$

Where:

$PE_{ND,y}$  : Project emissions from N<sub>2</sub>O not destroyed in year y (tCO<sub>2</sub>e)

$PE_{N2O,y}$  : Project emissions of N<sub>2</sub>O in year y (tN<sub>2</sub>O)

$GWP_{N2O}$  : Global warming potential of N<sub>2</sub>O = 310

$F_{TE,i}$  : Volume flow rate at the exit of the destruction facility during interval  $i$  (Nm<sup>3</sup>/h)

$CO_{N2O,i}$  : N<sub>2</sub>O concentration in the tail gas of the N<sub>2</sub>O destruction facility during interval  $i$  (tN<sub>2</sub>O/Nm<sup>3</sup>)

$M_i$  : Length of measuring interval  $i$  (h)

$i$  : Interval

$n$  : Number of intervals during the year

**b) Project emissions from the operation of the destruction facility ( $PE_{DF,y}$ )**

The emissions related to the operation of the N<sub>2</sub>O destruction facility are given by (i) upstream emissions related to the production of ammonia used as input and (ii) on-site emissions due to the hydrocarbons use as input to the N<sub>2</sub>O destruction facility:

$$PE_{DF,y} = PE_{NH_3,y} + PE_{HC,y} \quad (3)$$

Where:

$PE_{DF,y}$  : Project emissions related to the operation of the destruction facility in year y (tCO<sub>2</sub>e)

$PE_{NH_3,y}$  : Project emissions related to ammonia input to destruction facility in year y (tCO<sub>2</sub>e)

$PE_{HC,y}$  : Project emissions related to hydrocarbon input to re-heater in year y (tCO<sub>2</sub>e)

The term of  $PE_{NH_3,y}$  is for (i) upstream emissions related to the production of ammonia used as input, and the other term of  $PE_{HC,y}$  is for (ii) on-site emissions due to the hydrocarbons use as input to the N<sub>2</sub>O destruction facility.

**(i) Upstream emissions of Ammonia Input to the Destruction Facility ( $PE_{NH_3,y}$ )**

On the basis of AM0028(version 4.2), the project ammonia input should be considered equal to the ammonia input of the baseline scenario, in case SCR De-NO<sub>x</sub> unit is already existed prior to the starting date of the project activity. That is to say, in case this project, it doesn't have to be calculated that the project emissions related to producing ammonia to be fed for operating SCR De-NO<sub>x</sub> unit, because that will be offset by the baseline emissions caused by producing ammonia for the same purpose as in the project activity. Consequently, the emissions related to the operation of the N<sub>2</sub>O destruction facility ( $PE_{DF,y}$ ) are equal to the on-site project emissions by hydrocarbon Input ( $PE_{HC,y}$ ).

$$PE_{DF,y} = PE_{HC,y} \quad (4)$$

**(ii) On-site project emissions by Hydrocarbon Input ( $PE_{HC,y}$ )**

Hydrocarbons can be used as reducing agent and/or re-heating the tail gas to enhance the catalytic N<sub>2</sub>O reduction efficiency. In this case hydrocarbons are mainly converted to CO<sub>2</sub> ( $HCE_{C,y}$ ), while some methane remain unconverted to CO<sub>2</sub> ( $HCE_{NC,y}$ ).

The emissions by hydrocarbon input are given by:

$$PE_{HC,y} = HCE_{C,y} + HCE_{NC,y} \quad (5)$$

Where:

$PE_{HC,y}$  : Project emissions related to hydrocarbon input to re-heater in year y (tCO<sub>2</sub>e)

$HCE_{C,y}$  : Converted hydrocarbons emissions in year y (tCO<sub>2</sub>)

$HCE_{NC}$  : Methane emissions in year y (tCO<sub>2</sub>e)



In this project, natural gas is used for re-heating the tail gas to enhance the catalytic N<sub>2</sub>O reduction efficiency.

For calculation of the GHG emissions related to the unconverted natural gas, the following formulae are used:

$$HCE_{NC,y} = \rho_{CH_4} \times Q_{CH_4,y} \times GWP_{CH_4} \times (1 - OXID_{CH_4}/100) \quad (6)$$

Where:

$HCE_{NC,y}$  : Methane emissions from unconverted natural gas in year y (tCO<sub>2</sub>e)

$\rho_{CH_4}$  : Methane density (t/m<sup>3</sup>)

$Q_{CH_4,y}$  : Methane used in year y (Nm<sup>3</sup>/yr)

$GWP_{CH_4}$  : Global warming potential of methane

$OXID_{CH_4}$  : Oxidation factor of methane (%)

GHG emissions resulted from converted natural gas is calculated as follows:

$$HCE_{C,y} = (\rho_{HC} \times Q_{HC,y} \times EF_{HC} \times OXID_{HC}/100) + (\rho_{CH_4} \times Q_{CH_4,y} \times EF_{CH_4} \times OXID_{CH_4}/100) \quad (7)$$

Where:

$HCE_{C,y}$  : Converted Natural gas emissions in year y (tCO<sub>2</sub>e)

$\rho_{HC}$  : Hydrocarbon density (t/m<sup>3</sup>)

$Q_{HC,y}$  : Hydrocarbon, with two or more molecules of carbon, input in year y (Nm<sup>3</sup>/yr)

$EF_{HC}$  : CO<sub>2</sub> emissions factor of hydrocarbon (tCO<sub>2</sub>/t HC), with two or more molecules of carbon

$OXID_{HC}$  : Oxidation factor of hydrocarbon (%), with two or more molecules of carbon.

$EF_{CH_4}$  : CO<sub>2</sub> emissions factor of CH<sub>4</sub> (tCO<sub>2</sub>/t HC).

(iii) The project emissions from the operation of the destruction facility ( $PE_{DF,y}$ )

As mentioned above, the project emissions from the operation of the destruction facility ( $PE_{DF,y}$ ) is calculated by the equation (3) :

$$PE_{DF,y} = PE_{NH_3,y} + PE_{HC,y} \quad (3)$$

The equation (3) can be rearranged to be the equation (8) with integrating the equations from (4) to (7) as follows:

$$\begin{aligned} PE_{DF,y} &= PE_{HC,y} \\ &= HCE_{C,y} + HCE_{NC,y} \\ &= [(\rho_{HC} \times Q_{HC,y} \times EF_{HC} \times OXID_{HC}/100) + (\rho_{CH_4} \times Q_{CH_4,y} \times EF_{CH_4} \times OXID_{CH_4}/100)] \\ &\quad + [\rho_{CH_4} \times Q_{CH_4,y} \times GWP_{CH_4} \times (1 - OXID_{CH_4}/100)] \end{aligned} \quad (8)$$

**c) Project emissions ( $PE_y$ )**

As previously stated, the project emissions ( $PE_y$ ) are accounted by the equation (1) ;

$$PE_y = PE_{ND,y} + PE_{DF,y} \quad (1)$$

Here, the equation (1) can be adapted for (9) through combining the equation (2) and (8)

$$\begin{aligned} PE_y &= PE_{ND,y} + PE_{DF,y} \\ &= \left( \sum_i^n F_{TE,i} \times CO_{N2O,i} \times M_i \right) \times GWP_{N2O} \\ &\quad + [(\rho_{HC} \times Q_{HC,y} \times EF_{HC} \times OXID_{HC}/100) + (\rho_{CH4} \times Q_{CH4,y} \times EF_{CH4} \times OXID_{CH4}/100)] \\ &\quad + [\rho_{CH4} \times Q_{CH4,y} \times GWP_{CH4} \times (1-OXID_{CH4}/100)] \end{aligned} \quad (9)$$

**2. Baseline Emissions**

Baseline emissions are given by the following equation:

$$BE_y = BE_{N2O} \times GWP_{N2O} \quad (10)$$

Where:

$BE_y$  : Baseline emissions in year y (tCO<sub>2</sub>e)

$BE_{N2O,y}$  : Baseline emissions of N<sub>2</sub>O in year y (tN<sub>2</sub>O)

$GWP_{N2O}$  : Global warming potential of N<sub>2</sub>O = 310

However, baseline emissions are limited to the design capacity of the existing caprolactam production plant.

**a) Baseline emissions of N<sub>2</sub>O ( $BE_{N2O,y}$ )**

As defined in B.4, the continuation of current practice is considered as a baseline scenario for this project, because there is no compulsory reason to install any N<sub>2</sub>O emission reduction unit, and SCR De-NO<sub>x</sub> unit is already existed prior to considering this project. Therefore the baseline scenario for this project corresponds to “**Case I**” as shown below:

**Case I**

The most plausible baseline scenario is that no N<sub>2</sub>O would be abated in the absence of the project activity (i.e. no secondary or tertiary reductions measures and no NSCR De-NO<sub>x</sub> unit would be installed).





So, the baseline N<sub>2</sub>O emissions ( $BE_{N_2O}$ ) are calculated by indication corresponding to “Case I” as shown below:

$$BE_{N_2O,y} = QI_{N_2O,y} \quad (11)$$

Where:

$BE_{N_2O,y}$  : Baseline emissions of N<sub>2</sub>O in year y (tN<sub>2</sub>O)

$QI_{N_2O,y}$  : Quantity of N<sub>2</sub>O supplied to the destruction facility in year y (tN<sub>2</sub>O)

The quantity of N<sub>2</sub>O supplied to the N<sub>2</sub>O destruction facility is calculated based on continuous measurement of the tail gas volume flow rate and the N<sub>2</sub>O concentration at the inlet of the N<sub>2</sub>O destruction facility. Therefore the quantity of the N<sub>2</sub>O at the inlet is given by:

$$QI_{N_2O,y} = \left( \sum_i^n F_{TI,i} \times CI_{N_2O,i} \times M_i \right) \quad (12)$$

Where:

$QI_{N_2O,y}$  : Quantity of N<sub>2</sub>O supplied to the destruction facility in year y (tN<sub>2</sub>O)

$F_{TI,i}$  : Volume flow rate at the inlet of the destruction facility during interval  $i$  (Nm<sup>3</sup>/h)

$CI_{N_2O,i}$  : N<sub>2</sub>O concentration in the tail gas of the N<sub>2</sub>O destruction facility during interval  $i$  (tN<sub>2</sub>O/Nm<sup>3</sup>)

$M_i$  : Length of measuring interval  $i$  (h)

$i$  : Interval

$n$  : Number of intervals during the year

However, if the new national regulations concerning N<sub>2</sub>O emissions are provided in the future, the baseline emissions are re-assessed automatically according to the latest version of AM0028.

#### **b) Baseline emissions ( $BE_y$ ), if $P_{product,y} \leq P_{product, max}$**

As previously stated, the project emissions ( $BE_y$ ) are accounted by the equation (10) ;

$$BE_y = BE_{N_2O} \times GWP_{N_2O} \quad (10)$$

Here, the equation (10) can be rearranged to (13) by combination of the equation (11) and (12)

$$BE_y = \left( \sum_i^n F_{TI,i} \times CI_{N_2O,i} \times M_i \right)^1 \times GWP_{N_2O} \quad (13)$$

<sup>1</sup> As indicated in AM0028/Version4.2, the Value adopted for Quantity of N<sub>2</sub>O at the inlet of the destruction facility should be calculated considering conservatively the error included in the measurement.

**c) Baseline emissions ( $BE_y$ ), if  $P_{product,y} > P_{product,max}$** 

If the actual production of caprolactam ( $P_{product,y}$ ) exceeds the design capacity ( $P_{product,max}$ ) then emissions related to the production above  $P_{product,max}$  will neither be claimed for the baseline nor for the project scenario.

$$BE_{N_2O,y} = SE_{N_2O,y} \times P_{product,max} \quad (14)$$

Where:

$BE_{N_2O,y}$  : Baseline emissions of  $N_2O$  in year y (t $N_2O$ )

$SE_{N_2O,y}$  : Specific  $N_2O$  emissions per unit of output product of caprolactam in year y (t $N_2O$ / t Product)

$P_{product,max}$  : Design capacity (t Product )

The specific  $N_2O$  emissions per caprolactam output are defined as:

$$SE_{N_2O,y} = QI_{N_2O,y} / P_{product,y} \quad (15)$$

Where:

$SE_{N_2O,y}$  : Specific  $N_2O$  emissions per unit of output product of caprolactam in year y (t $N_2O$ / t Product)

$QI_{N_2O,y}$  : Quantity of  $N_2O$  emissions at the inlet of the destruction facility in year y (t $N_2O$ )

$P_{product,y}$  : Production of caprolactam in year y (t Product)

Consequently, in case of that caprolactam output ( $P_{product,y}$ ) exceeds the design capacity ( $P_{product,max}$ ), the project emissions ( $BE_y$ ) can be accounted as given by :

$$BE_y = \left( \sum_i^n F_{TI,i} \times CI_{N_2O,i} \times M_i \right) \times GWP_{N_2O} \times (P_{product,max} / P_{product,y}) \quad (16)$$

### **3. Leakage**

The De- $N_2O$  system has a function of “Regenerative Heat Exchanger”. Therefore the installation of the  $N_2O$  destruction facility will not result in significant additional energy consumption at the caprolactam production plant. In conclusion, no leakage is expected at this project.

The emission by leakage is accounted as follows:

$$LE_y = 0 \quad (17)$$



#### 4. Determining the permitted operating conditions of the caprolactam production plant

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In order to avoid that the operation of the caprolactam production plant is manipulated in a way to increase the N<sub>2</sub>O generation, thereby increasing the CERs, the following procedures relating to the operating temperature and pressure and the use of ammonia oxidation catalysts shall be applied.

##### 1) Operating temperature and pressure of the Ammonia Oxidation Reactor (AOR):

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If the actual average daily operating temperature and/or pressure in the ammonia oxidation reactor ( $T_g$  and  $P_g$ ) are outside a “permitted range” of operating temperatures and/or pressures ( $T_{g,hist}$  and  $P_{g,hist}$ ), the baseline N<sub>2</sub>O emissions are capped at 5.4kgN<sub>2</sub>O/tonne of caprolactam conservatively applying the IPCC default value during the operating period in the outside of “permitted range”.

Required monitoring parameters:

$T_{g,d}$  : Actual operating temperature of AOR on day  $d$  (°C)

$P_{g,d}$  : Actual operating pressure of AOR on day  $d$  (Pa gauge)

$T_{g,hist}$  : Historical operating temperature range of AOR (°C)

$P_{g,hist}$  : Historical operating pressure range of AOR (Pa gauge)

Since the judgment whether normal operating conditions exceed the limit on permissible conditions shall be undertaken daily, the actual operating temperature ( $T_{g,d}$ ) and pressure ( $P_{g,d}$ ) of AOR shall be monitored every working day. The figures of historical operating temperature ( $T_{g,hist}$ ) and pressure ( $P_{g,hist}$ ) of AOR are shown in Figure 3 and Annex 3.

##### 2) Composition of ammonia oxidation catalyst:

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The first composition of ammonia oxidation catalyst used during the crediting period shall be of the same kind of catalyst composition already in operation in the specific nitric acid or caprolactam production plant.

If the composition of ammonia oxidation catalysts is changed from the historical one ( $G_{sup,hist}$  &  $G_{com,hist}$ ) to the new one ( $G_{sup}$  &  $G_{com}$ ), and the composition is not common practice in the region and not reported as being in use in the relevant literature. The project applicant shall demonstrate that the choice of the new composition was based on considerations other than an attempt to increase the rate of N<sub>2</sub>O production, with appropriate and verifiable reasons (either by economic or other arguments). Otherwise, baseline emissions are limited to the maximum specific N<sub>2</sub>O emissions of previous periods (tN<sub>2</sub>O/t Caprolactam), documented in the verified monitoring reports.

Required monitoring parameters:

$G_{sup}$  : Supplier of the ammonia oxidation catalyst

$G_{com}$  : Composition of the ammonia oxidation catalyst



$G_{sup,hist}$  : Historical supplier of the ammonia oxidation catalyst

$G_{com,hist}$  : Historical composition of the ammonia oxidation catalyst

$SE_{N_2O,y}$  : Specific  $N_2O$  emissions per ton of product of caprolactam in year y (t $N_2O$ /t Product)

The historical supplier ( $G_{sup,hist}$ ) and composition ( $G_{com,hist}$ ) of the ammonia oxidation catalyst are indicated in B.6.2.

### 3) Ammonia flow rate to the Ammonia Oxidation Reactor(AOR):

If the actual daily ammonia flow rate exceeds the (upper) limit on maximum historical daily permitted ammonia flow rate, the baseline  $N_2O$  emissions for this operating day are capped at conservative IPCC default values. Where, the upper limit on ammonia flow should be determined based on “the historical operating data on maximum daily average ammonia flow”.

Required monitoring parameters:

$A_{OR,d}$  : Actual ammonia input to oxidation reactor on daily basis (t $NH_3$ /day)

$A_{OR,hist}$  : Maximum historical ammonia input to oxidation reactor (t $NH_3$ /day)

The figure of the maximum historical ammonia input to AOR is shown in Figure 3 and Annex 3.

## 5. Emission Reductions

The emission reduction  $ER_y$  by the project activity during a given year y is the difference between the baseline emissions ( $BE_y$ ) and project emissions ( $PE_y$ ), as follows:

$$ER_y = BE_y - PE_y - LE_y \quad (18)$$

Taking all explained at B.6.1 into consideration, each term of the equation (15),  $BE_y$ ,  $PE_y$  and  $LE_y$ , can be replaced the terms corresponding with following equations ;

If  $P_{product,y} \leq P_{product,max}$ ,

$$BE_y = \left( \sum_i^n F_{TI,i} \times CI_{N_2O,i} \times M_i \right)^2 \times GWP_{N_2O} \quad (13)$$

If  $P_{product,y} > P_{product,max}$ ,

$$BE_y = \left( \sum_i^n F_{TI,i} \times CI_{N_2O,i} \times M_i \right) \times GWP_{N_2O} \times (P_{product,max} / P_{product,y}) \quad (16)$$

<sup>2</sup> As indicated in AM0028/Version4.2, the value adopted for Quantity of  $N_2O$  at the inlet of the destruction facility should be calculated considering conservatively the error included in the measurement.



$$\begin{aligned}
PE_y = & \left( \sum_i^n F_{TE,i} \times CO_{N_2O,i} \times M_i \right) \times GWP_{N_2O} \\
& + [(\rho_{HC} \times Q_{HC,y} \times EF_{HC} \times OXID_{HC}/100) + (\rho_{CH_4} \times Q_{CH_4,y} \times EF_{CH_4} \times OXID_{CH_4}/100)] \\
& + [\rho_{CH_4} \times Q_{CH_4,y} \times GWP_{CH_4} \times (1 - OXID_{CH_4}/100)]
\end{aligned}
\tag{9}$$

$$LE_y = 0 \tag{14}$$

<b>B.6.2. Data and parameters that are available at validation:</b>
---

It is the data and parameters in section B.6.2 that are not monitored throughout the crediting period but that are determined only once. Thus that remain fixed throughout the crediting period, and that are available when validation is undertaken.

<b>Data / Parameter:</b>	<b><math>GWP_{N_2O}</math></b>
Data unit:	tCO <sub>2</sub> e/tN <sub>2</sub> O
Description:	Global warming potential of the nitrous oxide
Source of data used:	IPCC, The Second Assessment Report
Value applied:	310
Justification of the choice of data or description of measurement methods and procedures actually applied :	Specified in the methodology
Any comment:	The value may be changed in the 2 <sup>nd</sup> Commitment Period, on condition that COP/MOP decided so.

<b>Data / Parameter:</b>	<b><math>GWP_{CH_4}</math></b>
Data unit:	tCO <sub>2</sub> e/tN <sub>2</sub> O
Description:	Global warming potential of the methane
Source of data used:	IPCC, The Second Assessment Report
Value applied:	21
Justification of the choice of data or description of measurement methods and procedures actually applied :	Specified in the methodology
Any comment:	The value may be changed in the 2 <sup>nd</sup> Commitment Period, on condition that COP/MOP decided so



Data / Parameter:	$P_{product, max}^3$																	
Data unit:	t Caprolactam /yr																	
Description:	Design capacity of caprolactam production of the targeted line  It is the “designed capacity” that “existing production capacity” is defined as, measured in tons of caprolactam per year. Definition of “existing” production capacity is applied for the process with the existing ammonia oxidation reactor where N <sub>2</sub> O is generated and not for the process with new ammonia oxidizer.																	
Source of data used:	Historical data																	
Value applied:	128609 ton/yr (Plant I : 63271 ton/yr   Plant II : 65338 tons/yr )																	
Justification of the choice of data or description of measurement methods and procedures actually applied :	<div>Specified in the methodology</div> <div>All of ammonia oxidation reactors of these plants are keeping with the same as they were installed at the beginning. Each plant of Capro’s design capacity is established upon the maximum daily production and maximum operating days till 31 December 2005.</div> <table><tr><td></td><td>Plant I</td><td>Plant II</td></tr><tr><td>Maximum Daily production (ton/day)</td><td>174.30</td><td>183.02</td></tr><tr><td>Maximum operating day (day/yr)</td><td>363</td><td>357</td></tr><tr><td>Design Capacity for each plant (ton/yr)</td><td>63271</td><td>65338</td></tr><tr><td>Design Capacity, <math>P_{product, max}</math>(ton/yr)</td><td colspan="2">128609</td></tr></table>				Plant I	Plant II	Maximum Daily production (ton/day)	174.30	183.02	Maximum operating day (day/yr)	363	357	Design Capacity for each plant (ton/yr)	63271	65338	Design Capacity, $P_{product, max}$ (ton/yr)	128609	
	Plant I	Plant II																
Maximum Daily production (ton/day)	174.30	183.02																
Maximum operating day (day/yr)	363	357																
Design Capacity for each plant (ton/yr)	63271	65338																
Design Capacity, $P_{product, max}$ (ton/yr)	128609																	
Any comment:	The amount of emission reductions is capped by $P_{product, max}$ through the formula (16) described in B.6.1 If the actual production of caprolactam ( $P_{product, y}$ ) exceeds the design capacity ( $P_{product, max}$ ) then emissions related to the production above $P_{product, max}$ will neither be claimed for the baseline nor for the project scenario.																	

<b>Data / Parameter:</b>	$A_{OR, his}$
<b>Data unit:</b>	tNH <sub>3</sub> /day
<b>Description:</b>	Maximum of historical ammonia flow rate of the ammonia oxidation reactor (AOR)
<b>Source of data used:</b>	Existing Distributed Control System (DCS)
<b>Value applied:</b>	$A_{OR, hist-1}$ : 40.196tNH <sub>3</sub> /day (total flow rate for AOR-a and AOR-b in Plant I) $A_{OR, hist-2}$ : 43.653tNH <sub>3</sub> /day (total flow rate for AOR-c and AOR-d in Plant II)
<b>Justification of the</b>	As shown in Figure 3, each caprolactam production plant has two of AORs

<sup>3</sup>  $P_{product, hist}$  is shown as the parameter of design capacity of caprolactam production in the table of the approved monitoring methodology (AM0028/Version04.2). However, here, we use  $P_{product, max}$ , which is consistent with equation (4) in section B.6.1.



choice of data or description of measurement methods and procedures actually applied :	<p>(Plant I: AOR-a, AOR-b, Plant II: AOR-c, AOR-d).</p> <p>In each plant, the total ammonia input flows through the one line with one flow meter, and that is supplied into both of two AOR equally. So, every plant has one flow meter for measuring ammonia input.</p> <p><math>A_{OR,his-1}</math> is for the maximum of historical ammonia flow rate of the ammonia oxidation reactors (AOR-a, AOR-b) in Plant I, and <math>A_{OR,his-2}</math> is for AOR-c and AOR-d in Plant II.</p> <p>Therefore, in this project, 2 parameters of <math>A_{OR,his-1}</math>, and <math>A_{OR,his-2}</math> are set for each plant including corresponded two AORs.</p> <p>These values are set based on maximum values of historical daily data within latest 3 years before 31, December, 2005 (1<sup>st</sup> Jan.2003 – 31<sup>st</sup> Dec.2005)</p> <p>Since, the historical operating data on maximum daily average ammonia flow is existed in each plant on Capro, the upper limit on ammonia flow is determined on this historical data.</p>
Any comment:	No.

<b>Data / Parameter:</b>	$T_{g,his}$
Data unit:	°C
Description:	Historical operating temperature range of the ammonia oxidation reactor
Source of data used:	Existing Distributed Control System (DCS)
Value applied:	$T_{g,his-a}$ : 677.27– 742.02°C (for AOR-a in Plant I) $T_{g,his-b}$ : 690.63–756.06 °C (for AOR-b in Plant I) $T_{g,his-c}$ : 717.67– 770.10°C (for AOR-c in Plant II) $T_{g,his-d}$ : 726.25– 765.99°C (for AOR-d in Plant II)
Justification of the choice of data or description of measurement methods and procedures actually applied :	<p>As shown in Figure 3, each caprolactam production plant has two of AORs (Plant I: AOR-a, AOR-b, Plant II: AOR-c, AOR-d), and every AOR has an independent operating temperature measuring equipment.</p> <p>The permitted range of operating temperatures are set based on historical data within latest 3 years before 31, December, 2005 (1<sup>st</sup> Jan.2003 – 31<sup>st</sup> Dec.2005)</p> <p>The time series data are interpreted as a sample from a stochastic variable. All data that are part of the 2.5% Quantile or that are part of the (100-2.5) % Quantile of the sample distribution are defined as outliers and are eliminated. The permitted range of operating temperature is then calculated based on the remaining historical minimum and maximum operating conditions.</p>
Any comment:	The data is used to check whether the ammonia oxidation reactor is operated normally.



<b>Data / Parameter:</b>	$P_{g,his}$
Data unit:	Pa gauge
Description:	Historical operating pressure range of the ammonia oxidation reactor
Source of data used:	Existing Distributed Control System (DCS)
Value applied:	$P_{g,hist\_1}$ : 47268– 93752 Pa gauge (for AOR-a and AOR-b in Plant I) $P_{g,hist\_2}$ : 54525– 93654 Pa gauge (for AOR-c and AOR-d in Plant II)
Justification of the choice of data or description of measurement methods and procedures actually applied :	<p>Presented values correspond to the pressure of ammonia input to AOR.</p> <p>As shown in Figure 3, each caprolactam production plant has two of AORs (Plant I: AOR-a, AOR-b, Plant II: AOR-c, AOR-d), and in each plant, the total ammonia input flows through the one lines. Accordingly, there is one <math>P_{g,hist}</math> for both of AORs in each plant.</p> <p>The permitted range of operating pressure are set based on historical data within latest 3 years before 31, December, 2005 (1<sup>st</sup> Jan.2003 – 31<sup>st</sup> Dec.2005)</p> <p>The time series data are interpreted as a sample from a stochastic variable. All data that are part of the 2.5% Quantile or that are part of the (100-2.5) % Quantile of the sample distribution are defined as outliers and are eliminated. The permitted range of operating pressure is then calculated based on the remaining historical minimum and maximum operating conditions.</p>
Any comment:	The data is used to check whether the ammonia oxidation reactor is operated normally.

<b>Data / Parameter:</b>	$G_{sup,his}$
Data unit:	-
Description:	Historical supplier of the ammonia oxidation catalyst
Source of data used:	Purchase order record
Value applied:	Name of the supplier: Johnson Matthey
Justification of the choice of data or description of measurement methods and procedures actually applied :	Specified in the methodology.
Any comment:	From the beginning to present, Johnson Matthey's catalyst has been used in Capro.

<b>Data / Parameter:</b>	$G_{com,his}$
Data unit:	%
Description:	Historical composition of the ammonia oxidation catalyst
Source of data used:	Purchase order record
Value applied:	Pt (90%): Rh (10%)





Justification of the choice of data or description of measurement methods and procedures actually applied :	Specified in the methodology.
Any comment:	No

<b>Data / Parameter:</b>	<b><math>OXID_{HC}</math></b>
Data unit:	%
Description:	Oxidation factor of natural gas, with two or more molecules of carbon
Source of data used:	AM0028/Version04.2
Value applied:	100%
Justification of the choice of data or description of measurement methods and procedures actually applied :	Specified in the methodology.  For this project, in conservative manner, 100% is applied for this parameter based on AM0028/Version04.2.
Any comment:	No

<b>Data / Parameter:</b>	<b><math>EF_{CH_4}</math></b>
Data unit:	tCO <sub>2</sub> /tCH <sub>4</sub>
Description:	Emission factor of methane
Source of data used:	Theoretical calculation
Value applied:	2.75(tCO <sub>2</sub> /tCH <sub>4</sub> )
Justification of the choice of data or description of measurement methods and procedures actually applied :	This value is theoretically calculated as follows; 44 gCO <sub>2</sub> /16gCH <sub>4</sub>
Any comment:	

<b>Data / Parameter:</b>	<b><math>\rho_{CH_4}</math></b>
Data unit:	t/m <sup>3</sup>
Description:	Density of methane
Source of data used:	Tool to determine project emissions from flaring gases containing methane
Value applied:	0.000716 t/m <sup>3</sup>
Justification of the choice of data or description of measurement methods and procedures	Tool to determine project emissions from flaring gases containing methane. Here, this value is given at the normal condition (0°C, 1atm). For this project, the value converted into the normal condition is applied as this parameter.



actually applied :	In case of the normal condition, this parameter can be given by theoretical value.
Any comment:	No.

<b>Data / Parameter:</b>	$M_i$
Data unit:	hour
Description:	Length of measuring interval
Source of data used:	Defined in the technical specifications of data logging system(DCS)
Value applied:	1 hour (to be measured continuously for 24 hours)
Justification of the choice of data or description of measurement methods and procedures actually applied :	This parameter is set based on recording frequencies for volume flow rates and N <sub>2</sub> O concentrations at N <sub>2</sub> O destruction facility inlet and outlet. It is specified by AM0028/Version04.2. (Please see B.7.1)
Any comment:	No.

### B.6.3. Ex-ante calculation of emission reductions:

>>

The emission reductions are estimated on the basis of assumptions.

Main assumptions applied for Ex-ante calculation are follows:

- The N<sub>2</sub>O decomposition efficiency is 90%.
- The number of operating day in a year is 363 and 357 of Plant I and Plant II respectively.
- The number of operating time in a day is 24hr.
- The N<sub>2</sub>O concentration and the flow rate of tail gas are continuously monitored.
- The value adopted as the quantity of N<sub>2</sub>O includes the combined uncertainty of the applied monitoring equipment at the inlet of the destruction facility.
- The Oxidation factor of methane,  $OXID_{CH_4}$ , is established to be 99.5%, referred to B.7.1
- All of hydrocarbon with two or more molecules of carbon in the natural gas used for re-heating DF are oxidized,  $OXID_{HC} = 100\%$ .

Detail information about the value of parameters and the data is able to be referred at section B.7.1

Two of independent plants are involved in this proposed project. Therefore for each plant, separate ex-ante calculation of emission reduction is accomplished in this section.

### Plant I

Ex-ante calculation of Baseline Emission,  $BE_{y-1}$



As described in the equation (13) of Section B.6.1, the baseline emission is given by

$$BE_y = \left( \sum_i^n F_{TI,i} \times CI_{N_2O,i} \times M_i \right) \times GWP_{N_2O} \quad (13)$$

Following values for parameter are applied to the equation (13), and the baseline emission for Plant I ( $BE_{y-1}$ ) is estimated to about 358086.54tCO<sub>2</sub>/yr.

Parameter		Value	Unit
$n$	Number of intervals during the year	8712	Cycle/yr
$M_i$	Length of Measuring Interval	1	hr/cycle
$F_{TI,i}$	Volume flow rate at the inlet of the DF during interval $i$	45000	Nm <sup>3</sup> /hr
$CI_{N_2O,i}$	N <sub>2</sub> O concentration in the tail gas of the DF inlet during interval $i$	$2.9464 \times 10^{-6}$	tN <sub>2</sub> O/ Nm <sup>3</sup>
$GWP_{N_2O}$	Global warming potential of the nitrous oxide	310	-
The baseline emission for Plant I ( $BE_{y-1}$ ) = 358086.54tCO <sub>2</sub> /yr			

Ex-ante calculation of Project Emission,  $PE_{y-1}$

As described in the equation (9) of Section B.6.1, the baseline emission is given by

$$\begin{aligned}
 PE_y = & \left( \sum_i^n F_{TE,i} \times CO_{N_2O,i} \times M_i \right) \times GWP_{N_2O} \\
 & + [(\rho_{HC} \times Q_{HC,y} \times EF_{HC} \times OXID_{HC}/100) + (\rho_{CH_4} \times Q_{CH_4,y} \times EF_{CH_4} \times OXID_{CH_4}/100)] \\
 & + [\rho_{CH_4} \times Q_{CH_4,y} \times GWP_{CH_4} \times (1-OXID_{CH_4}/100)] \quad (9)
 \end{aligned}$$

Following values for parameter are applied to the equation (9), and the project emission for Plant I ( $PE_{y-1}$ ) is estimated to 36827 tCO<sub>2</sub>/yr.

Parameter		Value	Unit
$n$	Number of intervals during the year	8712	Cycle/yr
$M_i$	Length of Measuring Interval	1	hr/cycle
$F_{TE,i}$	Volume flow rate at the exit of the DF during interval $i$	45415	Nm <sup>3</sup> /hr
$CO_{N_2O,i}$	N <sub>2</sub> O concentration in the tail gas of the DF exit during interval $i$	$2.9464 \times 10^{-7}$	tN <sub>2</sub> O/ Nm <sup>3</sup>
$GWP_{CH_4}$	Global warming potential of CH <sub>4</sub>	21	-
$GWP_{N_2O}$	Global warming potential of the nitrous oxide	310	-
$\rho_{CH_4}$	Density of methane	0.000716	tCH <sub>4</sub> /m <sup>3</sup>



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$\rho_{HC}$	Density of HC	0.001452	tHC/m <sup>3</sup>
$EF_{CH_4}$	CO <sub>2</sub> emission factor of CH <sub>4</sub>	2.75	tCO <sub>2</sub> e/tCH <sub>4</sub>
$EF_{HC}$	CO <sub>2</sub> emission factor of HC with two or more carbon molecules in natural gas	2.99	tCO <sub>2</sub> e/tHC
$Q_{CH_4,y}$	Methane used in year y	267231	Nm <sup>3</sup> /y
$Q_{HC,y}$	HC with two or more carbon molecule in natural gas used in year y	33333	Nm <sup>3</sup> /y
$OXID_{CH_4}$	Oxidation factor of methane	99.5	%
$OXID_{HC}$	Oxidation factor of HC	100	%
The Project emission for Plant I ( $PE_{y-1}$ ) = 36827 tCO <sub>2</sub> /yr			

Ex-ante calculation of Emission Reduction,  $ER_{y-1}$

$$\begin{aligned}
 ER_{y-1} &= BE_{y-1} - PE_{y-1} \\
 &= (358086.54 - 36827) \text{ tCO}_2/\text{yr} \\
 &= 321259.52 \text{ tCO}_2/\text{yr}
 \end{aligned}$$

Therefore the ex-ante emission reduction to Plant I is about 321259.52 tCO<sub>2</sub>/yr.

## Plant II

Ex-ante calculation of Baseline Emission,  $BE_{y-2}$

As described in the equation (13) of Section B.6.1, the baseline emission is given by

$$BE_y = \left( \sum_i^n F_{Ti,i} \times CI_{N_2O,i} \times M_i \right) \times GWP_{N_2O} \quad (13)$$

Following values for parameter are applied to the equation (13), and the baseline emission for Plant II (  $BE_{y-2}$  ) is estimated to 383471.55 tCO<sub>2</sub>/yr.

Parameter		Value	Unit
$n$	Number of intervals during the year	8568	Cycle/yr
$M_i$	Length of Measuring Interval	1	hr/cycle
$F_{Ti,i}$	Volume flow rate at the inlet of the DF during interval $i$	49000	Nm <sup>3</sup> /hr
$CI_{N_2O,i}$	N <sub>2</sub> O concentration in the tail gas of the DF inlet during interval $i$	$2.9464 \times 10^{-6}$	tN <sub>2</sub> O/ Nm <sup>3</sup>
$GWP_{N_2O}$	Global warming potential of the nitrous oxide	310	-
The baseline emission for Plant II ( $BE_{y-2}$ ) = 383471.55 tCO <sub>2</sub> /yr			



Ex-ante calculation of Project Emission,  $PE_{y-2}$

As described in the equation (9) of Section B.6.1, the baseline emission is given by

$$PE_y = \left( \sum_i^n F_{TE,i} \times CO_{N_2O,i} \times M_i \right) \times GWP_{N_2O} + [(\rho_{HC} \times Q_{HC,y} \times EF_{HC} \times OXID_{HC}/100) + (\rho_{CH_4} \times Q_{CH_4,y} \times EF_{CH_4} \times OXID_{CH_4}/100)] + [\rho_{CH_4} \times Q_{CH_4,y} \times GWP_{CH_4} \times (1-OXID_{CH_4}/100)] \quad (9)$$

Following values for parameter are applied to the equation (9), and the project emission for Plant II ( $PE_{y-2}$ ) is estimated to 39548.99tCO<sub>2</sub>/yr.

Parameter		Value	Unit
$n$	Number of intervals during the year	8568	Cycle/yr
$M_i$	Length of Measuring Interval	1	hr/cycle
$F_{TE,i}$	Volume flow rate at the exit of the DF during interval $i$	49498	Nm <sup>3</sup> /hr
$CO_{N_2O,i}$	N <sub>2</sub> O concentration in the tail gas of the DF exit during interval $i$	$2.9464 \times 10^{-7}$	tN <sub>2</sub> O/m <sup>3</sup>
$GWP_{CH_4}$	Global warming potential of CH <sub>4</sub>	21	-
$GWP_{N_2O}$	Global warming potential of the nitrous oxide	310	-
$\rho_{CH_4}$	Density of methane	0.000716	tCH <sub>4</sub> /m <sup>3</sup>
$\rho_{HC}$	Density of HC	0.001452	tHC/m <sup>3</sup>
$EF_{CH_4}$	CO <sub>2</sub> emission factor of CH <sub>4</sub>	2.75	tCO <sub>2</sub> e/tCH <sub>4</sub>
$EF_{HC}$	CO <sub>2</sub> emission factor of HC with two or more carbon molecule in natural gas	2.99	tCO <sub>2</sub> e/tHC
$Q_{CH_4,y}$	Methane used in year $y$	315377	Nm <sup>3</sup> /y
$Q_{HC,y}$	HC with two or more carbon molecule in natural gas used in year $y$	39338	Nm <sup>3</sup> /y
$OXID_{CH_4}$	Oxidation factor of methane	99.5	%
$OXID_{HC}$	Oxidation factor of HC	100	%
The Project emission for Plant II ( $PE_{y-2}$ ) = 39548.99 tCO <sub>2</sub> /yr			

Ex-ante calculation of Emission Reduction,  $ER_{y-2}$

$$ER_{y-2} = BE_{y-2} - PE_{y-2} = (383471.55 - 39548.99) \text{ tCO}_2/\text{yr} = 343922.56 \text{ tCO}_2/\text{yr}$$

Therefore the ex-ante emission reduction to Plant II is about 343922.56 tCO<sub>2</sub>/yr.

### Total ex-ante Emission Reductions from the project

$$\begin{aligned}
 ER_y &= ER_{y-1} + ER_{y-2} \\
 &= (321259.52 + 343922.56) \text{ t CO}_2/\text{yr} \\
 &= 665182.08 \text{ tCO}_2/\text{yr}
 \end{aligned}$$

Therefore the ex-ante emission reduction to Plant I and II is about 665182 tCO<sub>2</sub>/yr

#### B.6.4 Summary of the ex-ante estimation of emission reductions:

>>

The result of the *ex-ante* estimation of emission reductions for all years of the crediting period can be summarized by the table below.

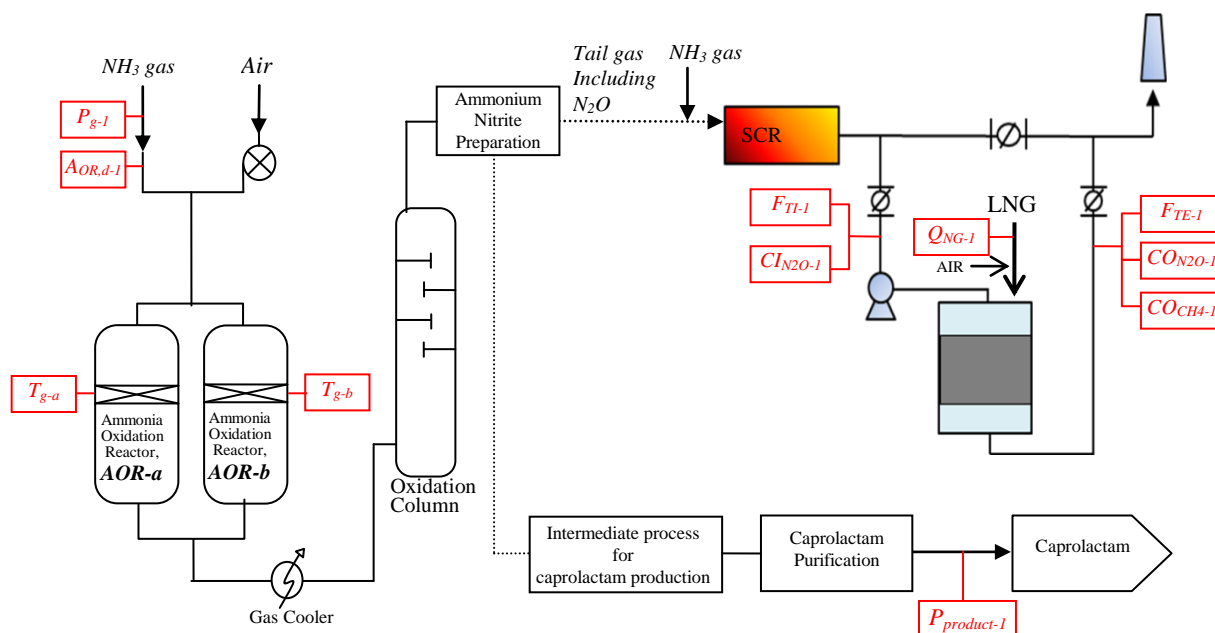
Year	Estimation of project activity emissions (tonnes of CO <sub>2</sub> e)	Estimation of baseline emissions (tonnes of CO <sub>2</sub> e)	Estimation of leakage (tonnes of CO <sub>2</sub> e)	Estimation of Overall emission reductions (tonnes of CO <sub>2</sub> e)
2010	76376	741558	0	665182
2011	76376	741558	0	665182
2012	76376	741558	0	665182
2013	76376	741558	0	665182
2014	76376	741558	0	665182
2015	76376	741558	0	665182
2016	76376	741558	0	665182
2017	76376	741558	0	665182
2018	76376	741558	0	665182
2019	76376	741558	0	665182
Total (tonnes of CO <sub>2</sub> e)	763760	7415581	0	6651821

#### B.7. Application of the monitoring methodology and description of the monitoring plan:

>>

The following sections (B.7.1 and B.7.2) provide a detailed description of the application of the monitoring methodology and a description of the monitoring plan, including an identification of the data to be monitored and the procedures that will be applied during monitoring. The data monitored and required for verification and issuance are to be kept for two years after the end of the crediting period or the last issuance of CERs for this project activity, whichever occurs later.

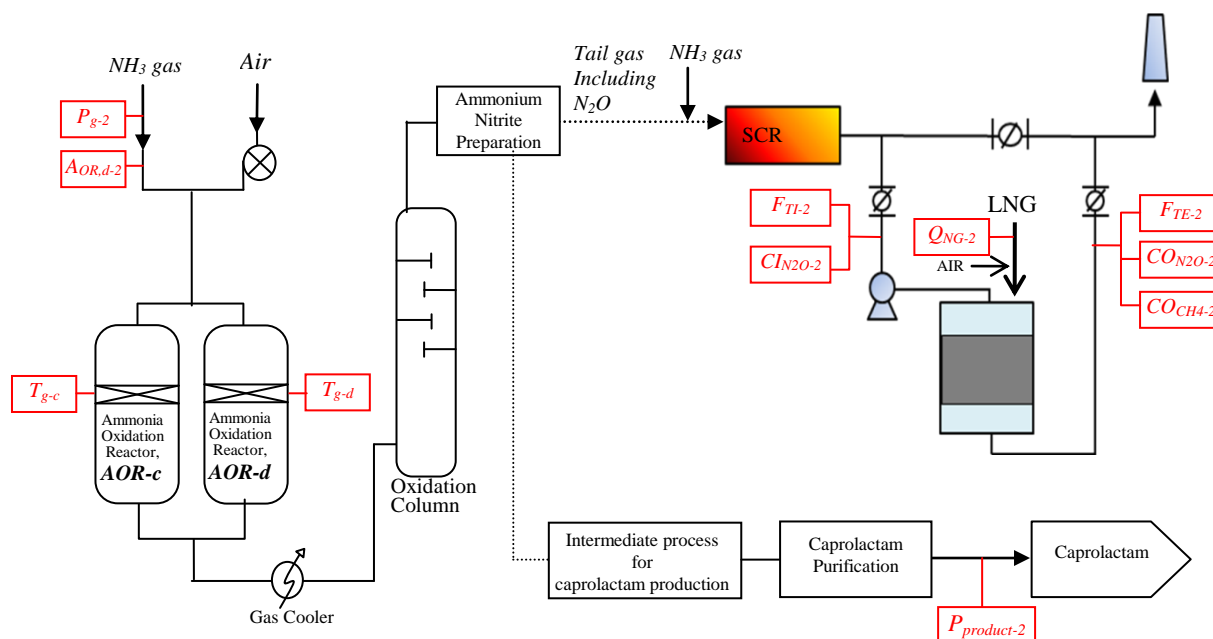
Monitoring points for key parameters are shown in Figure 6 and 7, and the Tag No. for that is summarized in Table 2 and 3 as below.



**Figure 6. Monitoring points for key parameters in Plant I**

**Table 2. Tag No. for key parameters in Plant I**

Parameter	Description	Tag No.
$A_{OR,d-1}$	Actual ammonia flow rate to AOR in Plant I	FI-1201
$P_{g-1}$	Actual operating pressure of the AOR-a, b in Plant I	PI-1205
$T_{g-a}$	Actual operating temperature of the AOR-a in Plant I	TI-1204
$T_{g-b}$	Actual operating temperature of the AOR-b in Plant I	TI-1206
$F_{TI-1}$	Volume flow rate at the inlet of the destruction facility in Plant 1	FIT-1521
$F_{TE-1}$	Volume flow rate at the exit of the destruction facility in Plant 1	FIT-1522
$CI_{N2O-1}$	N <sub>2</sub> O concentration at destruction facility inlet in Plant I	AIT-1521
$CO_{N2O-1}$	N <sub>2</sub> O concentration at destruction facility outlet in Plant I	AIT-1522
$Q_{NG-1}$	Additional natural gas input for re-heating the tail gas in Plant I	FI-1523
$CO_{CH4-1}$	CH <sub>4</sub> concentration at destruction facility outlet in Plant I	AIT-1523
$P_{product-1}$	Plant output of caprolactam in Plant I	FQIT-7705



**Figure 7. Monitoring points for key parameters in Plant II**

**Table 3. Tag No. for key parameters in Plant II**

Parameter	Description	Tag No.
$A_{OR,d-2}$	Actual ammonia flow rate to AOR in Plant II	2FI-1201
$P_{g-2}$	Actual operating pressure of the AOR-c, d in Plant II	2PI-1205
$T_{g-c}$	Actual operating temperature of the AOR-c in Plant II	2TI-1204
$T_{g-d}$	Actual operating temperature of the AOR-d in Plant II	2TI-1206
$F_{TI-2}$	Volume flow rate at the inlet of the destruction facility in Plant II	2FIT-1521
$F_{TE-2}$	Volume flow rate at the exit of the destruction facility in Plant II	2FIT-1522
$CI_{N2O-2}$	$N_2O$ concentration at destruction facility inlet in Plant II	2AIT-1521
$CO_{N2O-2}$	$N_2O$ concentration at destruction facility outlet in Plant II	2AIT-1522
$Q_{NG-2}$	Additional natural gas input for re-heating the tail gas in Plant II	2FI-1523
$CO_{CH4-2}$	$CH_4$ concentration at destruction facility outlet in Plant II	2AIT-1523
$P_{product-2}$	Plant output of caprolactam in Plant II	2FIT-7705



**B.7.1 Data and parameters monitored:**

&gt;&gt;

Data / Parameter:	$F_{TI,i}$											
Data unit:	Nm <sup>3</sup> /hr											
Description:	Volume flow rate at the inlet of the destruction facility											
Source of data to be used:	Flow meter with normalizing functions											
Value of data applied for the purpose of calculating expected emission reductions in section B.5	45000 Nm <sup>3</sup> /hr and 49000 Nm <sup>3</sup> /hr for Plant I and Plant II respectively. So, totally 94000 Nm <sup>3</sup> /hr.											
Description of measurement methods and procedures to be applied:	<p>Corresponding data for this parameter will be directly measured by Flow meter qualified on EN14181. (See Annex 4)</p> <p>This parameter will be expressed in normal conditions, and the temperature and pressure of actual conditions of gas will be recorded.</p> <p>It will be automatically recorded that not only the measured actual flow rate but also the adjusted flow rate to standard temperature and pressure.</p> <p>For verification, these parameters are planned to be measured and recorded as:</p> <ul style="list-style-type: none"><li>• Measuring device : Pitot-Tube with D/P Transmitter (D-FL-100 system, DURAG)</li><li>• Measuring period : Continuously</li><li>• Recording frequency : Daily</li><li>• Data record : Electronic Evaluation Unit, New PC for back-up</li></ul> <p>Instrument Tag No.</p> <table><tr><th><math>F_{TI,i}</math></th><th>Instrument Tag No.</th><th>Location</th></tr><tr><td><math>F_{TI-1}</math></td><td>FIT-1521</td><td>Plant I (see the Figure 6)</td></tr><tr><td><math>F_{TI-2}</math></td><td>2FIT-1521</td><td>Plant II(see the Figure 7)</td></tr></table>			$F_{TI,i}$	Instrument Tag No.	Location	$F_{TI-1}$	FIT-1521	Plant I (see the Figure 6)	$F_{TI-2}$	2FIT-1521	Plant II(see the Figure 7)
$F_{TI,i}$	Instrument Tag No.	Location										
$F_{TI-1}$	FIT-1521	Plant I (see the Figure 6)										
$F_{TI-2}$	2FIT-1521	Plant II(see the Figure 7)										
QA/QC procedures to be applied:	Refer to QA / QC procedures stated below. Both parameters, $F_{TE,i}$ and $F_{TI,i}$ , shall be cross-checked to ensure that no leak of N <sub>2</sub> O is taking place. In case of discrepancy, conservative calculation of emission reduction shall be provided. Calibration details are shown in Annex 4.											
Any comment:	Key parameter											

<b>Data / Parameter:</b>	$F_{TE,i}$
Data unit:	Nm <sup>3</sup> /hr
Description:	Volume flow rate at the exit of the destruction facility
Source of data to be used:	Flow meter with normalizing functions



Value of data applied for the purpose of calculating expected emission reductions in section B.5	45415Nm <sup>3</sup> /hr and 49498Nm <sup>3</sup> /hr for Plant I and Plant II respectively. So, totally 94913Nm <sup>3</sup> /hr									
Description of measurement methods and procedures to be applied:	<p>Corresponding data for this parameter will be directly measured by Flow meter qualified on EN1418. (See Annex 4)</p> <p>This parameter will be expressed in normal conditions, and the temperature and pressure of actual conditions of gas will be recorded. It will be automatically recorded that not only the measured actual flow rate but also the adjusted flow rate to standard temperature and pressure.</p> <p>For verification, these parameters are planned to be measured and recorded as:</p> <ul style="list-style-type: none"><li>• Measuring device : Pitot-Tube with D/P Transmitter (D-FL-100 system, DURAG)</li><li>•Measuring period : Continuously</li><li>•Recording frequency : Daily</li><li>•Data record : Electronic Evaluation Unit, New PC for back-up</li></ul> <p>Instrument Tag No.</p> <table><tr><th><math>F_{TE,i}</math></th><th>Instrument Tag No.</th><th>Location</th></tr><tr><td><math>F_{TE-1}</math></td><td>FIT-1522</td><td>Plant I (see the Figure 6)</td></tr><tr><td><math>F_{TE-2}</math></td><td>2FIT-1522</td><td>Plant II(see the Figure 7)</td></tr></table>	$F_{TE,i}$	Instrument Tag No.	Location	$F_{TE-1}$	FIT-1522	Plant I (see the Figure 6)	$F_{TE-2}$	2FIT-1522	Plant II(see the Figure 7)
$F_{TE,i}$	Instrument Tag No.	Location								
$F_{TE-1}$	FIT-1522	Plant I (see the Figure 6)								
$F_{TE-2}$	2FIT-1522	Plant II(see the Figure 7)								
QA/QC procedures to be applied:	<p>Refer to QA / QC procedures stated below. Both parameters, <math>F_{TE,i}</math> and <math>F_{TI,i}</math>, shall be cross-checked to ensure that no leak of N<sub>2</sub>O is taking place. In case of discrepancy, conservative calculation of emission reduction shall be provided. Calibration details are shown in Annex 4.</p>									
Any comment:	Key parameter									

Data / Parameter:	$CI_{N2O,i}$		
Data unit:	tN <sub>2</sub> O/Nm <sup>3</sup>		
Description:	N <sub>2</sub> O concentration at destruction facility inlet		
Source of data to be used:	Non-dispersion infrared absorption analyzer (NDIR)		
Value of data applied for the purpose of calculating expected emission reductions in section B.5			
		Plant I	Plant II
	$CI_{N2O,i}$ as ppm(v )	1500	1500
	$CI_{N2O,i}$ as tN <sub>2</sub> O/Nm <sup>3</sup>	2.9464×10 <sup>-6</sup>	2.9464×10 <sup>-6</sup>
	These values are the approximate N <sub>2</sub> O concentrations measured at the effluent tail gas from SCR for each plant before project start.		



	The unit of (tN <sub>2</sub> O /Nm <sup>3</sup> ) is adjusted from the ppm(v) unit by following equation : $x \text{ [tN}_2\text{O/Nm}^3\text{]} = y \text{ ppm(v)} \times 10^{-6} \times 44/22.4 /1000$		
Description of measurement methods and procedures to be applied:	Corresponding data for this parameter will be directly measured by NDIR qualified on EN14181. (See Annex 4)		
	For verification, these parameters are planned to be measured and recorded as:		
	<ul style="list-style-type: none"><li>• Measuring Device : Non-dispersion infrared absorption analyzer, (ULTRAMAT 6, SIEMENS)</li><li>• Measuring period : Continuous</li><li>• Recording frequency : Daily</li><li>• Data record : Electronic Evaluation Unit, New PC for back-up</li></ul>		
	Instrument Tag No.		
	$CI_{N2O,i}$	Instrument Tag No.	Location
	$CI_{N2O-1}$	AIT-1521	Plant I (see the Figure 6)
	$CI_{N2O-2}$	2AIT-1521	Plant II(see the Figure 7)
QA/QC procedures to be applied:	In case Non-dispersion infrared absorption analyzer is used, it shall be checked by sampling by gas chromatography periodically. QA/QC for the analyzer shall be subjected to the EN14181 or another good industrial practices whichever practically feasible in the region. Refer to Annex 4.		
Any comment:	Key parameter		

Data / Parameter:	CO <sub>N2O,i</sub>		
Data unit:	tN <sub>2</sub> O/Nm <sup>3</sup>		
Description:	N <sub>2</sub> O concentration at destruction facility outlet		
Source of data to be used:	Non-dispersion infrared absorption analyzer (NDIR)		
Value of data applied for the purpose of calculating expected emission reductions in section B.5			
		Plant I	Plant II
	CO <sub>N2O,i</sub> as ppm(v )	150	150
	CO <sub>N2O,i</sub> as tN <sub>2</sub> O/Nm <sup>3</sup>	2.9464×10 <sup>-7</sup>	2.9464×10 <sup>-7</sup>
	These values are estimated based on the approximate N <sub>2</sub> O concentration measured at the effluent tail gas from SCR before project start and the about 90% of expected N <sub>2</sub> O destruction catalyst efficiency.		
The unit of (tN <sub>2</sub> O /Nm <sup>3</sup> ) is adjusted from the ppm(v) unit by following equation :			
$x \text{ [tN}_2\text{O/Nm}^3\text{]} = y \text{ ppm(v)} \times 10^{-6} \times 44/22.4 /1000$			



Description of measurement methods and procedures to be applied:	Corresponding data for this parameter will be directly measured by NDIR qualified on EN14181. (See Annex 4)		
	For verification, these parameters are planned to be measured and recorded as:		
	<ul style="list-style-type: none"><li>• Measuring Device : Non-dispersion infrared absorption analyzer, (ULTRAMAT 6, SIEMENS), dual-channel type</li><li>• Measuring period : Continuous</li><li>• Recording frequency : Daily</li><li>• Data record : Electronic Evaluation Unit, New PC for back-up</li></ul>		
	Instrument Tag No.		
	$CO_{N2O,i}$	Instrument Tag No.	Location
	$CO_{N2O-1}$	AIT-1522	Plant I (see the Figure 6)
	$CO_{N2O-2}$	2AIT-1522	Plant II(see the Figure 7)
QA/QC procedures to be applied:	In case Non-dispersion infrared absorption analyzer is used, it shall be checked by sampling by gas chromatography periodically. QA/QC for the analyzer shall be subjected to the EN14181 or another good industrial practices whichever practically feasible in the region. Refer to Annex 4.		
Any comment:	Key parameter		

Data / Parameter:	$P_{product,y}$							
Data unit:	t Caprolactam/yr							
Description:	Plant output of caprolactam							
Source of data to be used:	Production report base on the value measured by Mass flow meter							
Value of data applied for the purpose of calculating expected emission reductions in section B.5	Not needed.							
Description of measurement methods and procedures to be applied:	• Instrument Tag No.:							
	$P_{product,y}$	Instrument Tag No.	Location					
	$P_{product-1}$	FQIT-7705	Plant I (see the Figure 6)					
	$P_{product-2}$	2FIT-7705	Plant II(see the Figure 7)					
	<table><tr><th colspan="2">Plant I</th></tr><tr><td>• Measuring device</td><td>: Existing mass flow meter Type : mass flow meter Model : PROMASS63 Maker : ENDRESS HAUSER</td></tr><tr><td>• Measuring period</td><td>: Continuous</td></tr></table>			Plant I		• Measuring device	: Existing mass flow meter Type : mass flow meter Model : PROMASS63 Maker : ENDRESS HAUSER	• Measuring period
Plant I								
• Measuring device	: Existing mass flow meter Type : mass flow meter Model : PROMASS63 Maker : ENDRESS HAUSER							
• Measuring period	: Continuous							



	<ul style="list-style-type: none"><li>• Recording frequency : Daily</li><li>• Measuring point : Between the distillation column and inlet of Caprolactam Storage tank</li><li>• Measuring range : 0~8 ton/hr</li><li>• Accuracy : ± 0.1%</li><li>• Data record : existed DCS system, New PC for back-up</li></ul>			
	<table><tr><th colspan="2">Plant II</th></tr><tr><td><ul style="list-style-type: none"><li>• Measuring device : Existing mass flow meter Type : mass flow meter Model : PROMASS63 Maker : ENDRESS HAUSER</li><li>• Measuring period : Continuous</li><li>• Recording frequency : Daily</li><li>• Measuring point : Between the distillation column and inlet of Caprolactam Storage tank</li><li>• Measuring range : 0~10 ton/hr</li><li>• Accuracy : ±0.15%</li><li>• Data record : existed DCS system, New PC for back-up</li></ul></td><td></td></tr></table>	Plant II		<ul style="list-style-type: none"><li>• Measuring device : Existing mass flow meter Type : mass flow meter Model : PROMASS63 Maker : ENDRESS HAUSER</li><li>• Measuring period : Continuous</li><li>• Recording frequency : Daily</li><li>• Measuring point : Between the distillation column and inlet of Caprolactam Storage tank</li><li>• Measuring range : 0~10 ton/hr</li><li>• Accuracy : ±0.15%</li><li>• Data record : existed DCS system, New PC for back-up</li></ul>
Plant II				
<ul style="list-style-type: none"><li>• Measuring device : Existing mass flow meter Type : mass flow meter Model : PROMASS63 Maker : ENDRESS HAUSER</li><li>• Measuring period : Continuous</li><li>• Recording frequency : Daily</li><li>• Measuring point : Between the distillation column and inlet of Caprolactam Storage tank</li><li>• Measuring range : 0~10 ton/hr</li><li>• Accuracy : ±0.15%</li><li>• Data record : existed DCS system, New PC for back-up</li></ul>				
QA/QC procedures to be applied:	<ul style="list-style-type: none"><li>• Capro’s Maintenance and testing regime (by ISO 14001 standard) for the Mass flow meters.</li><li>• Calibration frequency : Once every three years by 3<sup>rd</sup> party</li><li>• Cross-check of amount of the produced caprolactam is performed on the basis of stock change data and weighbridge data. Measurement devices can be subjected to QA /QC scheme consistent with respect to equipment certification, installation and performance.</li></ul>			
Any comment:	No			

<b>Data / Parameter:</b>	$T_g$
Data unit:	$^{\circ}\text{C}$
Description:	Actual operating temperature of the ammonia oxidation reactor
Source of data to be used:	Thermocouple
Value of data applied for the purpose of calculating expected emission reductions in section B.5	Not needed.
Description of measurement methods and procedures to be applied:	<p>Each caprolactam production plant has two of AORs (Plant I: AOR-a, AOR-b, Plant II: AOR-c, AOR-d), and every AOR has an independent operating temperature measuring equipment.</p> <ul style="list-style-type: none"> <li>• Instrument Tag No.:</li> </ul>



	$T_g$	Instrument Tag No.	Location	
	$T_{g-a}$	TI-1204	AOR-a	Plant I (see Figure6)
	$T_{g-b}$	TI-1206	AOR-b	
	$T_{g-c}$	2TI-1204	AOR-c	Plant II(see Figure7)
	$T_{g-d}$	2TI-1206	AOR-d	
	<ul style="list-style-type: none"><li>• Measuring device : existing thermocouple <math>T_{g-a}, T_{g-b}</math> (Model : R121, Maker : WISE) <math>T_{g-c}, T_{g-d}</math> (Model : C1EST, Maker : WISE)</li><li>• Measuring period : Continuous</li><li>• Recording frequency : Continuous</li><li>• Measuring point : inside reactor, See Figure 6 and Figure 7</li><li>• Measuring range : 0~1000 °C</li><li>• Accuracy : <math>\pm 2.5^{\circ}\text{C}</math></li><li>• Data record : existed DCS system, New PC for back-up</li></ul> <p>If the actual average daily operating temperature in the ammonia oxidation reactor (<math>T_g</math>) is outside <math>T_{g,hist}</math> (permitted range) in any of AORs, the baseline N<sub>2</sub>O emissions for that period are capped at 5.4kgN<sub>2</sub>O/tonne of caprolactam conservatively applying the IPCC default value.</p>			
QA/QC procedures to be applied:	<ul style="list-style-type: none"><li>• Capro’s maintenance and testing regime (by ISO 14001 standard)</li><li>• Calibration frequency: Every general turnaround (: 3 Year)</li></ul>			
Any comment:	To check whether “normal” operation is undertaken.			

Data / Parameter:	$P_g$		
Data unit:	Pa gague		
Description:	Actual operating pressure of the ammonia oxidation reactor		
Source of data to be used:	Pressure gauge		
Value of data applied for the purpose of calculating expected emission reductions in section B.5	Not needed.		
Description of measurement methods and procedures to be applied:	Each caprolactam production plant has two of AORs (Plant I : AOR-a, AOR-b, Plant II : AOR-c, AOR-d ), and the total ammonia input flows through the one lines in every plant. Accordingly, for both of AORs in the same plant, each actual operating pressure is measured by one device.		
	• Instrument Tag No.:		
	$P_g$	Instrument Tag No.	Location
	$P_{g-1}$	PI-1205	AOR-a
	AOR-b		
$P_{g-2}$	2PI-1205	AOR-c	Plant II(see Figure7)



		AOR-d	
	<ul style="list-style-type: none"> <li>• Measuring device : Existing Gauge pressure (Differential Pressure type) (Model : STG 944, Maker : Honeywell)</li> <li>• Measuring period : Continuous</li> <li>• Recording frequency : Continuous</li> <li>• Measuring range : 0~3 kg/cm<sup>2</sup>Gr</li> <li>• Accuracy : ± 0.1%</li> <li>• Data record : DCS system, New PC for back-up</li> </ul> <p>If the actual average daily operating pressure in the ammonia oxidation reactor is outside <math>P_{g,hist}</math> (permitted range) in any of AORs, the baseline N<sub>2</sub>O emissions for that period are capped at 5.4kgN<sub>2</sub>O/tonne of caprolactam conservatively applying the IPCC default value.</p>		
QA/QC procedures to be applied:	<ul style="list-style-type: none"> <li>• Capro's maintenance and testing regime (by ISO 14001 standard)</li> <li>• Calibration frequency: Every general turnaround (: 3 Year)</li> </ul>		
Any comment:	To check whether "normal" operation is undertaken.		

Data / Parameter:	$A_{OR,d}$										
Data unit:	tNH <sub>3</sub> /day										
Description:	Actual ammonia flow rate to the ammonia oxidation reactor (AOR)										
Source of data to be used:	Differential pressure transmitter with normalizing functions										
Value of data applied for the purpose of calculating expected emission reductions in section B.5	Not needed.										
Description of measurement methods and procedures to be applied:	<p>As for ammonia flow rate, the unit conversion of the volume flow rate (in normal condition) measured by the flow meter to the one of mass flow rate is as follows;</p> $x[\text{tNH}_3/\text{day}] = y [\text{Nm}^3 \text{NH}_3/\text{day}] \times 17.03/22.4 / 1,000$ <p>Each caprolactam production plant has two of AORs (Plant I: AOR-a, AOR-b, Plant II: AOR-c, AOR-d). In each plant, the total ammonia input flows through the one lines with one flower meter, and that is supplied into both of two AORs equally. So, every plant has one flow meter for measuring ammonia input. Therefore, in this project, 2 parameters of <math>A_{OR,d-1}</math>, and <math>A_{OR,d-2}</math> are set for each plant including corresponded two AORs.</p> <p>• Instrument Tag No.:</p> <table><tr><th><math>A_{OR,d}</math></th><th>Instrument Tag No.</th><th colspan="2">Location</th></tr><tr><td><math>A_{OR,d-1}</math></td><td>FI-1201</td><td>AOR-a</td><td>Plant I (see Figure6)</td></tr></table>			$A_{OR,d}$	Instrument Tag No.	Location		$A_{OR,d-1}$	FI-1201	AOR-a	Plant I (see Figure6)
$A_{OR,d}$	Instrument Tag No.	Location									
$A_{OR,d-1}$	FI-1201	AOR-a	Plant I (see Figure6)								



			AOR-b	Plant II(see Figure7)	
	$A_{OR,d-2}$	2FI-1201	AOR-c		
			AOR-d		
	For the $A_{OR,d-1}$ of AOR-a, AOR-b in Plant I				
	<ul style="list-style-type: none"><li>• Measuring device : Existing Differential Pressure Model : STD 924, Maker : Honeywell</li><li>• Measuring period : Continuous</li><li>• Recording frequency : Continuous</li><li>• Measuring range : 0~2500 Nm<sup>3</sup>/hr</li><li>• Accuracy : ± 0.1% Span</li><li>• Data record : DCS system, New PC for back-up</li></ul>				
	For the $A_{OR,d-2}$ of AOR-c, AOR-d in Plant II				
	<ul style="list-style-type: none"><li>• Measuring device : Existing Differential Pressure Model : STD 924, Maker : Honeywell</li><li>• Measuring period : Continuous</li><li>• Recording frequency : Continuous</li><li>• Measuring range : 0~2000 Nm<sup>3</sup>/hr</li><li>• Accuracy : ± 0.1% Span</li><li>• Data record : DCS system, New PC for back-up</li></ul>				
	If the daily ammonia input to the oxidation reactor ( $A_{OR,d}$ ) exceeds maximum historical ammonia input to oxidation reactor ( $A_{OR,hist}$ ) in any AOR, the baseline N <sub>2</sub> O emissions for that period are capped at 5.4kg N <sub>2</sub> O/tonne of caprolactam conservatively applying the IPCC default value.				
	QA/QC procedures to be applied:	<ul style="list-style-type: none"><li>• Capro’s maintenance and testing regime (by ISO 14001 standard)</li><li>• Calibration frequency: Every general turnaround (: 3 Year)</li></ul>			
	Any comment:	To check whether “normal” operation is undertaken			

<b>Data / Parameter:</b>	$G_{sup}$
Data unit:	-
Description:	Supplier of the ammonia oxidation catalyst
Source of data to be used:	Supplier information on the purchase order record
Value of data applied for the purpose of calculating expected emission reductions in section B.5	Johnson Matthey
Description of measurement methods	Capro will most likely use above catalyst supplier in the future. However, Capro does not guarantee to use only the same supplier in the future. So the supplier's





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and procedures to be applied:	information will be monitored.
QA/QC procedures to be applied:	Not needed
Any comment:	No.

<b>Data / Parameter:</b>	<b><math>G_{com}</math></b>
Data unit:	%
Description:	Composition of the ammonia oxidation catalyst
Source of data to be used:	Catalyst information on the purchase order record
Value of data applied for the purpose of calculating expected emission reductions in section B.5	Pt (90)% : Rh(10)%
Description of measurement methods and procedures to be applied:	<p>Capro has been using the catalyst of above composition for all of AORs and has no reason to change its composition particularly in the future. However this will be monitored.</p> <ul style="list-style-type: none"> <li>• Recording frequency : Date of changing gauze composition</li> <li>• Data record : New PC for back-up</li> </ul>
QA/QC procedures to be applied:	Not needed
Any comment:	No.

<b>Data / Parameter:</b>	<b><math>Type_{NG}</math></b>
Data unit:	
Description:	Type of hydrocarbon
Source of data to be used:	Hydrocarbon supplier
Value of data applied for the purpose of calculating expected emission reductions in section B.5	<p>Natural gas supplier : KyungDong city gas CO., Ltd.</p> <p>This company is one of the city gas companies in the Republic of Korea. The most of natural gas supplied by KyungDong city gas CO., Ltd. is provided from Korea Gas Corporation (hereafter, KOGAS), which imports natural gas from around the world and supplies it to power generation plants, gas-utility companies and city gas companies throughout the country.</p>
Description of measurement methods and procedures to be applied:	This parameter will be monitored.
QA/QC procedures to	Not needed



be applied:	
Any comment:	No

Data / Parameter:	$Q_{NG,y}$			
Data unit:	Nm <sup>3</sup>			
Description:	Natural gas input for re-heating the tail gas			
Source of data to be used:	Flow meter with normalizing functions			
Value of data applied for the purpose of calculating expected emission reductions in section B.5	For the DF corresponding to each plant, this value is derived on the ground of the Technical Proposal by Hyosung Ebara Engineering Co., Ltd. as the following;			
		Plant I	Plant II	
	$Q_{NG,hr}$ as Nm <sup>3</sup> /hr	34.5	41.4	
	$Q_{NG,y}$ as Nm <sup>3</sup> /yr	300564	354715	
	Year-base input value of natural gas $Q_{NG,y}$ is from the hourly taking amount and operating time as follows:			
	$Q_{NG,y}$ (Nm <sup>3</sup> /yr ) = $Q_{NG,y}$ (Nm <sup>3</sup> /hr ) × 24hr /day × D day/yr			
	Where,			
	D : the number of historical maximum operating days per year since 31,Dec., 2005			
	Here, 363 day/yr is adopted for Plant I and 357 day/yr is for Plant II.			
	24 : the number of operating time for a day			
For this project, the actual measuring value will be adjusted to the parameter in the normal condition.	• Instrument Tag No.:			
	$Q_{NG,y}$	Instrument Tag No.	Location	
	$Q_{NG-1}$	FI-1523	Plant I (see the Figure 6)	
	$Q_{NG-2}$	2FI-1523	Plant II(see the Figure 7)	
	• Measuring device : Flow meter with normalizing functions			
	• Measuring period : Continuous			
	• Recording frequency : Daily			
	• Data record : Electronic Evaluation Unit, New PC for back-up			
	QA/QC procedures to be applied:	• Capro’s Maintenance and testing regime (by ISO 14001 standard) • Calibration frequency: Every general turnaround ( :3 Year)		
	Any comment:	No.		



<b>Data / Parameter:</b>	$CF_{CH_4}$
Data unit:	-
Description:	Methane content of hydrocarbon (natural gas)
Source of data to be used:	Natural gas content provided by the fuel supplier
Value of data applied for the purpose of calculating expected emission reductions in section B.5	0.8891  This value is based on the data source offered by natural gas supplier.
Description of measurement methods and procedures to be applied:	Although the methane content of the natural gas does not significantly affect the project emissions, this parameter will be monitored once prior to the project start and daily after the project start.
QA/QC procedures to be applied:	Not needed
Any comment:	No.

Data / Parameter:	$Q_{CH_4,y}$		
Data unit:	Nm <sup>3</sup> /yr		
Description:	Methane part of the natural gas used.		
Source of data to be used:	Calculated by measured natural gas input and the methane content of the natural gas provided by the natural gas supplier		
Value of data applied for the purpose of calculating expected emission reductions in section B.5			
		Plant I	Plant II
	$Q_{CH_4,y}$ as Nm <sup>3</sup> /yr	267231	315377
	Year-base input value of $Q_{CH_4,y}$ is calculated :		
	$Q_{NG,y}$ (Nm <sup>3</sup> /yr ) = $Q_{NG,y}$ (Nm <sup>3</sup> /yr) × $CF_{CH_4}$		
Where;			
$Q_{NG,y}$ : Natural gas input measured in a year y [Nm <sup>3</sup> /yr]			
$CF_{CH_4}$ : Methane content of the natural gas provided by the fuel supplier.			
For now this value is set as the following;			
$Q_{NG,y}$ is 300564 Nm <sup>3</sup> /yr for Plant I and 354715 Nm <sup>3</sup> /yr is for Plant II in Capro.			
$CF_{CH_4}$ is 0.8891			
For this project, the actual measuring value will be adjusted to the parameter in the normal condition.			



Description of measurement methods and procedures to be applied:	As stated previously, this parameter is calculated by natural gas input measured by orifice flow meter with normalizing function ( $Q_{NG,y}$ ) and the methane content ( $CF_{CH4}$ ) of the natural gas provided by the fuel supplier. This parameter will be monitored once prior to the project start and daily after the project start.
QA/QC procedures to be applied:	The same as $Q_{NG,y}$
Any comment:	No

Data / Parameter:	$Q_{HC,y}$		
Data unit:	Nm <sup>3</sup>		
Description:	The hydrocarbon with two or more molecules of carbon in natural gas used		
Source of data to be used:	Calculated by measured natural gas input and the methane content of the natural gas provided by the fuel supplier,		
Value of data applied for the purpose of calculating expected emission reductions in section B.5			
		Plant I	Plant II
	$Q_{HC,y}$ as Nm <sup>3</sup> /yr	33333	39338
	$Q_{HC,y} = Q_{NG,y} \times (1 - CF_{CH4})$		
	Where; $Q_{NG,y}$ : Natural gas input measured in a year y [Nm <sup>3</sup> ] $CF_{CH4}$ : Methane content of the natural gas provided by the fuel supplier  For now this value is set as the following; $Q_{NG,y}$ is 300564 Nm <sup>3</sup> /yr for Plant I and 354715 Nm <sup>3</sup> /yr is for Plant II in Capro. $CF_{CH4}$ is 0.8891  For this project, the value converted into the normal condition is applied as this parameter.		
Description of measurement methods and procedures to be applied:	As stated previously, this parameter is calculated by natural gas input measured by orifice flow meter with normalizing function ( $Q_{NG,y}$ ) and the methane content ( $CF_{CH4}$ ) of the natural gas provided by the fuel supplier. This parameter will be once prior to the project start and daily after the project start.		
QA/QC procedures to be applied:	Not needed		
Any comment:	No.		

<b>Data / Parameter:</b>	$\rho_{NG}$
Data unit:	t/Nm <sup>3</sup>
Description:	Density of the natural gas
Source of data to be	Natural gas density provided by the fuel supplier



used:	
Value of data applied for the purpose of calculating expected emission reductions in section B.5	0.000798 t/Nm <sup>3</sup>  For now, this value is set based on data source by natural gas supplier. For this project, the value converted into the normal condition is applied as this parameter.
Description of measurement methods and procedures to be applied:	Although the density of the natural gas makes little impact on the project emissions, the parameter will be monitored once prior to the project start and monthly after the project start.  <ul style="list-style-type: none"> <li>• Recording frequency : Yearly</li> <li>• Data record : New PC for back-up</li> </ul>
QA/QC procedures to be applied:	Not needed
Any comment:	No

<b>Data / Parameter:</b>	$\rho_{HC}$
Data unit:	t/m <sup>3</sup>
Description:	Density of the hydrocarbon with two or more molecules of carbon in natural gas
Source of data to be used:	Calculated by methane content/density of the natural gas provided by the fuel supplier and specified methane density
Value of data applied for the purpose of calculating expected emission reductions in section B.5	0.001452 tHC/m <sup>3</sup>  $\rho_{HC} = (\rho_{NG} - \rho_{CH_4} \times CF_{CH_4}) / (1 - CF_{CH_4})$ <p>Where;</p> <p><math>\rho_{NG}</math>: Density of the natural gas provided by the Natural gas supplier, and for now, 0.000798 t/m<sup>3</sup>.</p> <p><math>\rho_{CH_4}</math>: Density of the methane gas, which is the characteristic number of 0.000716t /m<sup>3</sup>.</p> <p><math>CF_{CH_4}</math>: Methane content of the natural gas provided by the fuel supplier, and for now, 0.8891.</p>
Description of measurement methods and procedures to be applied:	As stated previously, this parameter is calculated by methane content ( $CF_{CH_4}$ ), the density ( $\rho_{NG}$ ) of the natural gas provided by the fuel supplier and specified methane density ( $\rho_{CH_4}$ ). These parameters will be monitored once prior to the project start. Furthermore, after the project start, methane content will be daily monitored and methane density will be monthly monitored.  <ul style="list-style-type: none"> <li>• Recording frequency : Yearly</li> <li>• Data record : New PC for back-up</li> </ul>
QA/QC procedures to be applied:	Not needed
Any comment:	No



<b>Data / Parameter:</b>	<b><math>EF_{NG}</math></b>
Data unit:	tCO <sub>2</sub> /tNG
Description:	Emission factor of the natural gas
Source of data to be used:	Data provided by the natural gas supplier
Value of data applied for the purpose of calculating expected emission reductions in section B.5	<p>2.798 tCO<sub>2</sub>/tNG</p> <p>This value is calculated by following equation</p> $EF_{NG} = COEF_{NG} \times NCV_{NG} / \rho_{NG} \times 44/12$ <p>Where</p> <p><math>COEF_{NG}</math> : Carbon Emission factor of natural gas [tC/TJ] 15.3[tC/TJ] is applied to this project as Ex-ante value by IPCC DEFAULT VALUES OF CARBON CONTENT of “Natural Gas” in TABLE 1.3 (2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2, Energy)</p> <p><math>NCV_{NG}</math> : Net calorific value of the natural gas [TJ/Nm<sup>3</sup>] For this project, 9500 kcal/Nm<sup>3</sup> is offered by Natural gas supplier. 9500 kcal/Nm<sup>3</sup> is able to be converted to 3.9775×10<sup>-5</sup> TJ/Nm<sup>3</sup></p> <p><math>\rho_{NG}</math> : Density of the natural gas[t/Nm<sup>3</sup>] For this project, 0.000798 t/Nm<sup>3</sup> is set based on data source by Natural gas supplier.</p>
Description of measurement methods and procedures to be applied:	<p>As stated previously, this parameter is estimated by Emission factor of natural gas (<math>COEF_{NG}</math>) specified by IPCC default value. The net calorific value (<math>NCV_{NG}</math>) and density (<math>\rho_{NG}</math>) of the natural gas are provided by the fuel supplier.</p> <p>These parameters will be monitored once prior to the project start and monthly after the project start.</p> <ul style="list-style-type: none"> <li>• Recording frequency : Yearly</li> <li>• Data record : New PC for back-up</li> </ul>
QA/QC procedures to be applied:	Not needed
Any comment:	No

<b>Data / Parameter:</b>	<b><math>EF_{HC}</math></b>
Data unit:	tCO <sub>2</sub> /tNG
Description:	Emission factor of the hydrocarbon with two or more molecular of carbon, which is existed as a contents of the natural gas
Source of data to be used:	<p>Calculated based on the followings:</p> <p>Methane content offered by the fuel supplier ;</p>



	The density of the natural gas provided by the fuel supplier ; Estimated emission factor of the natural gas, and Specified methane density.
Value of data applied for the purpose of calculating expected emission reductions in section B.5	<p>2.99 tCO<sub>2</sub>e/tHC</p> <p>It is the major part of hydrocarbon except for CH<sub>4</sub> in the natural gas that ethane, propane and CO<sub>2</sub> (refer Annex 3).</p> <p><math>EF_{HC}</math> is calculated by the following equation ;</p> $EF_{HC} = (EF_{NG} \times \rho_{NG} - EF_{CH_4} \times \rho_{CH_4} \times CF_{CH_4}) / (1 - CF_{CH_4}) / \rho_{HC}$ <p>Where</p> <p><math>EF_{NG}</math> : CO<sub>2</sub> emission factor of NG[tCO<sub>2</sub>/tNG] For this project, 2.798 [tCO<sub>2</sub>/tNG] is taken as described above</p> <p><math>\rho_{NG}</math> : Density of natural gas (tNG/m<sup>3</sup>) The value <math>\rho_{NG}</math> for this is 0.000798 (tNG/ m<sup>3</sup>) in this project</p> <p><math>EF_{CH_4}</math> : CO<sub>2</sub> emission factor of CH<sub>4</sub>(tCO<sub>2</sub>/tCH<sub>4</sub>) 2.75(tCO<sub>2</sub>/tCH<sub>4</sub>) by theoretical calculation.</p> <p><math>\rho_{CH_4}</math> : Density of methane (tCH<sub>4</sub>/ m<sup>3</sup>), 0.000716 as a characteristic number</p> <p><math>CF_{CH_4}</math> : Methane fraction in the natural gas 0.8891 is set based on data source by Natural gas supplier</p>
Description of measurement methods and procedures to be applied:	<p>Calculated by the data of natural gas and methane</p> <p>These parameters will be monitored once prior to the project start and monthly after the project start.</p> <ul style="list-style-type: none"> <li>• Recording frequency : Yearly</li> <li>• Data record : New PC for back-up</li> </ul>
QA/QC procedures to be applied:	Not needed
Any comment:	No

<b>Data / Parameter:</b>	<b><math>SE_{N_2O}</math></b>
Data unit:	kgN <sub>2</sub> O/tCaprolactam
Description:	N <sub>2</sub> O emission rate per ton of caprolactam
Source of data to be used:	Monitoring Reports
Value of data applied for the purpose of calculating expected emission reductions in section B.5	<p>5.4 kgN<sub>2</sub>O/tCaprolactam</p> <p>For now, this value is set by the conservative IPCC default value of caprolactam production plants which is based on the default emission factor for Raschig process. (9kg N<sub>2</sub>O/tonne of caprolactam, accounting for 40% uncertainty factor)</p>



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Description of measurement methods and procedures to be applied:	<p>This parameter is calculated by the baseline N<sub>2</sub>O emission and the caprolactam production during the project as follows;</p> $SE_{N_2O} = BE_y / P_{product,y} / GWP_{N_2O}$ <ul style="list-style-type: none"> <li>Recording frequency : Yearly</li> <li>Data record : New PC for back-up</li> </ul>
QA/QC procedures to be applied:	Not needed
Any comment:	This value is to be used for cap of the baseline emission in case that N <sub>2</sub> O regulation starts.

Data / Parameter:	CO <sub>CH4</sub>		
Data unit:	ppm (v)		
Description:	Methane concentration at destruction facility outlet.		
Source of data to be used:	Non-dispersion infrared absorption analyzer with dual-channel as a gas path		
Value of data applied for the purpose of calculating expected emission reductions in section B.5	Not need		
Description of measurement methods and procedures to be applied:	• Measuring Device : Non-dispersion infrared absorption analyzer, (ULTRAMAT 6, SIEMENS), dual-channel type Shared with NDIR for measuring CO <sub>N2O</sub>		
	• Measuring period : Continuous		
	• Measuring point : The same with CO <sub>N2O</sub>		
	• Recording frequency : Daily		
	• Data record : Electronic Evaluation Unit, New PC for back-up		
	• This parameter will be expressed in normal condition.		
	• Instrument Tag No.:		
	CO <sub>CH4</sub>	Instrument Tag No.	Location
	CO <sub>CH4-1</sub>	AIT-1523	Plant I (see the Figure 6)
	CO <sub>CH4-2</sub>	2AIT-1523	Plant II(see the Figure 7)
QA/QC procedures to be applied:	Capro’s Maintenance and testing regime (by ISO 14001 standard)		
Any comment:	No.		

<b>Data / Parameter:</b>	<b>OXID<sub>CH4</sub></b>
Data unit:	%
Description:	Oxidation factor of CH <sub>4</sub> in natural gas for re-heating tail gas





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Source of data to be used:	Calculated by $CO_{CH_4}$ , $Q_{CH_4}$ , and $F_{TEi}$
Value of data applied for the purpose of calculating expected emission reductions in section B.5	<p>99.5%</p> <p>Here,  <math>CH_4</math> in the natural gas used for re-heating DF is expected to be oxidized totally. However the instrumental error of the <math>CH_4</math> analyser to be installed at the destruction facility outlet is regarded as to be less than 0.5%. Therefore Oxidation factor of methane, <math>OXID_{CH_4}</math>, is conservatively established to be 99.5%.</p> <p>This parameter is calculated for monitoring as follows;</p> $OXID_{CH_4} = \{ Q_{CH_4} - (\sum_i^n F_{TE,i} \times CO_{CH_4,i} \times 10^{-6}) \} / Q_{CH_4} \times 100$
Description of measurement methods and procedures to be applied:	<p>Calculated by <math>CO_{CH_4}</math>, <math>Q_{CH_4}</math>, and <math>F_{TEi}</math></p> <ul style="list-style-type: none"> <li>• Recording frequency : Daily</li> <li>• Data record : New PC for back-up</li> </ul>
QA/QC procedures to be applied:	Not needed
Any comment:	No

<b>Data / Parameter:</b>	<b><math>Reg_{NOx}</math></b>
Data unit:	tNO <sub>x</sub> /Nm <sup>3</sup>
Description:	National regulation on NO <sub>x</sub> emissions
Source of data to be used:	The “Clean Air Conservation Act”, one of the National environmental legislation, Ministry of Environment
Value of data applied for the purpose of calculating expected emission reductions in section B.5	<p><math>4.10714 \times 10^{-7}</math> tNO<sub>x</sub>/Nm<sup>3</sup> (as a NO<sub>2</sub> concentration)</p> <p>Calculated.  According to Article 5 of the Enforcement Regulation Of The Clean Air Conservation Act, the highest permit limit for NO<sub>x</sub> emission is 200 ppm(v) as a NO<sub>2</sub> concentration level.</p>
Description of measurement methods and procedures to be applied:	<p>The information for changing NO<sub>x</sub> regulations will be monitored every three months, checking public information from the local government.</p> <ul style="list-style-type: none"> <li>• Recording frequency : Date of Regulation</li> <li>• Data record : New PC for back-up</li> </ul>
QA/QC procedures to be applied:	Not needed
Any comment:	This is used to check whether the host company complies with the regulation.



<b>Data / Parameter:</b>	<b><math>RSE_{N_2O,y}</math></b>
Data unit:	tNO <sub>x</sub> /tCaprolactam
Description:	Regulatory limit of N <sub>2</sub> O emissions per unit of outlet of caprolactam (tN <sub>2</sub> O/t caprolactam)
Source of data to be used:	<p>National legislation in Republic of Korea. (That may be mostly like environmental regulation.)</p> <p>In case national regulations concerning N<sub>2</sub>O emissions are implemented during the crediting period, the impact on baseline N<sub>2</sub>O emissions is considered without any delay by adjusting the measured N<sub>2</sub>O emissions at the time the regulation has to be implemented.</p>
Value of data applied for the purpose of calculating expected emission reductions in section B.5	<p>No. There is no mandatory regulation for N<sub>2</sub>O emission in the Republic of Korea at present.</p> <p>Change in N<sub>2</sub>O regulations will automatically cause a re-assessment of the baseline scenario.</p>
Description of measurement methods and procedures to be applied:	<p>In case of that the new national regulations concerning N<sub>2</sub>O emissions is provided in the future, the baseline emissions are automatically re-assessed according to the latest version of AM0028.</p> <ul style="list-style-type: none"><li>• Recording frequency : Date of Regulation</li><li>• Data record : New PC for back-up</li></ul>
QA/QC procedures to be applied:	Not needed
Any comment:	Change in N <sub>2</sub> O regulations will automatically cause a re-assessment of the baseline scenario.

**B.7.2. Description of the monitoring plan:**

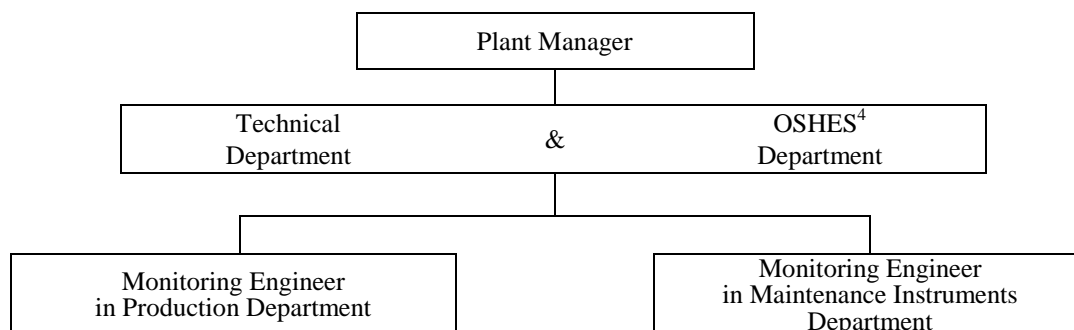
&gt;&gt;

The purpose of Monitoring Plan (MP) is to provide standard by which Capro to conduct monitoring and record consistent data necessary for the verification of the Project. The monitoring methodology for the Project is in compliance with the monitoring methodology AM0028/Version04.2.

**1. Organization Structure with Management & Operation Process**

The participant in charge of the project operation is Capro. Therefore Capro will establish the operational and management structure that the project operator will implement in order to monitor emission reductions and any leakage effects generated by the project activity.

A scheme of the operational and management structure is described as Figure 8.



**Figure 8. The scheme of the operational and management structure**

Capro has supervised and measured the operation parameter for a long time before this project. Therefore Capro has the well-organized system and the experienced monitoring engineers for measuring and maintaining. These monitoring engineers also will take the responsibility for monitoring the parameters and for maintaining the instrument associated with this project. The calibrations for instruments are concerned by the monitoring engineer in maintenance instruments department. The Technical Department performs the work to collect data, to make reports periodically, and to archive the required data and reports for verification. The OSHES Department play a role for indicating the direction and managing according to the monitoring plan including Capro's Maintenance and Testing regime by ISO 14001 standard.

All required data will be automatically monitored and recorded onto the electronic media. If some data deviation is discovered, the monitoring engineer under the Production Department will check the operating parameters of the caprolactam plant to grasp the source of the deviation, and fix the cause. However if the monitoring engineer under Production Department find out no problem from the operating parameters, he will inform immediately to the other monitoring engineer assigned to Instruments Department. Then, this monitoring engineer under Instruments Department will correct the error after inspecting all gauges and analysers. Both of the monitoring engineers will document the abnormal event and notify to the Technical Department and the OSHES Department. The staffs in

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<sup>4</sup> Occupational Safety, Health and Environment



Technical Department will make a daily report including that abnormal event documented by monitoring engineers.

## **2. Layout of the Monitoring Points:**

Figure 6 and 7 (Section B.7) are referable.

## **3. Data Management Systems**

Plant I and II already have an independent DCS (Distributed Control System), and the data of AOR operating parameters ( $A_{or}$ ,  $T_g$ ,  $P_g$ ) will be logged and stored by existing DCS.

Besides, New DAS (Data Acquisition System) will be installed for logging the data from the project boundary at each plant. This new DAS belonged to each plant consists of a 'Data Communication Unit (D-MS 500KE, DURAG)' and an 'Electronic Evaluation Unit (D-EMS 2000, DURAG)'.

Data Communication Unit (here after, DCU) is connected to 'Electronic Evaluation Unit (here after, EEU)'. DCU records the raw measurement data and transmits those to EEU. Major function of DCU is the intermediated data storage with the ring memory of 16days minute values.

The EEU for this project satisfies the minimum requirements described in AM0028 (version 04.2) as below:

- (a) Evaluation unit needs to take into account registration, mean average determination, validation, and evaluation;
- (b) The system and concept of emission data processing needs to be described;
- (c) Protocols and out-prints are required.

Therefore, the raw measurement data required for identifying the  $N_2O$  decomposition amount and  $CH_4$  emission caused by each DF operating is recorded on DCU and transmitted to EEU. And the hourly average value is validated by EEU at the end of the integration interval from the integral values of the raw measurement data by subtracting the measurement uncertainty as a constant value. Then, negatively validated average values will be set to zero. The daily average values are formed as the arithmetic mean of the validated hourly average values. The calibration curve for the measuring instrument is determined using a standard reference method. The validity of the calibration curve is proved by EEU. The validity range for the calibration is specified in the calibration report. This calibration report will be printed and kept for back-up.

Validated average values outside the valid calibration range are to be stored with the associated time and with their status and are to be logged on EEU at the end of the day and year.

Even though EEU does not only fulfils the requirement of AM0028 but also has a storage function, additional "New PC" will be installed for back-up and long storage of the data and reports for verification, since the storage capacity of EEU with only 5year-ring memory is not enough to keep them all safely during the crediting period plus 2 years according to AM0028.

This new PC for back-up will collect and store not only the data and reports transmitted from all of DCS and DAS in two plants, but also the other data and parameters excepting the data from DCS and DAS.



Moreover, some of data which should be generated by calculation using other parameters and/or data are estimated, recorded and reported for appropriate monitoring. All of the report and documents are able to be recorded and printed by this new PC for back-up.

Supposing that no operator is required to the all the monitoring systems composted by a pair of the existing DCS, new DAS and the new PC for back-up to integrate and save all data and report, monitoring engineers will be disposed to ensure that the system is in normal operation and take necessary action to follow the monitoring plan.

The personnel of Technical Department will investigate the data from DAS and DCS, and will make back-up data periodically.

For verification, the following reports and information will be documented.

- Daily reports with all integral values incl. status information
- Monthly reports with all daily average values including status information
- Annual reports with all monthly average values including status information
- Documentation of failure of AMS for the operator's information
- Three QALs and AST performance record for AMS

The logging data and all reports printed out from the system are kept during the credit period plus 2 years.

#### **4. Quality Assurance for AMS**

According to approved monitoring methodology AM0028(version 04.2), the accuracy of the N<sub>2</sub>O emissions monitoring results is to be ensured by installing a monitoring system that has been certified to meet (or exceeds) the requirements of the prevailing best industry practice or monitoring standards in terms of operation, maintenance and calibration. This monitoring methodology is also guide that the latest applicable European standards and norms (EN 14181) or equivalent standards, which prescribes the features needed for “Automated Measuring Systems (AMS)” and how they are to be calibrated and maintained, shall be used as the basis for selecting and operating the monitoring system.

Because AMS will be applied to measure N<sub>2</sub>O emission in this project, the latest applicable EN 14181 is adopted as the standards to choose the monitoring system for analyzing N<sub>2</sub>O emission. Besides, this selected system will be calibrated and maintained in compliance with EN 14181(: Quality assurance of automated measuring systems, 2004).

EN 14181 stipulates three levels of quality assurance tests (QALs) and one annual functional test for AMS which are recommended to be used as guidance regarding the selection, installation and operation of the AMS under the monitoring methodology. The three QALs and one annual functional test with corresponding monitoring plan related with AMS are as follows:

##### **(1) QALI: Quality assurance of tested AMS.**

QAL 1 specifies the suitability of a measuring instrument by calculating the total measuring uncertainty in accordance with EN ISO 14956 prior to installation. AMS equipped at instrument must have performance certificate (e.g. MCERTS) according to approved methods such as ISO 14956.



This project will be performed at two plants in Capro, Plant I and Plant II. A De-NO<sub>x</sub> System will be facilitated for each plant independently. One pair of the N<sub>2</sub>O concentration analyzers and the volume flow meters for tail gas is installed at before and after every De-N<sub>2</sub>O systems. All of the N<sub>2</sub>O analyzers and tail gas flow meters will have MCERTS certifications according to QAL1 requirement.

For this project, Non-Dispersive Infrared Absorption Photometer (SIEMENS, Model: ULTRAMAT 6) will be equipped as the N<sub>2</sub>O concentration analyzer, and Pitot-Tube with D/P Transmitter (D-FL-100, DURAG) will be set to measure tail gas flow rate. The equipment characteristics for these models are described at the Annex 4.

### **(2) QAL2: Quality assurance of installation and calibration testing of AMS**

AM0028(version 04.2) require Quality assurance of installation and calibration of the AMS according to the Standard Reference Measurement Method (SRM) shall be accomplished in order to determine the measurement uncertainty/variability of the AMS and to inspect the compliance with the prescribed measurement uncertainties.

On purpose to comply with AM0028 in this project, such Quality assurance test will be carried out for all of the N<sub>2</sub>O analyzers and tail gas flow meters by organizations that have an accredited quality assurance system such as one according to ISO/IEC 17025 or relevant standards. Items to be considered include the following:

- (a) Selection of the location of measurement;
- (b) Duly installation of the monitoring equipment;
- (c) Correct choice of measurement range;
- (d) Calibration of the AMS using the Standard-Reference-Method (SRM) as guidance;
- (e) Calibration curve either as linear regression or as straight line from absolute zero to centre of a scatter-plot;
- (f) Calculation of the standard deviation at the 95% confidence interval;
- (g) Inspection every three years.

### **(3) QAL3: Continuous quality assurance through the local operator/manager**

(drift and accuracy of the AMS, verification management and documentation).

Continuous Quality Assurance by the operator will be performed to meet the direction of AM0028 (version 04.2) . The contents mentioned below shall be performed according to requirement of QAL3.

- (a) Permanent quality assurance during the plant operation by the operating staff;
- (b) Assurance of reliable and correct operation of the monitoring equipment (maintenance evidence);
- (c) Regular controls: zero point, span, drift, meet schedule of manufacturer maintenance intervals;

Calibrations for the N<sub>2</sub>O analyzer and the tail gas flow meter are performed regularly by monitoring engineer in maintenance instruments department. The validity range for the calibration is specified in the calibration report. This calibration report will be recorded on Electronic Evaluation Unit of new DAS, and printed to be kept for back-up.

In case of the N<sub>2</sub>O analyzer(NDIR: SIEMENS, Model: ULTRAMAT 6), the calibration will be performed by using calibration gases (air as zero gas and standard gas as span gas) for N<sub>2</sub>O analyzer



according to the manufacturer's instructions by using calibration periodically. For the tail gas flow meter, the calibration procedure is annually carried out by electronic method for the transmitter as per supplier's requirement.

**(4) AST: Annual surveillance test**

In addition to three QALs, Annual surveillance test (AST) will be carried out by organizations that have an accredited quality assurance system such as one according to ISO/IEC 17025 or relevant standards for this project.

AST means the annual functionality test including SRM measurements to check for uncertainties in the data measured by the AMS. Items to be considered include the following:

- (a) Annual confirmation of the calibration curve;
- (b) Validity proof of calibration curves;
- (c) Back-setting of excess meter of invalid calibration range.

**5. Provision of non-available data from AMS**

In the event that the monitoring system is down, the lowest between the conservative default value established in the methodology or the last measured by product rate (whichever the lower) will be valid and applied for the downtime period for the baseline emission factor, and the highest measured by product rate during the project activity will be applied for the downtime period for the campaign emission factor. Every procedure taken and calculated results shall be recorded.

**6. Training**

The supplier of the NDIR system will provide complete training to the monitoring engineers in charge of operation and maintenance of the monitoring system. The provider of the De-N<sub>2</sub>O system, Hyosung, will initiate the operation technique for the system to the staff in the Technical department of Capro.

<p><b>B.8. Date of completion of the application of the baseline study and monitoring methodology and the name of the responsible person(s)/entity(ies):</b></p>
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Date of completion of the application of the baseline study and monitoring methodology: 02/09/2009

The name of the responsible person and entity :

Dr. Soyoung Myung

GreenPolaris Co., Ltd.

[soyoung@greenpolaris.com](mailto:soyoung@greenpolaris.com)

**SECTION C. Duration of the project activity / crediting period****C.1. Duration of the project activity:****C.1.1. Starting date of the project activity:**

&gt;&gt;

The expected starting date is 02/11/2009. This project is not started yet.

**C.1.2. Expected operational lifetime of the project activity:**

&gt;&gt;

The estimated operational lifetime is approximately 10 years.

**C.2. Choice of the crediting period and related information:****C.2.1. Renewable crediting period:****C.2.1.1. Starting date of the first crediting period:**

&gt;&gt;

Not applicable

**C.2.1.2. Length of the first crediting period:**

&gt;&gt;

Not applicable

**C.2.2. Fixed crediting period:****C.2.2.1. Starting date:**

&gt;&gt;

01/09/2010 or date of CDM registration, whichever occurs later (The crediting period of a project activity can commence subsequent to the date of registration).

**C.2.2.2. Length:**

&gt;&gt;

10 years

**SECTION D. Environmental impacts**

&gt;&gt;

**D.1. Documentation on the analysis of the environmental impacts, including transboundary impacts:**

&gt;&gt;

According to relevant environmental law and regulations, no Environmental Impact Assessment (EIA) is required for the proposed project. The environmental impact assessment for this project activity was conducted by the professional engineer qualification of environment field.





The main conclusions of the Environmental Impact Assessment (EIA) are provided as follows:

**1. Air quality**

EIA report says that air pollutants resulting from a forklift and crane for the installation of N<sub>2</sub>O abatement facility are expected to be emitted. However, they will be such small amount of pollutants that they could not affect air quality. In addition, there is no additional pollution in operation phase of N<sub>2</sub>O abatement facility due to no additional fuel use. Consequently, the project may help improve the air quality around the project site by decreasing N<sub>2</sub>O emissions.

**2. Water environment**

The project have no impact on water pollution and no additional water is required for the project activity's implementation or operation except for using water for installer and operators. However, it is recovered and treated by existing treatment process.

**3. Noise impact**

No additional noise will occur compared with the existing process as N<sub>2</sub>O abatement facility for this project is installed after the existing caprolactam production unit as an additional facility and has no its own operating equipment such as motor.

**4. Used catalyst**

According to EIA reports, used catalysts from N<sub>2</sub>O abatement facility will occurs. However, they will be completely recovered and consigned to special waste treatment company. Therefore, there is no impact caused by used catalysts.

**D.2. If environmental impacts are considered significant by the project participants or the host Party, please provide conclusions and all references to support documentation of an environmental impact assessment undertaken in accordance with the procedures as required by the host Party:**

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Not applicable. The environmental Impact Assessment (EIA) is not necessary for this project activity under the laws and regulations in the Republic of Korea and Ulsan City.

**SECTION E. Stakeholders' comments**

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**E.1. Brief description how comments by local stakeholders have been invited and compiled:**

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The project participants held the stakeholders meeting to introduce the proposed project activity and compile stakeholders' comments on the project activity on 25<sup>th</sup> June 2009 at the auditorium within Capro. The information on the project activity is announced by local newspapers, which are Ulsan press on 22<sup>nd</sup> June 2009 and Ulsan daily newspaper on 23<sup>th</sup> June 2009. Released newspaper advertisements with the details of stakeholders meeting are shown in Figure 9 and the picture of stakeholders meeting is shown Figure 10.



(a) Ulsan daily newspaper



(b) Ulsan press

Figure 9. Released newspaper advertisements of stakeholders meeting



Figure 10. The stakeholders meeting

There were 59 stakeholders joined the meeting, the attendants are invited from various organizations such as local government organizations, neighbouring companies, chemical companies, Capro, Hyosung and Korea Environmental Preservation Association (KEPA) etc. Table 4 shows the list of attendants.

Table 4. The list of attendants

Organization		Attendants
Project participants	CAPRO CO., LTD.	37
	HYOSUNG EBARA ENGINEERING CO.,LTD.	5
Neighbouring Companies	HANJU COPORATION	3
	ISU CHEMICAL CO.,LTD.	1
	KOREA PETROCHEMICAL IND. CO.,LTD.	1
	TONGSUH PETORCHMICAL CO.,LTD	1
	KOLON INDUSTRIES, INC.	1
	KP CHEMICAL CORP.	1
	LIG ENUSLTING CO.,LTD.	1
	GREEN POLARIS CO.,LTD	1
Governmental Organisation	KOREA ENVIRONMENTAL PRESERVATION ASSOCIATION	2
Local Governmental Organisations	SEONAM DONG OFFICE	3
	ULSAN METROPOLITAN CITY HALL	2
Total		59

Plant manager in Capro, Mr. S.Y. Park performed a welcome address to the stakeholders and project team manager in Capro, Mr. C.W. Lee introduced Capro. In addition, Mr. J.H. Park, Senior manager in environment business department in Hyosung, made the presentation of climate change negotiation and Mr. H.J. Kim in project team in Capro explained proposed project activity. The project activity is fully explained to the attendants. Therefore, the stakeholders expressed their interest and supports on the project activity and raised two questions about the project. Capro appropriately answered the questions raised at the meeting. In addition, the opinions were collected in the form of questionnaires. The questionnaires were distributed and 46 stakeholders out of 59 ones filled out the questionnaires. Reporting material of stakeholders meeting is shown in Figure 11.



Figure 11. Reporting material for stakeholders meeting

**E.2. Summary of the comments received:**

&gt;&gt;

The questions raised by stakeholders participated in the meeting are briefly summarized as follows:

1. Does the proposed project activity affect the existing yield? If so, does it cause any problem related to employment?
2. Is there any new occurring pollutants resulting from N<sub>2</sub>O abatement system for this project?

Moreover, the following table shows questionnaires as Table 5:

**Table 5. The list of Questions to the stakeholders**

No.	Questions to the stakeholders	Number of people	
		Yes	No
1	Have you ever heard of CDM (Clean Development Mechanism)?	42	4
2	Do you know that N <sub>2</sub> O (nitrous oxide) is a GHG (Greenhouse Gas)?	41	5
3	Is your company or the organization you are working for / you are presenting influenced by this CDM-Project?	32	14
4	Do you think that the Republic of Korea is affected by the climate change these days?	45	1
5	Do you think that the Republic of Korea shall take efforts towards reducing greenhouse gas emission within Korea?	45	0
6	Do you consider this CDM-project as being “additional”?	45	0
7	Do you think that this project has more positive effect on the global environment as a whole?	45	0
8	Do you think that this project is able to contribute to improve the air quality of Ulsan Metropolitan City?	44	1
9	Would you recommend to other private companies, to develop this kind of project under the Clean Development Mechanism?	43	2
10	Do you consider that Capro Co., Ltd. and Hyosung Ebara Eng Co., Ltd.’s N <sub>2</sub> O abatement project will contribute to sustainable development of the region and the republic of Korea?	45	0
11	In relation with the information that you have and your knowledge about environmental issues, climate change, Kyoto Protocol, Clean Development Mechanism and Global Carbon Market: Please express your opinion on the Capro CDM project	6	
12	If you have any other opinion, please feel free to describe.	1	

Opinions regarding the question 11 in questionnaire as follows:

- To respond to climate change respond is very positive under the condition that the related regulation and laws is becoming more district.
- The propose project should be conducted rapidly since it is little bit late considering the validation of CDM.



- The proposed project will contribute to air quality improvement in Ulsan Metropolitan City and prevention from global warming.
- The abatement facility for preventing GHG (Greenhouse Gas) is essential in the terms of the prevention of global warming and unexpected climate change.
- Such project with greenhouse gas including high GWP (Global Warming potential) will contribute to not only improving the environment but also Capro's management.
- It would be better for Capro to receive as much CERs (Certificate Emission Reduction) as possible through this project for the preparation of Post-Kyoto.

Opinion regarding the question 12 in questionnaire as follows:

- Sustainable efforts are required to contribute to not only developing local community and country but also green global environment through this project.

<b>E.3. Report on how due account was taken of any comments received:</b>
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>>

The questions raised by stakeholders participated in the meeting are answered as detailed as possible, the answers are briefed as follows:

1. The proposed project does not affect existing yield since applicable N<sub>2</sub>O abatement facility for this project is installed after the existing caprolactam production unit as an additional facility and AM 0028 was applied as CDM methodology at the beginning.
2. According to EIA (Environmental Impact Assessment). There is no additional pollution resulting from N<sub>2</sub>O abatement system. Especially, used catalysts from N<sub>2</sub>O abatement facility will occur. However, they will be completely recovered and consigned to special waste treatment company.

Consequently, the result of questionnaires is summarized as follows:

Most of the attendants had the basic knowledge of current environmental issues such as climate change, Kyoto Protocol and Clean Development Mechanism. Therefore, it is not difficult for project participants to explain the project activity. Moreover, they were mainly interested in how the project will affect local air quality and what the benefit is from the project. They all agreed that the project activity will contribute to improving the environment in local area and preventing the global warming.

**Annex 1****CONTACT INFORMATION ON PARTICIPANTS IN THE PROJECT ACTIVITY**

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**Annex 2**

**INFORMATION REGARDING PUBLIC FUNDING**

No public funding from Parties included in Annex I is used for this project activity.



**Annex 3****BASELINE INFORMATION****Production Information**

	Plant I	Plant II
Daily production (ton/day)	174.30	183.02
Maximum operating day (day/yr)	363	357
Design Capacity for each plant (ton/yr)	63271	65338
Design Capacity, $P_{product, max}$ (ton/yr)	128609	

All of ammonia oxidation reactors of the plants in Capro are keeping with the same as they were installed at the beginning.

Each plant of Capro's design capacity is established upon the maximum daily production and maximum operating days till 31 December 2005.

**Tail Gas Information (Before De-N<sub>2</sub>O Facility )**

		Plant I	Plant II
Flow Rate (in Normal Condition)		45000 Nm <sup>3</sup> /hr	49000Nm <sup>3</sup> /hr
Temperature (°C)		140	100
Pressure(mmH <sub>2</sub> O )		-100	-120
Composition	NO <sub>x</sub>	135ppm, as self-target (legal limit is <200ppm)	135ppm, as self-target (legal limit is <200ppm)
	N <sub>2</sub> O	$2.9464 \times 10^{-6}$ tN <sub>2</sub> O/ Nm <sup>3</sup>	$2.9464 \times 10^{-6}$ tN <sub>2</sub> O/ Nm <sup>3</sup>

**Technical Specification of the Abatement Technology Applied**

	Plant I	Plant II
N <sub>2</sub> O Abatement Performance	90% or more	90% or more
Natural gas consumption for reheating tail gas (designed by basis on maximum daily caprolactam production)	994 Nm <sup>3</sup> /day	1190 Nm <sup>3</sup> /day

**Natural Gas (as a reheating fuel) Information**

*Natural gas supplier* : Kyung Dong city gas CO., Ltd.

*Physical Property of Natural Gas*

Natural gas calorific value (kcal/Nm <sup>3</sup> )	LHV	9500kcal/Nm <sup>3</sup>
	HHV	10500 kcal/Nm <sup>3</sup>
Density of Natural gas (tNG/ Nm <sup>3</sup> )		0.000798
Specific Gravity		0.625
Methane Fraction in Natural Gas		0.8891
Stoichiometric air requirements Volume / Volume fuel (gases)		10.53

*Gas Composition (volume %)*

CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	C <sub>3</sub> H <sub>8</sub>	C <sub>3</sub> H <sub>6</sub>	N <sub>2</sub>	i-C <sub>4</sub> H <sub>10</sub>	n-C <sub>4</sub> H <sub>10</sub>	i-C <sub>6</sub> H <sub>12</sub>
88.91	8.93	-	1.34	0.02	0.36	0.38	0.06

**Parameters used to estimate emission reductions**

Parameters	Description	Value		Unit
		Plant I	Plant II	
$t$	Daily Operation time	24	24	hr/day
$D$	Operation day per year	363	357	day/yr
$n$	Number of intervals during the year	8712	8568	Cycle/yr
$M_i$	Length of Measuring interval	1	1	hr/cycle
$F_{Ti,i}$	Volume flow rate at the inlet of the destruction facility during interval	45000	49000	Nm <sup>3</sup> /hr
$F_{TE,i}$	Volume flow rate at the exit of the destruction facility during interval	45415	49498	Nm <sup>3</sup> /hr
$CI_{N_2O,i}$	N <sub>2</sub> O concentration in inlet of the tail gas of the N <sub>2</sub> O destruction facility during interval	$2.9464 \times 10^{-6}$	$2.9464 \times 10^{-6}$	tN <sub>2</sub> O/ Nm <sup>3</sup>
$CO_{N_2O,i}$	N <sub>2</sub> O concentration in outlet of the tail gas of the N <sub>2</sub> O destruction facility during interval	$2.9464 \times 10^{-7}$	$2.9464 \times 10^{-7}$	tN <sub>2</sub> O/ Nm <sup>3</sup>
$Q_{NG,y}$	Natural Gas used in year y	300564	354715	Nm <sup>3</sup> /yr
$Q_{CH_4,y}$	Methane used in year y	267231	315377	Nm <sup>3</sup> /yr



Parameters	Description	Value	Unit
$GWP_{CH_4}$	Global warming potential of $CH_4$	21	-
$GWP_{N_2O}$	Global warming potential of the nitrous oxide	310	-
$\rho_{CH_4}$	Density of methane	0.000716	t $CH_4$ /m <sup>3</sup>
$\rho_{NG}$	Density NG	0.000798	tNG/m <sup>3</sup>
$\rho_{HC}$	Density of HC	0.001452	tHC/m <sup>3</sup>
$CF_{CH_4}$	Methane Fraction in natural gas	0.8891	-
$NCV_{NG}$	Net Caloric Value of natural gas	$3.977 \times 10^{-5}$	TJ/Nm <sup>3</sup>
$EF_{CH_4}$	CO <sub>2</sub> emission factor of $CH_4$	2.75	tCO <sub>2</sub> e/t $CH_4$
$EF_{HC}$	CO <sub>2</sub> emission factor of HC	2.99	tCO <sub>2</sub> e/tHC
$EF_{NG}$	CO <sub>2</sub> emission factor of natural gas	2.798	tCO <sub>2</sub> e/tNG
$COEF_{NG}$	Carbon emission Factor of natural gas	15.3	tC/TJ
$OXID_{CH_4}$	Oxidation factor of methane	99.5	%
$OXID_{HC}$	Oxidation factor of hydrocarbon	100	%

### ***Permitted operating conditions of AOR***

#### ***Permitted AOR operating range of temperature and pressure***

In order to avoid that the operation of the caprolactam production plant is manipulated in a way to increase the N<sub>2</sub>O generation, thereby increasing the CERs, the following procedures relating to the operating temperature and pressure and the use of ammonia oxidation catalysts are required in accordance with the methodology.

- Firstly, data on historical temperature and pressure ranges; or, if no data on historical temperatures and pressures are available, then
- Secondly, by range of temperature and pressure stipulated in the operating manual for the existing equipment; or, if no operating manual is available or the operating manual gives insufficient information, then
- Thirdly, by literature reference (e.g., from Ullmann's Encyclopedia of Industrial Chemistry, Fifth, completely revised edition, Volume A 17, VCH, 1991, P. 298, Table 3. or other standard reference work or literature source).

In this project, methodological option a) and b) are available. Therefore, a) is applied as specified in the methodology. Historical AOR operating temperature and pressure as well as its ammonia consumption were measured and recorded using existing instruments and production monitoring system established



and operated by Capro.

Since, the historical data (1<sup>st</sup> Jan.2003 – 31<sup>st</sup> Dec.2005) on daily operating temperatures and pressures are available for this project, statistical analysis is used for determining the permitted range of operating temperature and pressure. To exclude the possibility of manipulating the process, outliers of historical operating temperature and pressure are eliminated by statistical methods. Therefore, the time series data are interpreted as a sample from a stochastic variable. All data that are part of the 2.5% Quantile or that are part of the (100-2.5) % Quantile of the sample distribution are defined as outliers and are eliminated. The permitted range of operating temperature and pressure is then calculated based on the remaining historical minimum and maximum operating conditions.

		$T_{g,hist-a}$	$T_{g,hist-b}$	$T_{g,hist-c}$	$T_{g,hist-d}$
$T_{g,hist}$	Available daily data number	986	986	984	984
	Daily average (°C)	719.38	735.63	754.43	745.17
	Lower limit of permitted range (°C)	677.27	690.63	717.67	726.25
	Upper limit of permitted range (°C)	742.02	756.06	770.10	765.99

		$P_{g,hist-1}$	$P_{g,hist-2}$
$P_{g,hist}$	Available daily data number	986	984
	Daily average (Pa gauge)	83944	83552
	Lower limit of permitted range (Pa gauge)	47268	54525
	Upper limit of permitted range (Pa gauge)	93752	93654

#### *Permitted maximum daily average Ammonia flow*

On the ground of AM0028(version 04.2), the upper limit on ammonia flow should be determined based on:

- Historical operating data on maximum daily average ammonia flow; or, if not existing; on
- Calculation of the maximum ammonia flow rate allowed as specified by ammonia oxidation catalyst manufacturer or on typical catalyst loadings; or, if not existing;
- Based on the literature.

If the daily ammonia input to the oxidation reactor exceeds the limit on permissible ammonia input, baseline N<sub>2</sub>O emissions are capped at conservative IPCC default values.

Since, the historical operating data (1<sup>st</sup> Jan.2003 – 31<sup>st</sup> Dec.2005) on maximum daily average ammonia flow is existed in each plant on Capro, the upper limit on ammonia flow is determined on this historical data.

	$A_{OR,hist-1}$	$A_{OR,hist-2}$
Historical maximum daily average ammonia flow (tNH <sub>3</sub> /day)	40.196	43.653

**Annex 4****MONITORING INFORMATION****Supplementary Information of Monitoring Equipments and Monitoring Parameters****1. Analyzer of the N<sub>2</sub>O concentration**

Non-Dispersive Infrared Absorption Photometer (ULTRAMAT 6, SIEMENS) will be equipped as the N<sub>2</sub>O concentration analyzer. NDIR at the inlet is with single-channel type of gas path for measuring only N<sub>2</sub>O concentration. But at the outlet, dual-channel of gas path is applied to NDIR to detect not only N<sub>2</sub>O but also CH<sub>4</sub> concentration of tail gas after De-N<sub>2</sub>O facility. Application of dual-channel type of NDIR is referred to the below paragraph for CH<sub>4</sub> concentration detection.

As mentioned at 4.1 Quality Assurance for AMS, all of NDIRs for this project have AMS certified to meet EN 14181, which stipulates three levels of quality assurance tests (QALs) and one annual functional test for AMS.

This current model has the performance certificate with calculation of uncertainty in accordance with ISO14956. The calculated uncertainty is as follows;

Component	C <sub>test</sub> (Daily average value) Vol.1.0%	Range of measurement Vol.1.0%	Expanded Uncertainty Vol.1.0%	In line with DIN EN ISO 14956
N <sub>2</sub> O	10 <sup>1)</sup>	0-10	0.46	Yes
N <sub>2</sub> O	100 <sup>1)</sup>	1-100	4.60	Yes

The uncertainty calculation according ISO 14956 was performed on the result of the laboratory testing regarding the following performance characteristics. :

Performance Characteristic	Value of uncertainty
a) Standard deviation	≤ 1 % of span
b) Lack of fit (linearity)	≤ 0.5 % of full-scale value
c) Repeatability at zero and reference points	≤ 1 % of measuring range
d) Time-dependent zero, span drift	<ul style="list-style-type: none"><li>• Zero drift ≤ 1% of measuring drift/ week:</li><li>• Measuring drift ≤ 1% of measuring range/ week</li></ul>
e) Temperature-dependence	<ul style="list-style-type: none"><li>• Ambient temperature in permissible range ≤ 1 % measuring range / 10 K (For a constant temperature of the reception cell)</li></ul>

<sup>1)</sup> As in the European Directives no limit values and requirements for N<sub>2</sub>O are defined for assessment a maximum expanded uncertainty of 20% of C<sub>test</sub> was assumed.  
The response time was with maximum 22s below the required value of 200s.



f) Voltage fluctuation	≤0.1% of output signal span with rated voltage ± 10V
g) Suitability test	EN14181(QAL3)
h) Cross sensitivity to likely components of the stack gas	5% H <sub>2</sub> O: ≤1% of span 5% CO: ≤1% of span 100ppm NO: ≤1% of span 100ppm NO <sub>2</sub> : ≤1% of span
i) Influence of variations in flow rate on extractive AMS	• Flow Effect Flow rate in the 20-100 l/h range : within determination limits
j) Response time	• Warm-Up Time With ambient temperature ≤30 minutes (maximum accuracy achieved after 2 hours) • 90% Response Time Dependent on length of analyzer cell, small gas line and damping • Damping 0~100s, programmable • Dead time Approx 0.5~5s, depending on version
k) Detection limit	<30 min
l) Influence of ambient conditions variations on zero and span reading	Permissible ambient temperature -30...+70 °C during storage and transport +5...+40 °C during operation
m) Performance and accuracy	<0.1% of respective span
n) Availability	<1% of measured value per week
o) Susceptibility to physical disturbance	Vibration test to EN 60068-2-6:1996

Permanent quality assurance (QAL3) for NDIR will be carried out through the operating personnel during plant operation. Therefore the zero point, span and drift of NDIR will be checked in regular. If it is detected that the drift and/or repeatability of zero and/or span of any NDIR exceed the permissible range, the supplier of the NDIR will adjust to correct the zero and/or span of the instrument.

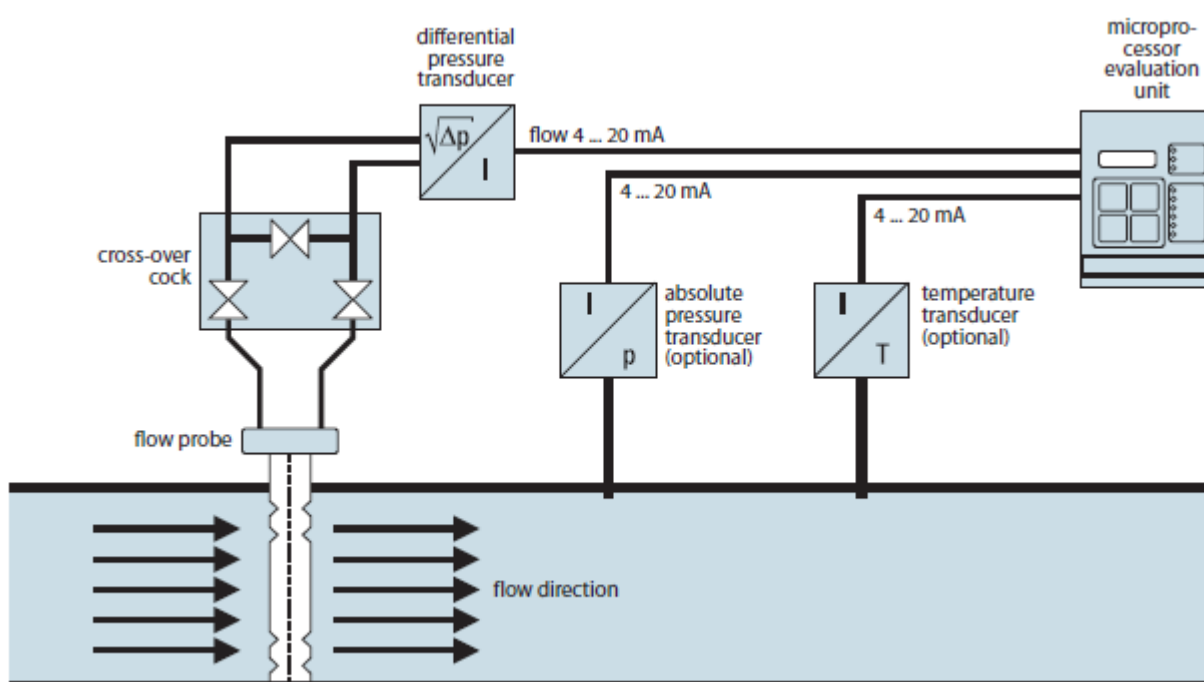
In case NDIR is found to be not performing according to its original performance, following measures are taken to assure the Monitoring of the data and immediate repair of the NDIR.

- Use gas chromatography to monitor and record the N<sub>2</sub>O concentration four times a day until NDIR is repaired.
- Repair NDIR using spare parts.
- Call for the service of NDIR supplier.
- Arrange to ship the back-up system.

In case of the N<sub>2</sub>O analyzer, NDIR(SIEMENS, Model: ULTRAMAT 6), calibration will be performed by using calibration gases (air as zero gas and standard gas as span gas) for N<sub>2</sub>O analyzer according to the manufacturer's instructions every three weeks at least, and the data from calibration will be recorded on the data logging system. During calibration, measured values can be storage.

## 2. Flow Meters for measuring the Tail gas flow rate

In order to measure tail gas flow rate, one pair of Pitot-Tube with D/P Transmitter (D-FL-100 system, DURAG) will be installed at the inlet and the outlet of DeN<sub>2</sub>O facility. The D-FL 100 measuring system operates according to the differential pressure principle. The probe has two separate chambers, between which the flow builds up a differential pressure. Taking account of the other flow parameters such as, e.g. absolute pressure and temperature, the volume flow can be converted from actual operating to standard conditions with the help of the evaluation unit.



This current model has the performance certificate with calculation of uncertainty in accordance with ISO14956.

The uncertainty calculation according ISO 14956 was performed on the result of the laboratory testing regarding the following performance characteristics. :

Performance Characteristic	Value of uncertainty
a) Standard deviation	<2% of measuring range
b) Lack of fit (linearity)	<±3%
c) Repeatability at zero and reference points	<2% of measuring range
d) Time-dependent zero, span drift	≤(0.25·r)% per 5 years, r=span ratio
e) Temperature-dependence	<ul style="list-style-type: none"> <li>Ambient temperature effect</li> <li>At -10 to +60 °C : ≤(0.1·r+0.2) %</li> <li>At -40 to -10 °C and +60 to 85 °C : ≤(0.1·r+0.15)%/10K</li> </ul>



f) Voltage fluctuation	0.005% per 1V change in voltage
g) Suitability test	Sira MC 060071/00
h) Cross sensitivity to likely components of the stack gas	$< \pm 4\%$
i) Influence of variations in flow rate on extractive AMS	10 to 60Hz( $\pm 4$ mm), 60 to 150Hz at 19.6m/s <sup>2</sup>
j) Response time	Approx. 0.2s, approx. 0.3s with 20-and 60-mbar (0.29 and 0.87 psi measuring cells)
k) Detection limit	$< 20\%$ of indication range
l) Influence of ambient conditions variations on zero and span reading	0.05%
m) Performance and accuracy	$< 2\%$ of measuring range
n) Availability	$\geq 95\%$
o) Susceptibility to physical disturbance	Vibration test to EN 60068-2-6:1996

The calibration for the tail gas flow meter is annually carried out by electronic method for the transmitter as per supplier's requirement.

If the leaking of the tail gas is detected between both of the measuring points at the inlet and the outlet, the monitoring engineer under the Production Department will identify and remove the cause of leaking on condition of that the cause is due to physical errors. However if the physical leak of the tail gas is not discovered through the investigation, the monitoring engineer in Maintenance Instruments will check whether there is any malfunction of the monitoring system including two flow meters or not, and then will correct the measuring device occurring the data.

During the period in which the data deviation is emerged, the baseline N<sub>2</sub>O emissions are capped at 5.4kgN<sub>2</sub>O/tonne of caprolactam conservatively applying the IPCC default value, until the deviation for the flow meters is adjusted.

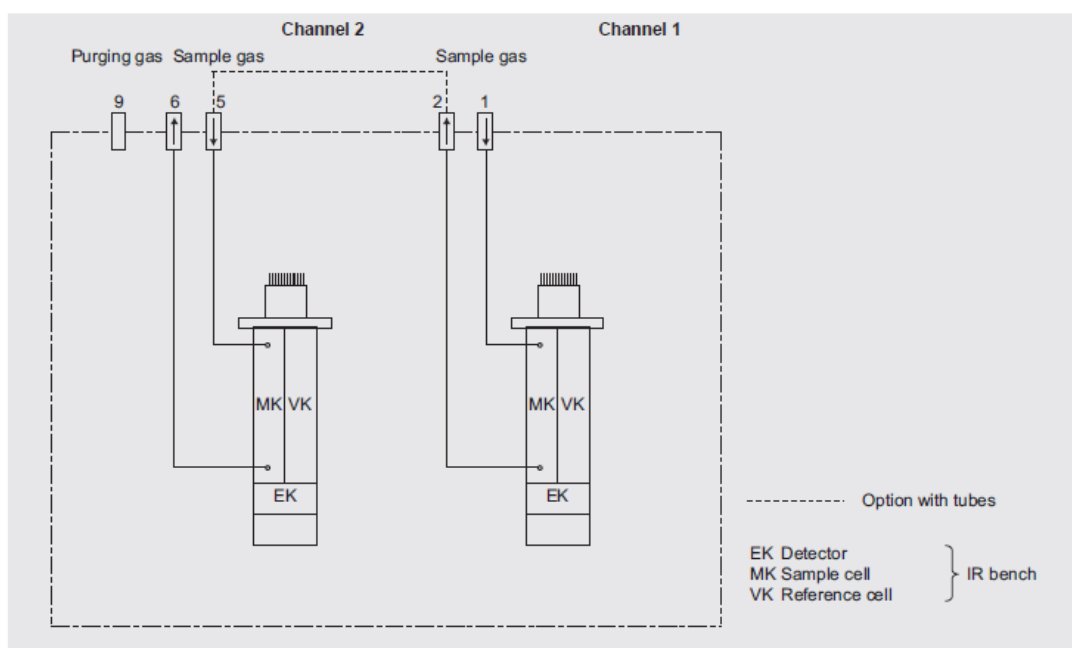
### 3. The flow rate of the natural gas input for re-heating the tail gas

Not decided yet.



#### 4. CH<sub>4</sub> Concentration at destruction facility outlet.

The same NDIR with that for analyzing N<sub>2</sub>O concentration at the outlet will be also used for measuring CH<sub>4</sub> concentration of tail gas after the DF. This NDIR (SIEMENS, Model: ULTRAMAT 6) has the dual channel through which 4 gas components (as maximum) can be measured simultaneously. Therefore not only N<sub>2</sub>O but also CH<sub>4</sub> will be detected at the same time by this one unit of NDIR at the outlet plant. With this one unit of NDIR at the outlet plant, not only N<sub>2</sub>O but also CH<sub>4</sub> will be detected from the tail gas after DF at the same time.



Gas path through the dual-channel unit of NDIR to be installed at the outlet of tail gas

CH<sub>4</sub> concentration of the tail gas after DF is measured continuously as same as N<sub>2</sub>O concentration of that. An average of the readings is recorded electronically at 1 hour interval. Data will be compiled hourly and daily data and kept in the electronic media.

This device will be subjected to Capro's Maintenance and testing regime by ISO14001 consistent with respect to the supplier's directions. Calibration of measuring devices will be carried out every three years. The monitored results are reported daily and monthly.

#### 5. Production of caprolactam

The production of caprolactam is continuously measured by existing mass flow meter (PROMASS 63, ENDRESS HAUSER) and recorded by the existing DCS system. This production amount is cross checked by stock change data every day and by weighbridge data every month. And monitored results are reported daily and monthly.

Measuring devices including flow meter and weighbridge will be subjected to Capro's Maintenance and



testing regime by ISO14001 consistent with respect to the supplier's directions. Calibration of measuring devices will be carried out every three years.

## 6. Actual temperature and pressure of the Ammonia Oxidation Reactor ( $T_g$ , $P_g$ )

In order to investigate whether the AOR operation is performed within the “Permitted range” on daily basis, the actual temperature and pressure of the ammonia oxidation reactor are continuously measured by the existing thermocouples and pressure gauges in the caprolactam production plant. The information of corresponding models with devices is as follows;

		Temperature		Pressure	
		Parameter	Device model	Parameter	Device model
Plant I	AOR-a	$T_{g-a}$	R121, WISE	$P_{g-1}$	STG944, Honeywell
	AOR-b	$T_{g-b}$	R121, WISE		
Plant II	AOR-c	$T_{g-c}$	C1EST, WISE	$P_{g-2}$	STG944, Honeywell
	AOR-d	$T_{g-d}$	C1EST, WISE		

These parameters are not only recorded by the existing DCS system but also are recorded by new PC for the project.

Measuring devices will be subjected to Capro's Maintenance and testing regime by ISO14001 consistent with respect to the supplier's directions. Calibration of measuring devices will be carried out every three years. The monitored results are reported daily and monthly.

## 7. Ammonia input to the ammonia oxidation reactor ( $A_{OR}$ )

In order to check whether the actual daily ammonia flow rate exceeds the upper limit on maximum historical daily permitted ammonia flow rate, the actual ammonia flow to the ammonia oxidation reactor is continuously measured by the existing differential pressure transmitter with normalizing functions. The information of corresponding models with devices is as follows;

		Ammonia input to the ammonia oxidation reactor	
		Parameter	Device information
Plant I	AOR-a	$A_{OR,d-1}$	Differential pressure : STD 924, Honeywell
	AOR-b		
Plant II	AOR-c	$A_{OR,d-2}$	Differential pressure : STD 924, Honeywell
	AOR-d		

Ammonia input is measured as an actual volume flow rate ( $\text{Nm}^3/\text{hr}$ ), before the value is converted to it on normal conditions ( $0^\circ\text{C}$ ,  $101.325\text{kPa}$ ). Then the volume flow rate on normal conditions is diverted to mass flow rate as follows;



$$x \text{ [tNH}_3\text{/day]} = y \text{ [Nm}^3\text{/day]} \times \text{M.W of NH}_3 / 22.4 / 1000$$

Where;

$$\text{M.W of NH}_3 = 17.03$$

These parameters are not only recorded by the existing DCS system but also are recorded by new PC for back-up.

Measuring devices will be subjected to Capro's Maintenance and testing regime by ISO14001 consistent with respect to the supplier's directions. Calibration of measuring devices will be carried out every three years. The monitored results are reported daily and monthly.