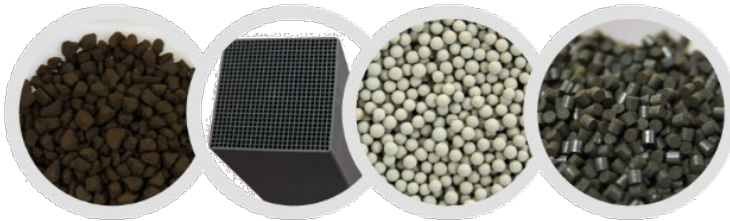
N_2O Abatement in Nitric Acid Production



- Involves the installation of both the Secondary in AOR and Tertiary N_2O abatement catalyst in SCR. For small capacity, only tertiary catalyst can be applied, and N_2O will be eliminated once it passes through the catalyst abatement system.

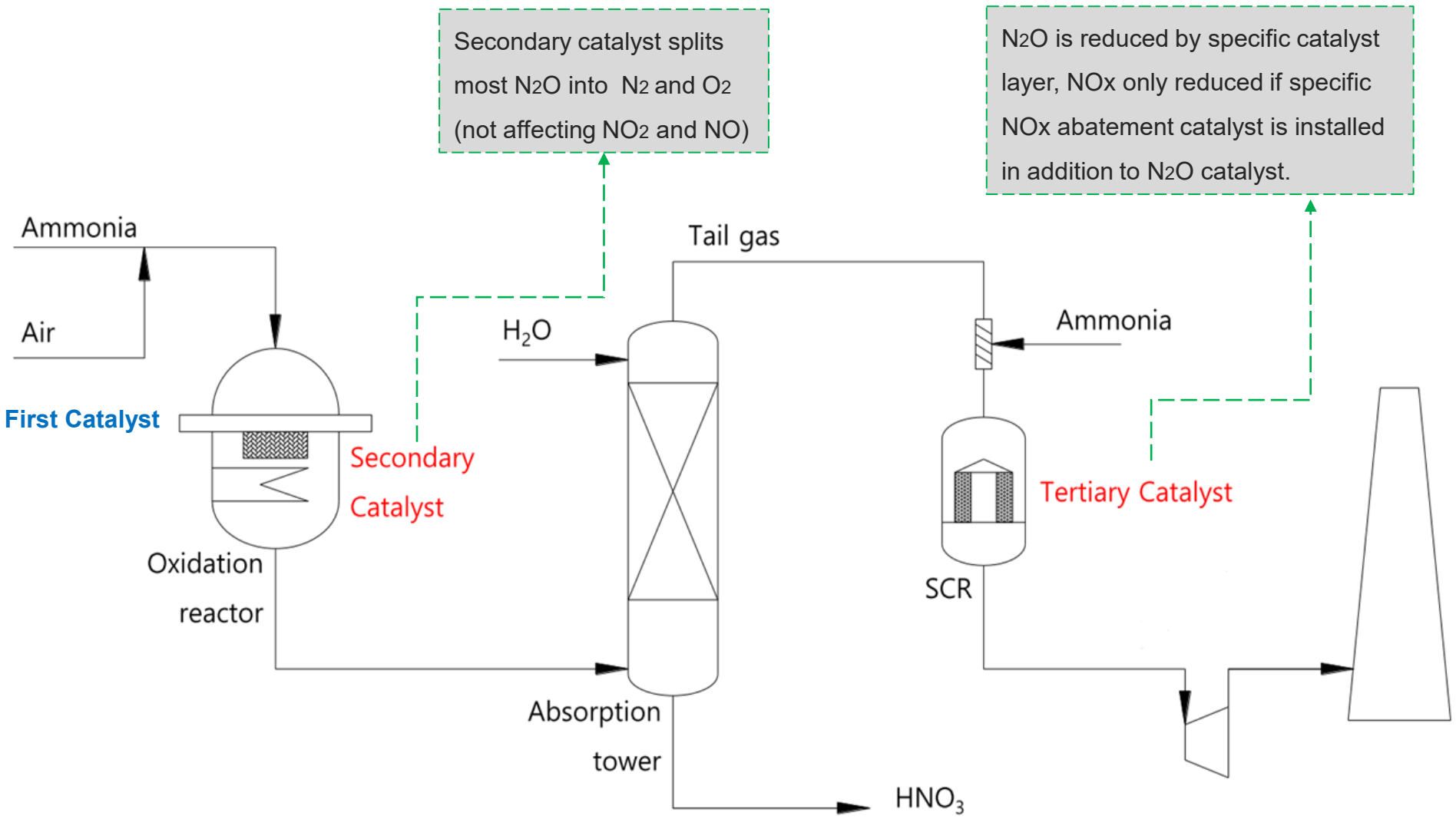
- The catalyst is composed of the active components which are optimised for decomposing N_2O to nitrogen and oxygen at operating temperatures.

$$2N_2O \leftrightarrow 2N_2 + O_2$$

- The final removal rate of N_2O in tail gas stream is more than 95%. (more than 80% for NOx)
- Most of N2O abatement projects registered at UNFCCC applied only secondary catalyst inside the main reactor(AOR) for ACM0019 methodology in UNFCCC.

AOR : Ammonia Oxidation Reactor, SCR : Selective Catalystic Reactor

How to reduce N2O in nitric acid plant



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N_2O Production Mechanism

1. NH_3 Oxidation

[Main Reaction]

- $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$
- $2NO + O_2 \rightarrow 2NO_2$

[Sub Reaction] Generate N_2O

- $2NH_3 + 2O_2 \rightarrow N_2O + 3H2O$
- $2NH_3 + 8NO \rightarrow 5N_2O + 3H_2O$
- $4NH_3 + 4NO + 3O_2 \rightarrow 4N_2O + 6H_2O$

2. HNO_3 Production by Absorption

[Main reaction]

- $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

N_2O & NOx Abatement Technology

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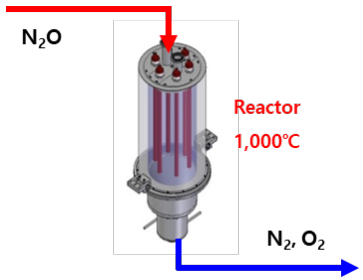
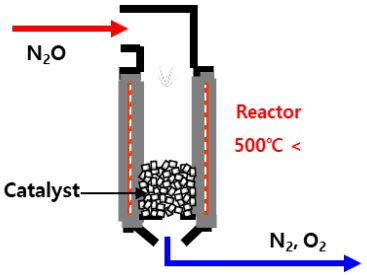
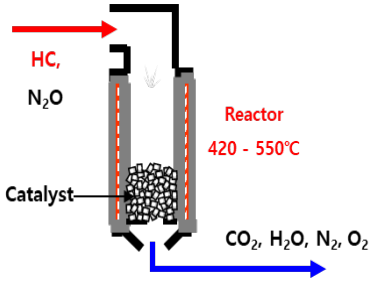
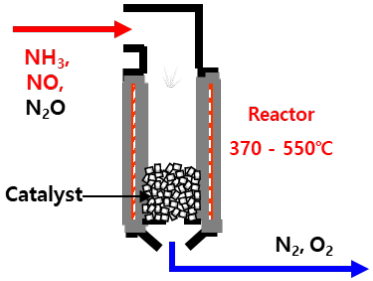
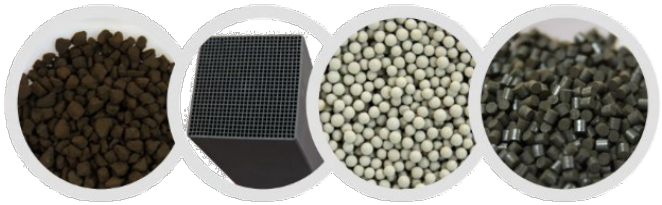
Secured by Ecopro HN

ITEM	Decomposition technology		Selective catalytic reduction(SCR) technology	
	Thermal decomposition	Catalytic decomposition	HC-SCR	NH_3-SCR
Operation temperature (℃)	1,000	500 <	420 - 550	370 - 550
Property	• High Concentration N_2O treatment • High energy consumption	• No reducing agent required • Relatively high temperature • NOx reduction impossible	• High stability • Relatively high temperature • NOx reduction impossible	• High efficiency at low temperature • NOx reduction possible • NH_3 storage tank required
Process flow				

- **Secondary** catalyst (Ecopro HN or 3rd Party Product)
  - Mounted directly downstream the primary catalyst, operated at 800-900°C
  - Additional HNO_3 yield as benefit for catalyst users:
    => **under development**



- **Tertiary** catalyst (Ecopro product)
  - Separate reactor, operated at 350-450°C
    (Fe-exchanged zeolite – Ecopro HN)
  - Conversion of N2O and NOx into N_2 and H_20 (95~99%) under addition of NH_3
  - Catalyst expected lifetime 10 years

N_2O Abatement Technology in Chemical Industry

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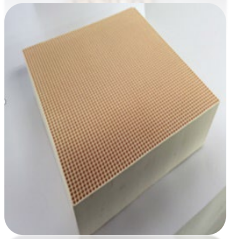
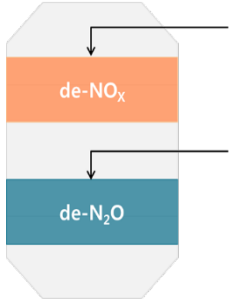
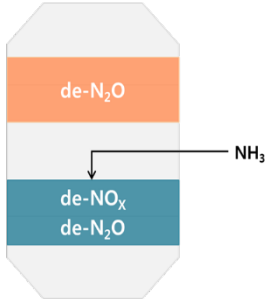
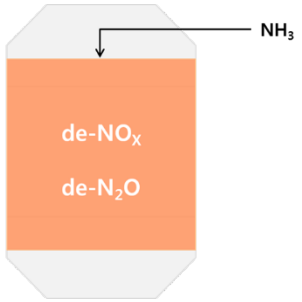
Overview

- GWP of N_2O : 265 (CO_2 =1)
- Usually produced from adipic, nitric or Caprolactam process
- Has references of N_2O mitigation catalyst
- Capable of providing optimal catalysts based on advanced molding and coating
- Partnership with global engineering firms for N_2O mitigation business



Characteristics

- Simple facility/process compared to typical (commercial) process
- Simultaneous removal of N_2O and NOx over at more than of 370℃ (need reducing agent)
- capable of decomposing N_2O over 450℃ (does NOT need reducing agent)

Commercial Process		ECOPROHN 공정
@ < 420℃	@ 420 - 550℃	@ 370 ~ 550℃
		

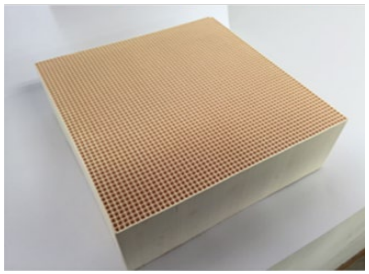
Reaction	
	• $4N_2O + 4NH_3 + O_2 \rightarrow 6N_2 + 6H_2O$
	• $4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$
	• $4NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$
	• $2N_2O \rightarrow 2N_2 + O_2$

Tertiary Catalyst : N_2O & NOx by Ecopro HN

EcoPro HN

3mm Pellet (Extruded)

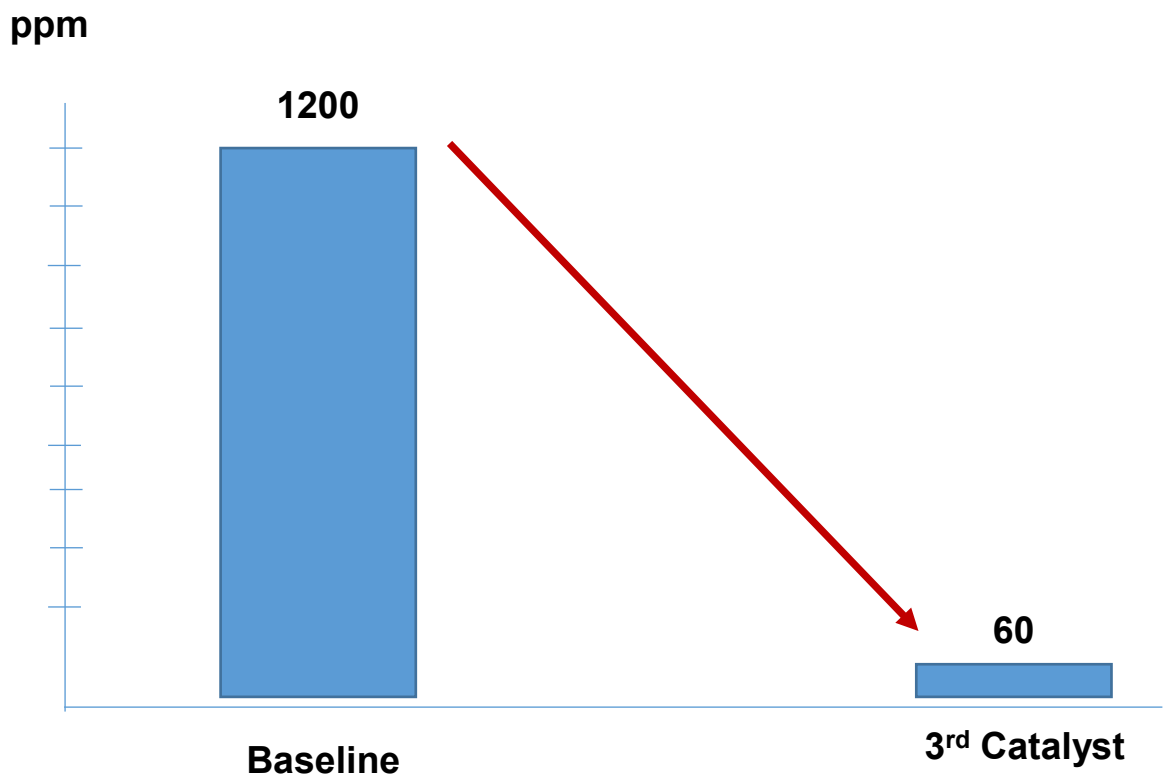
Honeycomb (Washcoated)



항목	Pellet Type	Honeycomb Type
Height (mm)	3 ~ 5(Max)	50 ~ 100
Diameter /W x D (mm)	3, 5	150 x 150
Property	Full impregnated catalyst	Partial impregnated catalyst
NH_3 Slip (ppm)	< 10	< 10
NOx Efficiency (%)	> 98	> 98
N_2O Efficiency (%)	> 95	> 95
Chemical composition	Fe-zeolite	Fe-zeolite

Total N_2O Removal

More than 95% removal of N2O is possible



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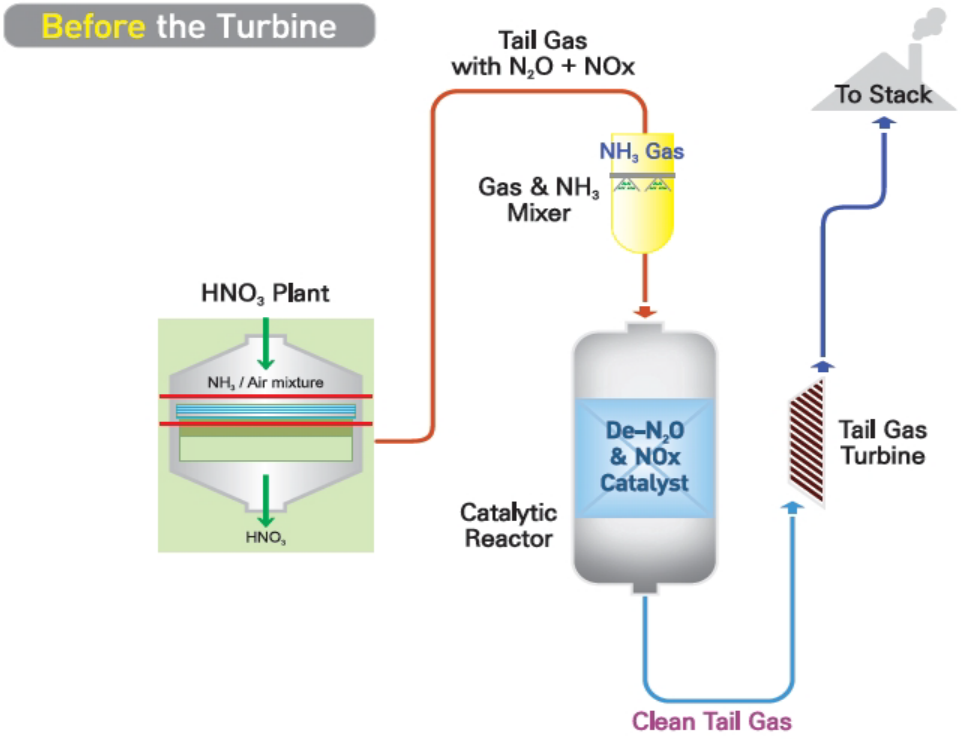
100,000 ton/year (and 120,000 ton/year) in Korea



- Project : De-N_2O & NOx Project
- Installation : 2016. 01
- Site : Ulsan, KOREA (Hanhwa)
- Size : Q = 51,000 m^3/hr
- Oper. Press. : 5~10bar
- Oper. Temp. : > 370℃
- Efficiency : N_2O, NOx ≥ 95%

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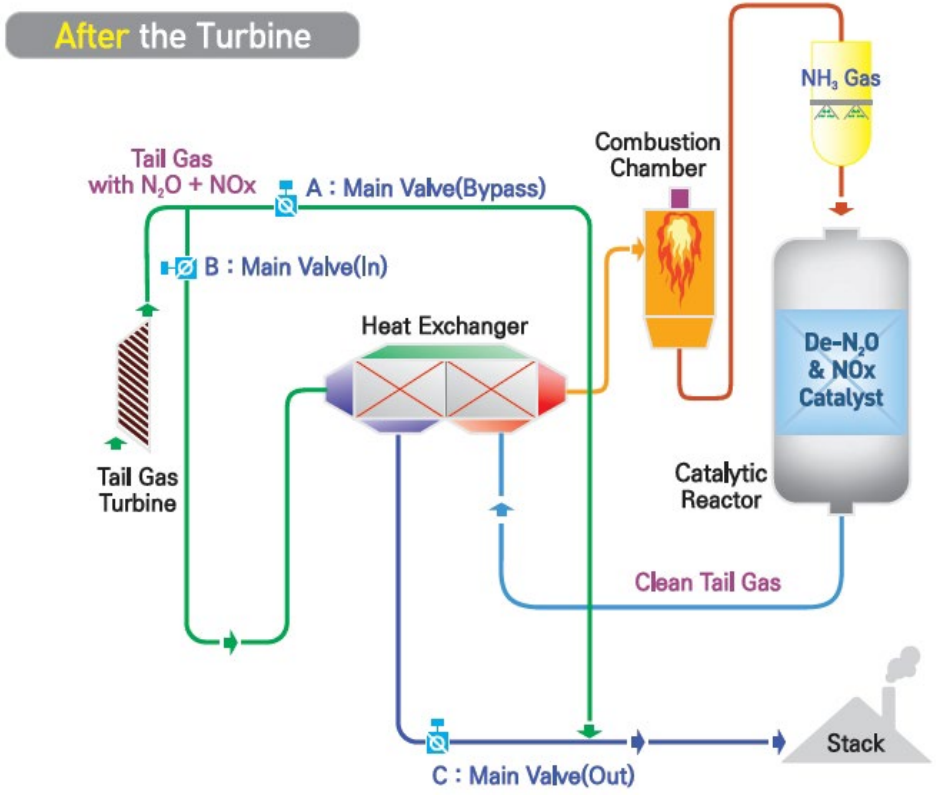
198,000 ton/year in Europe



- Project : CDM Project
- Installation : 2016. 07
- Site : Middle East
- Size : Q = 88,200 m^3/hr
- Oper. Press. : Normal
- Oper. Temp. : > 440℃
- Efficiency : N_2O, NOx ≥ 95%

Certificate of Performance and Operation Experience

< Europe >

Certificate of Performance and Operation Experience

Applicant	Supplier	ECOPRO	CEO	Lee. Dongchae
	Office & Plant	587-40 Gwahaksaneop 2-ro, Cheongwon-gu, Cheongju-si, Chungcheongbuk-do, 28116, Republic of Korea	Tel. No.	+82-43-240-7700
	Registration No.	214-86-26675		
	Purpose	Submission	Receiver	Shiraz Petrochemical Company
	Job class	Manufacture (○), Supply (○), Other (engineering, procurement, construction)		
	In case of Supplier Experience	Manufacture : ECOPRO Address : 587-40 Gwahaksaneop 2-ro, , Cheongwon-gu, Cheongju-si, Chungcheongbuk-do, 28116, Republic of Korea TEL: 043-240-7700, FAX: 043-218-7771		
Characteristics Catalyst	Plant	Nitric Acid manufacture		
	Flue Gas	88,200 Nm^3/hr		
	Temperature	425 ℃		
	Date Provided	2016.11.30		
	Manufacturer	ECORPO		
	TYPE	Ceramic honeycomb monolith		
	NH_3 Slip (ppm)	< 10		
	De-NOx Efficiency (%)	> 95		
	De-N_2O Efficiency (%)	> 95		
	Guarantee Life	2 yr		
	Catalyst volume	12.8 m^3		
	Chemical Composition	Fe-zeolite		
Status	Date of commissioning	2017.03.02. - 2017.04.02		
	Operation Time	29 months		
	Operation Status	■ Excellent □ Good □ Not good		
Authority Issued	We hereby Certify that the product provided by the above supplier meet the requirement of technical specification and performance test defined in contract document. June 24, 2019 No. 1, Farivar Alley, Ghaemmagham, Farahani Ave. Tehran, Iran			
	Issued by : Shiraz Petrochemical Company		Responsibility : Mana[illegible] (MD) Ah[illegible]arian	

SPC Shiraz Petrochemical

< Korea >

Certificate of Performance and Operation Experience

Applicant	Supplier	ECOPRO	CEO	Lee. Dongchae
	Office & Plant	587-40 Gwahaksaneop 2-ro, Cheongwon-gu, Cheongju-si, Chungcheongbuk-do, 28116, Republic of Korea	Tel. No.	+82-43-240-7700
	Registration No.	214-86-26675		
	Purpose	Submission	Receiver	Hanwha
	Job class	Manufacture (○), Supply (○), Other ( )		
	In case of Supplier Experience	Manufacture : ECOPRO Address : 587-40 Gwahaksaneop 2-ro, , Cheongwon-gu, Cheongju-si, Chungcheongbuk-do, 28116, Republic of Korea TEL: 043-240-7700, FAX: 043-218-7771		
Characteristics Catalyst	Plant	Nitric Acid manufacture		
	Flue Gas (Nm^3/hr)	43,000 Nm^3/hr		
	Temperature (℃)	370 - 380 ℃		
	Date Provided	2015.11.30		
	Manufacturer	ECORPO		
	TYPE	pellet		
	NH_3 Slip (ppm)	≤ 20		
	De-NOx Efficiency (ppm)	≤ 50		
	De-N_2O Efficiency (%)	≥ 95%		
	Guarantee Life	3 yr		
	Catalyst volume	7.3 m^3		
	Chemical Composition	Fe-zeolite		
Status	Date of commissioning	2016.02.16 ~ 2016.02.19		
	Operation Time	42 months		
	Operation Status	■ Excellent □ Good □ Not good		
Authority Issued	We hereby Certify that the product provided by the above supplier meet the requirement of technical specification and performance test defined in contract document. June 24, 2019 3, Sinmam-gil, Onsan-eup, Ulju-gun, Ulsan, Republic of Korea			
	Issued by : HanwhaCorp. Onsan plant		Responsibility : Plant manager, B.C. Song	

Thank You

EcoPro HN

Inquiry Sheet of Catalyst

Date :

1. Plant / Production Capacity :

2. Customer Information

Company	:	Address	:		
Name	:	Position	:	E-Mail	:
Tel	:	FAX	:	Mobile	:

3. Flue gas Information

Exhaust gas process	:		
Flue gas volume	:	Nm^3/hr (wet)	: Nm^3/hr (dry)
Flue gas temperature	:	^oC	
Flue gas Pressure*	:	mmAq	
Operating time	:	hr/day	
Flue gas Composition			
O_2 - actual	:	Vol. %, wet	
O_2 - reference	:	Vol. %, Dry	
H_2O	:	Vol. %	
NO inlet	:	ppm(dry)@ ref-O_2	
NO_2 inlet	:	ppm(dry)@ ref-O_2	
N_2O inlet	:	ppm(dry)@ ref-O_2	
SO_2/SO_3	:	ppm(dry)@ ref-O2	
CO_2	:	Vol. %	
Particles (Dust)	:	mg/Nm^3	
Requested NO outlet	:	ppm(dry)@ ref-O_2	

Calculation of Emission Reduction

EcoPro HN

Baseline Emission(BE_y)

$$BE_y = P_{production,y} \times EF_{new,y} \times \frac{(h_y - h_{r,y})}{h_y} \times GWP_{N20} \times 10^{-3}$$

Where:

BE_y	=	Baseline emissions in year *y* (t CO2e)
$P_{production,y}$	=	Production of nitric acid in year *y* (t HNO3)
$EF_{new,y}$	=	Baseline N_2O emission factor for nitric acid production in year *y* (kg N_2O/t HNO3)
GWP_{N20}	=	Global Warming Potential of N_2O valid for the commitment period
h_y	=	Number of hours in year *y* during which the plant was in operation (h)

Project Emission(PE_y)

$$PE_{N20,y} = \sum_{1}^{h_y - h_{r,y}} F_{N20,tail\ gas,h} \times GWP_{N20} \times 10^{-3}$$

Option C is applied based on the operating and measuring conditions

Where:

$PE_{N2O,y}$	=	Project emissions of N_2O from the project plant in year *y* (t CO_2e)
GWP_{N20}	=	Global warming potential of N_2O valid for the commitment period
$F_{N2O,tail\ gas,h}$	=	Mass flow of N_2O in the gaseous stream of the tail gas in the hour *h* (kg N_2O/h)
h_y	=	Number of hours in year *y* during which the plant was in operation (h)
$h_{r,y}$		Number of hours (h) in year *y* where:

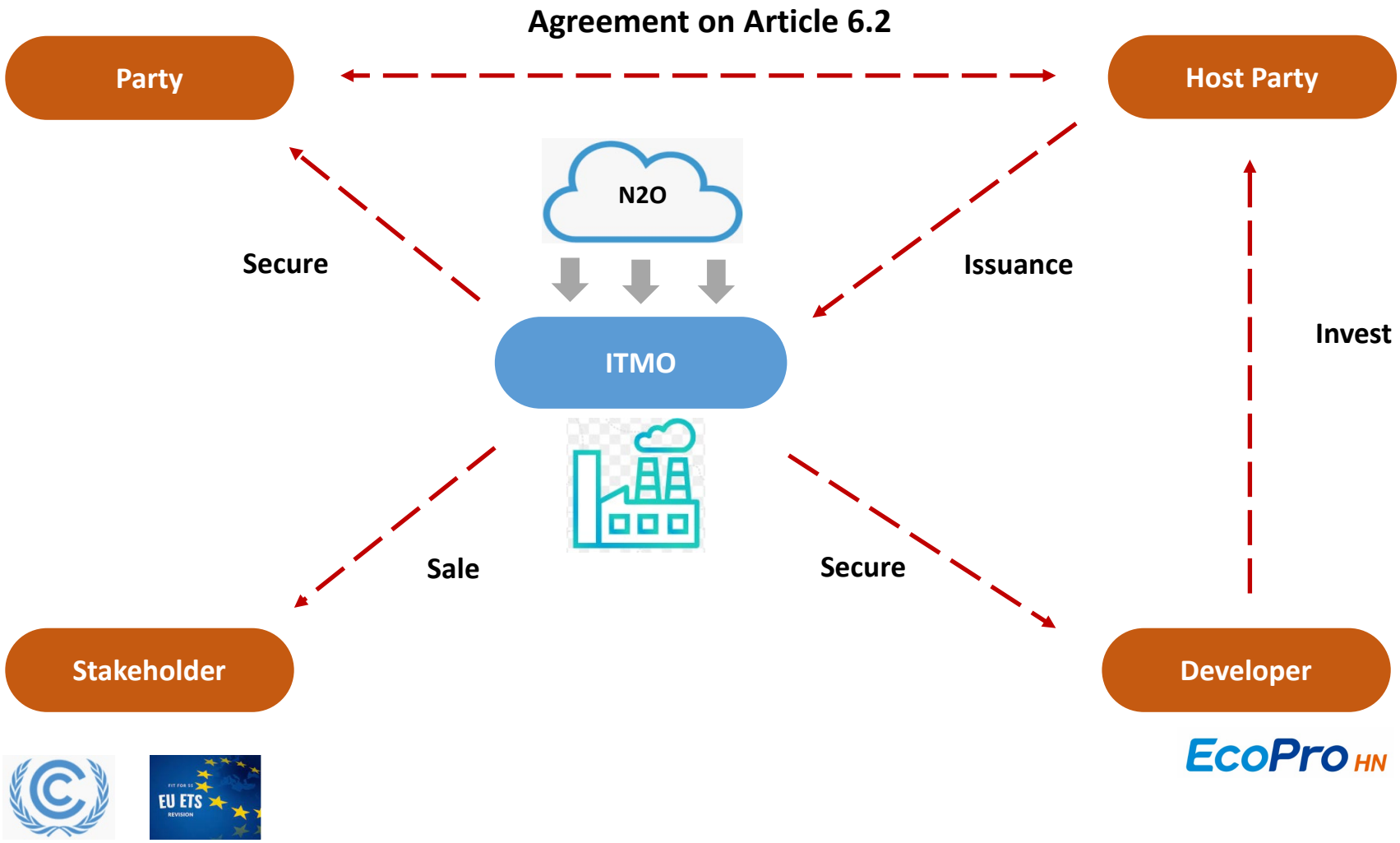
Emission Reduction(ER_y)

$$ER_y = BE_y - PE_y$$

Where:

ER_y	=	Emission reductions in year *y* (t CO_2e)
BE_y	=	Baseline emissions in year *y* (t CO_2e)
PE_y	=	Project emissions in year *y* (t CO_2e)

Structure based on Article 6.2



ITMO : internationally transferred migration outcome

Comparison of A6.2 and A6.4

	Article 6.2 (Cooperative Approach)	Article 6.4 (Sustainable Development Mechanism)
What it is	Approach for Cooperative Action between both Parties	A6.4 Mechanism
Project Approval	Committee of both Parties	A6.4 Supervisory Body
Methodology	Not yet (Possibly apply A6.4 methodology)	Existing CDM methodology (needs to be modified)
Crediting Periods	Not Specified	10 years (fixed) or 3 times of 5 years (renewal)
Share of Proceeds(SOP)	Not mandated but encouraged	7% of Emission Reductions
Key Outcomes	MO	6.4ER
Registry	Committee Registry or UNFCCC Registry	A6.4 Registry of UNFCCC

CO2 Baseline Emission

EcoPro HN

Applies ACM0019 Methodology
Emission factor for HNO3 is 2.5kgN2O/tonHNO3 since 2020

$$BE_y = P_{production,y} \times EF_{new,y} \times \frac{(h_y - h_{r,y})}{h_y} \times GWP_{N2O} \times 10^{-3}$$ Equation (3)

Where:

- BE_y = Baseline emissions in year *y* (t CO2e)
- $P_{production,y}$ = Production of nitric acid in year *y* (t HNO3)
- $EF_{new,y}$ = Baseline N_2O emission factor for nitric acid production in year *y* (kg N_2O/t HNO3)
- GWP_{N2O} = Global Warming Potential of N_2O valid for the commitment period
- h_y = Number of hours in year *y* during which the plant was in operation (h)
- $h_{r,y}$ = Number of hours (h) in year *y* where:
  - (a) For secondary N_2O abatement. Abatement system was not installed, underperforming or failed;
  - (b) For tertiary N_2O abatement. The abatement system is by-passed, underperforming or failed

Year	Emission factor (kgN_2O/t HNO_3)
2005	5.10
2006	4.90
2007	4.70
2008	4.60
2009	4.40
2010	4.20
2011	4.10
2012	3.90
2013	3.70
2014	3.50
2015	3.40
2016	3.20
2017	3.00
2018	2.80
2019	2.70
2020	2.50
2021	2.50
2022	2.50
2023	2.50
...	...
Year n	2.50

In case of 100,000 HNO3 Production

100% HNO_3 ton/yr	x	Emission Factor(kgN_2O/ton HNO_3)	x	GWP($tonCO_2$/$tonN_2O$)	x	1ton / 1,000kg		
100,000	x	2.5	x	265	x	0.001	=	66,250 $tonCO_2$/yr