Estimation CO_2, Non-CO_2 GHGs and Other Gas pollutant Emissions of Indonesia's Urea Fertilizer Factories

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Abstract

Urea fertilizer factory released CO_2 by two ways, one is direct CO_2 emission which derives from combustion of natural gas and other fossil fuel, and the another is indirect CO_2 emissions or due to over product of CO_2. This article shows estimation CO_2, non-CO_2 GHGs and other gas pollutant emissions from Indonesia's urea fertilizer factories based on natural gas and other liquid fossil fuel consumptions. The specific energy consumption (SEC), specific emissions factor (SEF) of direct and indirect CO_2, non-CO_2 GHGs and other gas pollutant emissions of Indonesia's urea fertilizer factories were estimated. Direct and indirect CO_2 emissions from Indonesia's urea fertilizer factories were estimated based on estimation method of Intergovernmental Panel on Climate Change (IPCC) and materials balance calculation methods by considered the natural gas and other fuel consumptions. Results of this study show that a lot of energy is consumed to produce urea. The SEC of Indonesia's urea factories was found around 13.7 to 42.4 TJ per thousand metric tones urea production. The analysis shows that indirect CO_2 emission gave much more contribution than direct CO_2 emissions did. The SEF of direct and indirect CO_2 emissions from Indonesia's urea factories were found about 0.001 and 0.360 Gg per thousand metric tones urea production, respectively. CO_2, CH_4, CO and NO_X emissions from Indonesia's urea factories in 2003 were estimated to be about 1,234.3; 0.142; 1.702; 23.185 Gg, respectively.

INTRODUCTION

Urea, known as carbamide or carbonyl diamide, is produced by reaction between liquid ammonia (NH_3) and carbon dioxide (CO_2). Urea is usually produced in frilled or granulates form to use as nitrogen source for plant cultivation[1]. Food and Agriculture Organization of the United Nations (FAO) reported that more than 45 million metric tones urea were produced in 2001, and about 78.0% of them were produced in developing countries[3]. The largest urea producer is China with share of 33.9%, followed by India with 19.2%. All Asian countries contribute about 72.9%, while Indonesia contributes for 5.1% of total world urea production. Table 1 shows the world urea production by region in 2001[3].

Indonesian chemical fertilizer manufacture were established in 1963 when the first urea factory in Palembang, South Sumatra known as Sriwidjadja Fertilizer factory (PUSRI)[2]. Indonesian chemical fertilizer manufacture grows up rapidly after that. Since 1984, fifteen chemical fertilizer factories have been established and most of them produce urea as main product. The amount of urea

production in Indonesia increased from about 2.0 million metric tones in 1980 to about 5.0 million metric tones in 1990. In 2002, it reached more than six million metric tones. The total Indonesia's urea production is projected to increase to around 8.6 million metric tones in 2005. This number includes the production from three new urea fertilizer factories which are now still under construction.

As for the material for urea produce, ammonia is produced from atmospheric nitrogen and hydrogen through reforming hydrocarbon feedstock. Natural gas is the most common hydrocarbon feedstock as hydrogen source. CO_2 is produced as by-product of reforming natural gas. The natural gas reforming process is conducted at high pressure and high temperature conditions; therefore these processes required a lot of energy. The operating conditions are achieved by utilizing natural gas as fuel gaseous. These conditions will potentially affect on global warming problem, due to accumulation of CO_2 and other greenhouse gas (non-CO_2 GHGs) in atmosphere.

Based on the above facts, CO_2, non-CO_2 GHGs and other gas pollutant emissions from urea factories are expected to become serious environmental problems in Asian region countries in the future, such as Indonesia. In 1990 (the base year of Indonesian GHGs inventories), the total Indonesia's GHGs emissions due to fossil fuel combustion was about 164,270 Gg CO_2 equivalent, where energy and industrial sectors contributed for 33% and 20%, respectively. The GHGs emissions due to fuel gaseous combustion contributed for 3.5% of the total GHGs emissions due to fossil fuel combustions [5].

This study shows estimation of CO_2, non-CO_2 GHGs and other gas pollutant emissions from Indonesian urea factories. The estimation of CO_2, non-CO_2 GHGs and other air pollutant emissions in this study are based on (a) the survey of natural gas and other fossil fuel consumptions from 5 of 12 total Indonesia urea factories conducted by author them self, and (b) statistical data conducted by Indonesian Fertilizer Producer Association (APPI)[4]. Results of this study in term of specific energy consumption (SEC), specific emission factor (SEF), and CO_2, non-CO_2 GHGs and other gas pollutant emissions has been described in the following section of this article.

Table 1. World urea production in 2001 by region

Region	Urea production (metric tones)	Share for world urea production (%)
Asia	33,156,024	2.63
Africa	1,195,788	10.59
America	4,818,887	72.89
Europe	6,147,824	13.51
Australia and New Zealand	171,100	0.38
World	45,489,623	100

ESTIMATION METHODS

In Indonesia, most of urea factories were constructed together with ammonia plant in the same location. CO_2, non-CO_2 GHGs and other gas pollutant emissions from both factories could not be estimated separately, because all energy consumed by both factories such as heat and electricity which were generated from same energy conservation unit, namely (a) primary reformer, (b) gas turbine generator, (c) package boiler, and (d) waste heat boiler.

Currently, there is no recommended estimation method to estimate CO_2, non-CO_2 GHGs and other gas pollutant emissions from ammonia and urea factories, which are constructed together in same location. In this study, CO_2, non-CO_2 GHGs and other gas pollutant emissions has been estimated based on natural gas and other fossil fuel consumptions and total material balance of both factories. The natural gas and other fossil fuel consumptions and urea production from 5 of 12 total Indonesia's urea factories during 1998 to 2002 period (except factory E) were collected by authors them selves for this study purpose. The specific energy consumption (SEC) is an indicator amounts of energy used to produce urea, and it was estimated based on the total energy consumption per unit physical product as introduced by A. Priambodo and S. Kumar [6]. The SEC of Indonesia's urea factories was estimate by following equation:

$$Equation\,(1) \quad SEC = \frac{FC}{FP}$$

where

FC = total annual natural gas and other fossil fuel consumptions (TJ)

FP = total annual urea production (metric tones)

CO_2, non-CO_2 GHGs and other gas pollutant emissions of urea factory are divided into two categories, namely direct and indirect emissions. In this study, direct and indirect gas emissions have been estimate independently. Direct emissions, which is due to natural gas and other fossil fuel combustions from energy conservation units, were calculate based on Intergovernmental Panel on Climate Change (IPCC) guideline[7] by considering natural gas and other fossil fuel consumption. The CO_2, non-CO_2 GHGs and other gas pollutant emissions from urea factory was calculated by the following equations:

$$Equation\,(2) \quad direct\,CO_2 = FC \times CEF \times f_O \times {}^{44}\!/_{12}$$

$$Equation\,(3) \quad direct\,e_i = FC \times CEF$$

where

FC = total annual natural gas and/or other liquid fossil fuel consumption in energy conservation unit of fertilizer factory during a year (TJ)

CEF = carbon emission factor of natural gas and other fossil fuel (tC/TJ)

f_O = carbon fraction of natural gas and other fossil fuel that has been oxidized during combustion process

${}^{44}\!/_{12}$ = mass conversion factor of mass carbon to mass CO_2 generated during combustion processes

e_i = emissions level of non-CO_2 GHGs and other gas pollutant component (metric tones)

Firstly, the quantities of natural gas and other fossil fuel consumption are converted into energy units (TJ) using appropriate conversion factor, then transformed into carbon emissions based on carbon emission factor (CEF). Though the IPCC has established CEF values, which can be used

for general cases, data regarding fuel combustion in particular country has not been determined. As an approximation, IPCC provides CEF value of natural gas, diesel, and coal that are 15.3 tC/TJ, 20.2 tC/TJ, and 26.4 tC/TJ (the average value of CEF for anthracite, coking coal, other bituminous coal, sub-bituminous coal and lignite). The fraction-oxidized value is used to account the carbon compound of natural gas and other fossil fuel that are not oxidized during combustion process. As an approximation, fraction-oxidized value of natural gas, diesel, and coal that are 0.995, 0.99, and 0.98 [7], respectively.

The most gas released to atmosphere through indirect way is CO_2. As reactant for urea formation reaction, CO_2 is produced from feed gas treatment system and is produced as by product of natural gas reforming process. Theoretically, based on coefficient of chemical reaction equation, CO_2 produced from natural gas reforming will be utilized for urea reaction formation. However, due to actual process requirement conditions those are the molar ratio NH_3:CO_2 from 3:1 to 4:1[11], parts of CO_2 produced is un-utilized to produce urea and will be released to atmosphere. In addition, concentration CO_2 in feed gases tends to increase as gas well exploration period increase. Therefore, the amount of CO_2 will be released to atmosphere depending upon CO_2 compositions in feed gases and the efficiency of urea formation reaction. In some cases, several factories make effort to reduce CO_2 emission by utilization of the over product of CO_2 to produce dry ice as by-product. However, after any purposes, CO_2 in dry ice form also will be released to atmosphere, the utilization CO_2 for dry ice production have not been considered in this estimation. Based on both above assumptions, indirect CO_2 emission from urea factory was estimate by the following equation:

$$Equation\,(4) \quad indirect\,CO_2\,emissions = c\,FD \times (1-x) - \left(FP \times \frac{44}{60}\right)$$

where
c = energy conversion factor of feed gas to that CO_2 produced from natural gas reforming (mole/MMBTU)
FD = total annual feed gases consumptions (MMBTU)
x = molar fraction of non-carbon compounds in feed gas
FP = total annual urea fertilizer production (metric tones)
$\frac{44}{60}$ = mass conversion factor of urea mass to CO_2 mass consumed to produce urea

The annual CO_2, non-CO_2 GHGs and other gas pollutant released in the urea factories, where we surveyed, is calculated using Eq. (2), (3) and (4). Then it is divided with annual urea production to estimate amount CO_2, non-CO_2 GHGs and other gas pollutant released per physical urea production. The amount of CO_2, non-CO_2 GHGs and other gas pollutant released per physical urea production of individual surveyed urea factories is shown as specific emission factor (SEF). SEF of the urea factories were then compiled to estimate average SEF of Indonesia's urea factories.

The average SEF was used to estimate amount CO_2, non-CO_2 GHGs and other gas pollutant released of un-surveyed urea factories. The total annual CO_2, non-CO_2 GHGs and other gas pollutant released of Indonesia's urea factories were estimate based on the annual statistical urea production data of each urea factory using the following equation:

$$Equation(5) \quad \sum e_j = SEF_j \times \sum FP$$

where

e_j = total annual CO_2, non-CO_2 GHGs and other gas pollutant (metric tones)

SEF_j = specific emissions factor each component of CO_2, non-CO_2 GHGs and other gas pollutant

FP = total annual urea production of individual urea factories (metric tones)

The annual statistical urea production data of each Indonesia's urea factory collected from Indonesia Fertilizer Producer Association (APPI)[4]. Based on the available data urea production of each factory, the total annual CO_2, non-CO_2 GHGs and other gas pollutant emission from all Indonesia's factories were estimate as the sum of annual CO_2, non-CO_2 GHGs and other gas pollutant emission of each factories.

ESTIMATION RESULTS

CO_2, non-CO_2 GHGs and other gas pollutant of Indonesia's urea factories has been estimated by considering natural gas and other fossil fuel consumptions, and urea production data collected by author them selves and APPI. In this study, two categories of sink and sources of CO_2, non-CO_2 GHGs and other gas pollutant emissions will be considered, namely direct, which is due to natural gas and other fossil fuel combustion, and indirect, which is due to over product of CO_2. Results of this study in term SEC, SEF, and annual CO_2, non-CO_2 GHGs and other gas pollutant emissions are described in the following section.

Specific Energy Consumptions

The specific energy consumption (SEC) is an indicator of energy such as heat and electricity used to produce urea. Most of Indonesia's urea factories burn natural gas and other fossil fuel to generate heat and electricity in energy conservation units such as package boiler, gases turbine generator and waste heat boiler. Based on the available data of natural gas and other fossil fuel consumptions SEC of each energy conservation units of surveyed urea factories were calculated separately.

Figure 1 illustrates an average SEC of individual surveyed urea factories by energy conservation units. The SEC of each energy conservation units was calculated using Eq. (1) based on the individually natural gas and other fossil fuel consumption and urea production data. This figure shows that about 50% of total energy is utilized for primary reformer which reforms natural gas to produce hydrogen and CO_2. The high-energy consumption is utilized to reform natural gas to be hydrogen due to the process requirement, where the reforming process of natural gas is an endothermic reaction and held at high temperature condition.

The aggregate of annual SEC of each energy conservation units is compiled to estimate individual SEC of urea factory. The individual SEC of surveyed urea factories has been presented by range and averages in Table 2. The average SEC of individual urea factory has been given in term of

natural gas and other fossil fuel consumption in TJ unit per thousand metric tones urea production. This result shows that around 13.7 to 42.4 TJ of energy were required to produce every thousand metric tones of urea. Compared with another study conducted by A. Priambodo and S. Kumar[6], SEC of urea factory were about two, three and four folds of Indonesia's fabricated metal, chemical, food and beverages industries, respectively.

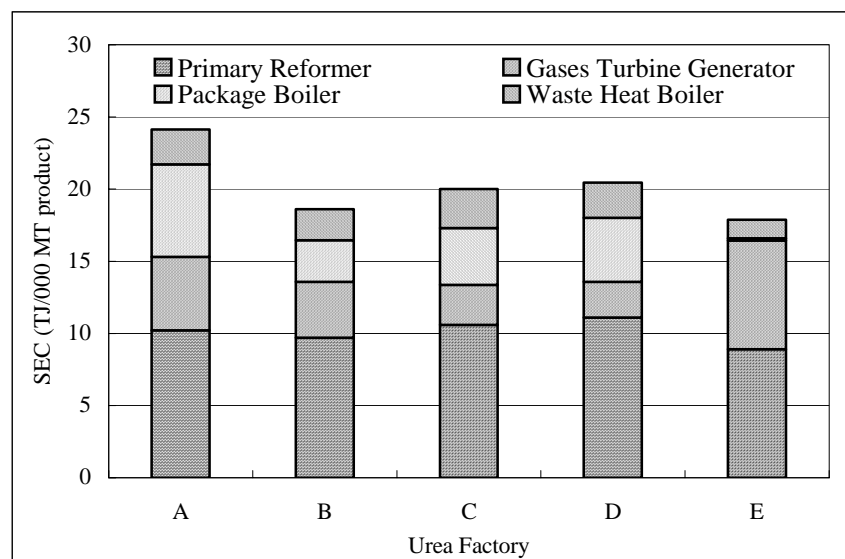**Figure 1**. An average SEC of surveyed urea factories by energy conservation units

Table 2. An averages and range of energy consumptions per physical product urea of individual surveyed urea factories

Urea factory	SEC of surveyed Indonesia's urea factories (TJ/thousand metric tones product)	
	Range	Average
A	19.438 – 42.414	24.139
B	13.700 – 26.324	17.160
C	17.401 – 29.830	20.018
D	16.994 – 31.692	20.444
E	NA	30.641

CO_2 non-CO_2 GHGs and other gas Pollutant Emissions

Based on the available data on natural gas and other fossil fuel consumption and urea production, CO_2, non-CO_2 GHGs and other gas pollutant emissions from Indonesia's urea factories were divided into two categories, direct and indirect emissions. Direct CO_2, non-CO_2 GHGs and other gas pollutant emissions were calculated using Eq. (2) and (3) based on IPPC guidelines. Indirect CO_2 emissions were calculated using Eq. (4) based on total material balance method.

Direct CO_2, non-CO_2 GHGs and other gas pollutant emissions

Direct CO_2, non-CO_2 GHGs and other gas pollutant emissions of each energy conservation units were calculated independently based on annual natural gas and other fossil fuel consumptions data. The amount of CO_2, non-CO_2 GHGs and other gas pollutant released to atmosphere during combustion process depends upon combustion technology and fuel used. The aggregates of CO_2, non-CO_2 GHGs and other gas pollutant of each energy conservation units were compiled to estimate

average annual CO_2, non-CO_2 GHGs and other gas pollutant of surveyed urea factories.

Figure 2 illustrates an average CO_2, non-CO_2 GHGs and other gas pollutant emissions of individual surveyed urea factories by gas types. This figure shows that main component of gas pollutant released from natural gas and other fossil fuel combustion is NO_X, which has the emissions level around 1,200 to 2,200 metric tones per year. This amount causes by high emission factor (EF) of natural gas and other fossil fuel burning in boiler only. The surveyed urea factories released other gas pollutants such as CO_2, CH_4 and CO about 520, 11 and 130 metric tones per year.

Figure 2. An averages annual CO_2, non-CO_2 GHGs and other gas pollutant emissions of surveyed urea factories by gas type
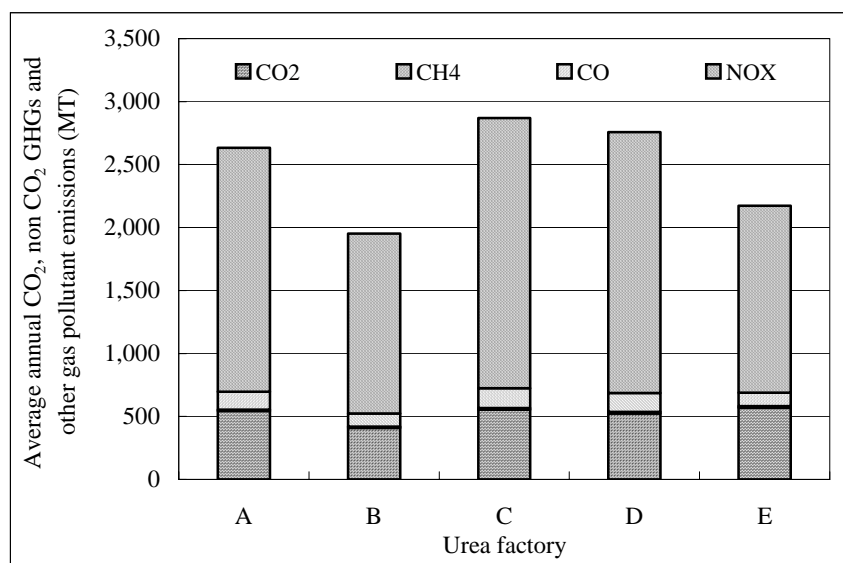
Indirect CO_2 emissions

Indirect CO_2 emission was estimated based on the total material balance of urea processing by considering the annual feed gas consumption and urea production. With assumption that urea production process in steady state conditions, the amount of CO_2 emission due to over product of CO_2 is equal with annual CO_2 produced minus CO_2 consumed to produce urea. Figure 3 illustrates an average amount of annual indirect CO_2 emissions of individual surveyed urea factories. This figure shows that CO_2 emissions due to over product is higher than CO_2 emissions derived from natural gas and other fossil fuel combustion, where most surveyed urea factories released CO_2 due to over product as around 50 to 400 times as CO_2 by combustion.

Figure 3 shows that among the surveyed urea factories, annual indirect CO_2 emissions were in wide range and depends upon CO_2 contents in feed gas and the reaction rate conversion of urea formation. These results show that the highest emitter of CO_2 emission by over product is factory "E" with about 230 thousand metric tones per year in the average annual CO_2 emissions. Based on the available data among surveyed urea factories, this factory has the lowest efficiency with the annual urea production only about 200 thousand metric tones of 460 thousand metric tones design capacity.

Specific Emission Factor (SEF)

CO_2, non-CO_2 GHGs and other gas pollutant of surveyed urea factories have been

calculated individually based on natural gas and other fossil fuel consumptions and material balance calculation methods. The amount of CO_2, non-CO_2 GHGs and other gas pollutant released to atmosphere per physical product of urea produced represents Specific Emission Factor (SEF). The SEF of CO_2, non-CO_2 GHGs and other gas pollutant of surveyed urea factories is presented by average in Table 3. An average SEF of individual urea factory has been given in term CO_2, non-CO_2 GHGs and other gas pollutant emissions in metric tones per thousand metric tones urea produced. The average SEF of individually urea factory were then compiled to estimate national levels SEF of urea factories. These SEF have been used to estimate CO_2, non-CO_2 GHGs and other gas pollutant emissions from all Indonesia's urea factories.

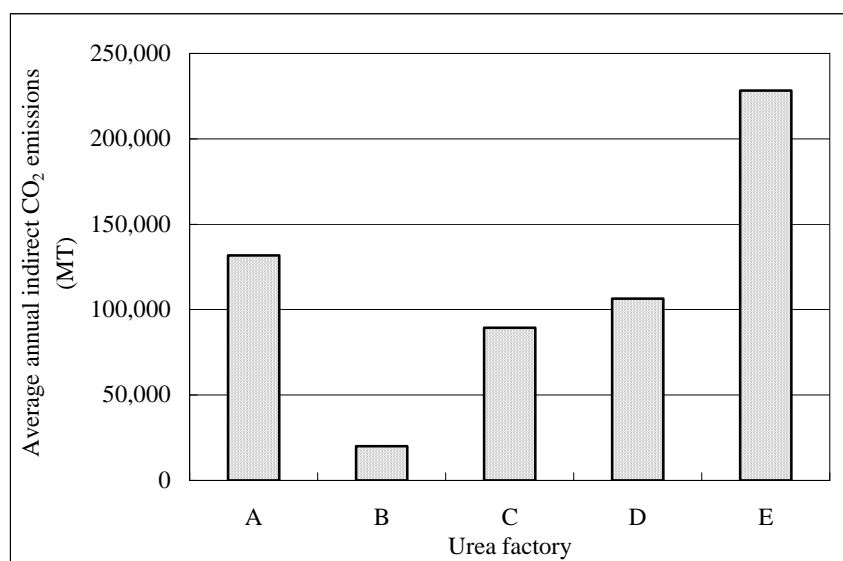**Figure 3**. An average of annual indirect CO_2 emissions of surveyed urea factories

Table 2. An average CO_2, non-CO_2 GHGs and other gas pollutant emissions per physical product urea individual SEF of surveyed Indonesia's urea factories by gas types

| Urea factory	SEF of surveyed Indonesia's urea factories (ton/thousand metric tones product)				
	Direct CO_2	Indirect CO_2	CH_4	CO	NO_X
A	1.183	289.448	0.026	0.311	4.214
B	0.856	15.502	0.019	0.220	2.979
C	1.002	160.932	0.023	0.283	3.871
D	1.018	212.712	0.024	0.294	4.028
E	1.001	686.403	0.019	0.191	2.604

These results show that around 16.3 to 687.4 metric tones CO_2 emissions every thousand metric tones urea production by direct and indirect ways, where more than 95% CO_2 emissions are released through indirect way. Compared to another studies, these results are lower than World Bank expecting, which were about 1.2 and 0.5 metric tones CO_2 will be released from feed gas treatment and natural gas reforming sections every tones urea produced, respectively[8].

The Annual CO_2, non-CO_2 GHGs and other Gas Pollutant Emissions of Indonesia Urea Factories

The total annual CO_2, non-CO_2 GHGs and other gas pollutant emissions from all

Indonesia's urea factories have been estimated using Eq. (5) based on the total annual urea production data from APPI. An average SEF of surveyed urea factories were utilized to estimate total annual CO_2, non-CO_2 GHGs and other gas pollutant emissions from all Indonesia's urea factories. Figure 4 illustrates total annual CO_2, non-CO_2 GHGs and other gas pollutant emissions from all Indonesia's factories from 1963 until 2005 in gigagram unit by gas types.

Figure 4. Total annual CO_2, non-CO_2 GHGs and other gas pollutant emissions from all Indonesia's urea factories from 1963 until 2005
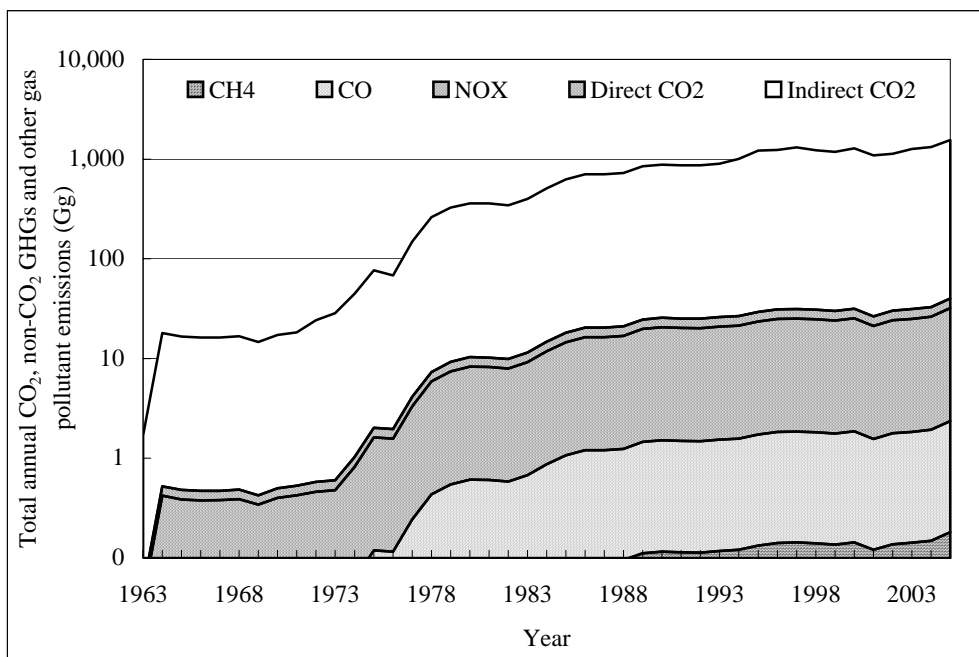
This figure shows that CO_2, non-CO_2 GHGs and other gas pollutant emissions from Indonesia's urea factories are increasing significantly from 1963 until 1984. During that period, Indonesia's urea industries were grown up rapidly with the increasing number of exploration natural gas well. In 2003, total CO_2 emission by direct and indirect ways were about 1,234.3 gigagram, and will increase to about 1,526.1 Gg in 2005, by the operation of three new factories. Referred to Indonesian government report to United Nations Framework Convention on Climate Change (UNFCCC) about Indonesian base line GHGs emissions, in 1990 urea factories contribute for 0.18% of total Indonesian's CO_2 emissions or about 4.83% of total CO_2 generated from industrial sector.

The amount of CO_2 emission is considered to become serious problem for environment with rapidly urea manufacture growth. In addition, regarding to phenomena that CO_2 content in natural gas tend to increase, urea factory will give more complicated problem to the environment in the future.

CONCLUSIONS

The study to estimate CO_2, non-CO_2 GHGs and other gas pollutant emissions from Indonesia's urea factories based on natural gas and other fossil fuel consumptions and urea production data of Indonesia's urea fertilizer factories has been done and described on previous sections. Based on the estimation results and above description the following conclusions are

considered in this section:

1. Urea manufacture processing requires a lot of energy to produce hydrogen gas by reforming hydrocarbon feedstock and urea formation reaction. The energy consumption per physical production in surveyed Indonesia's urea factories was found around 13.7 to 42.4 TJ per thousand metric tones urea production.

2. Urea factory released CO_2, non-CO_2 GHGs and other gas pollutant emissions by two ways, direct and indirect emissions. The average direct CO_2, non-CO_2 GHGs and other gas pollutant emissions were found about 1.01; 0.02; 0.26 and 3.54 metric tones of CO_2, CH_4, CO and NO_X emission thousand metric tones urea produced, respectively.

3. Indirect CO_2 emissions were found about 273.0 metric tones per thousand tones urea produced.

4. The total CO_2, CH_4, CO and NO_X released from Indonesia's urea factories in 2003 were about 1,234.3; 0.142; 1.702; and 23.185 Gg, respectively.

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