Nanjido Ecological Park

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1. Timeline

Nanjido was the only large waste landfill of Seoul to bury approx. 92 million ㎥ of domestic, construction, and industrial wastes for 15 years from 1978 to 1992. In the 1970s, Seoul experienced rapid economic and exponential population growth. As the result, waste levels sharply increased forcing the city to designate the location around Nanjido (540, Seongsan-dong, Mapo-gu, Seoul) as an urban planning facility in 1978: "Waste Disposal Facility". Nanjido was a perfect landfill site for Seoul because of its accessibility, location on the outskirts and vast size. Horizontal burying was performed from 1978 to 1985 while vertical burying was performed at the primary and secondary landfills from 1986 to 1992.

Figure 1. Vehicles heading for Nanjido on the Jayuro
(source : http://worldcuppark.seoul.go.kr)

But the insanitary burying caused leachate during the entire burying period which led to serious land and water pollution. The landfill gas was also prone to catching fire at times. The

[1] Translation by ESL®

environmental arrangement of the landfill was politically highlighted in 1990. The basic master plan of the 'Seoul, Capitalization 600 Yyears-old capital city project' was established in 1992 for the strategic development of Yeouido, Yongsan, Sangam, Tukseom, and the Magok area. A special urban development plan was prepared for Sangam, where Nanjido was located, reflecting that it was a gateway of both globalization and the unification of the South and North as the key area of Northwestern Seoul. In addition, there was a need to fix the local environment in order to build a world-cup stadium following the decision to build the 2002 Korea-Japan World-Cup stadium in Sangam in May, 1998. Moreover, the 'New Seoul, Our Han River' project that included the basic millennium park plan of Seoul in 1999 also included the Nanjido landfill stabilization and park construction plans.

The Nanjido landfill stabilization and park construction plans were quickly implemented for the World Cup. The landfill stabilization project was initiated in January, 1998 and finished in October, 2002 after 4 years and 10 months. The construction company was selected and started work within 3 months of finishing the design so as to shorten the construction period. An ecological park was also constructed from October, 2000 to June, 2002 alongside the stabilization project (KSP, 2014). The waste buried under Nanjido is still being biodegraded, and Seoul estimates that the stabilization will continue until 2020.

2. Situation: Background

'Nanji' of Nanjido is a combination of orchied (Nan) and gromwell (Jichi) meaning extreme beauty. Indeed, it was a beautiful island where peanuts and sorghum were grown and a place that students visited for picnics despite the frequent floods. However, Seoul buried about 20,000 tons of waste in Nanjido following its designation as a waste landfill site as well as a solid waste handling area in 1977. With the 15 years of landfill, about 9,200 million tons of waste was piled up in mountainous forms of around 812,800 pyeong (about 246,303 m2). It was originally planned to use Nanjido as a landfill for a mere 6 years from 1978 to 1984 considering the extent of the work done there. But it was difficult to find an alternative, so most of the waste of Seoul was dumped there and Nanjido eventually had a 100m high mountain of waste standing on it.

Figure 2. Geumseongpyeongsa in Geyonggyomyeongseungcheop: Gyeomjae Jeongseon 1676-1759
(Source: http://worldcuppark.seoul.go.kr)

Nanjido landfill was operated in typically insanitary ways – without any solution for gas generation, leachate, flying waste, or the harmful insects. The excessive volume of waste caused many problems. More importantly, the insanitary operation caused land, water, and air pollution with the leachate and landfill gas while the unplanned and excessive landfill caused safety issues including ground subsidence and slope collapse. The leachate had very high Biological Oxygen Demand (BOD) of 72mg/l, Chemical Oxygen Demand (COD) of 605mg/l, and Total Nitrogen (T-N) of 1,416mg/l, which can have adverse effects on neighboring streams, The Han River is connected to the streams, and this underground water is directly connected to the health of citizens. The landfill gas generated by the waste degradation process is mainly composed of greenhouse gases such as methane and carbon dioxide; the former is very flammable and explosive so Nanjido experienced several fire accidents. At the same time, unbalanced subsidence during the degradation and the massive weight of the waste layers gradually removed space so the leachate level and possibility of slope collapse increased. In addition, the waste trucks caused serious pollution including dust and noise.

Figure 3. Nanjido Landfill

Source: World-cup Park Management Office (2006) Nanjido recovers the scent)

Besides the environmental issues, the Nanjido landfill caused social issues. The Nanjido landfill was a living foundation for the urban poor who made their living with goods found from the waste. They suffered from the odors, dust, insects, birds, and air pollutants from the trucks every day. They also lived in very poor brick housing around the waste piles provided by the Seoul City Government. In a word, they were exposed to risks of environment, health, and safety.

Figure 4. Nanjido people collecting waste

(Source: http://worldcuppark.seoul.go.kr)

From the end of 1992, Seoul began to dump its waste at the Sudokown Landfill and finally stopped using Nanjido from 1994. Nanjido had been used as Seoul landfill for 15 years from 1978 to 1993. But the environmental issues of landfill did not suddenly disappear. As the landfill ceased, social issues appeared – including jobs and housing for the urban poor. Furthermore, Seoul had to discuss how to use the once-landfill land. Academia and various industries had different ideas regarding the early development and long-term development following the stabilization of Nanjido. The 'Early Development' was to relocate the buried waste to coastal landfill sites or other locations and then redevelop it as a housing or business site. On the other hand, the 'Long-term Development following Stabilization' was to develop it in the long term when the conditions were established after installing pollution prevention facilities for landfill gas and leachate, stabilizing the land, and finally building an environmental and ecological park on the ground. After analyzing the different aspects, Seoul decided "to maintain the current situation and postpone the development while preventing environmental pollution and stabilizing it."

3. The Importance of the Policy 111741492667723

The Nanjido Ecological Park Development policy has had a positive role in the eco-friendly management of Seoul in many aspects.

Firstly, the Nanjido Stabilization project was a case in which Seoul took the lead in managing the waste landfill instead of the central government. In 1993, when the Nanjido landfill had ceased being used, there were no follow-up management regulations in Korea. Post-landfill management regulations were found in the Waste Management Act in 1996 for the first time in Korea focusing on "establishing engineering solutions for appropriate follow-up management of landfills to be closed after 1998 and obliging environmental management for over 20 years." In 2010, the follow-up management regulations were reinforced to extend the follow-up environment management period to 30 years. Nanjido stopped being used for the burial of waste

in 1993 so it was not subject to those regulations. However, Seoul predicted political changes of sustainable waste management in Korea and overseas countries and preemptively opted for landfill stabilization and thus creating a good example of post-landfill management.

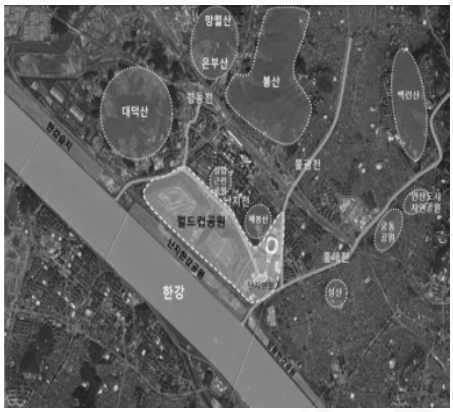


Figure 5. Green field and streams around Nanjido Ecological Park
Source: Seoul Institute, 2014, "2014 Economic Development Experience Modularization Project: Recovery of Nanjido Ecological Park")

Secondly, the Nanjido Ecological Park is connected to surrounding green areas and an ecology stream for self-sustainable recovery of the ecological functions. The Nanjido Ecological Park meets the Han River, Bulkwang Stream, Hongje Stream, and Hyangdong Stream while the grass fields on their watersides is connected to that of Nanjido Ecological Park. Even though Seoul is not home to much in the way of artificial features or design, except for some food plants and improvement of the habitat around the Nanjido park, the number of animals and plants have increased around the surrounding ecological space after developing the park.

Thirdly, the landfill gas obtained as part of the stabilization is used for district heating contributions to the 'resource cycling' city development policy of Seoul. Methane is one of the most valuable fuels, and about 232,572K m^3 of landfill gas had been used at the Nanjido Ecological Park from 2002 to December, 2013, which amounts to about 8.2 billion KRW of economic value. The collected landfill gas is supplied to a district heating facility located in the Nanjido Ecological Park. The park has an incineration facility (capacity of 750 tons) for handling the domestic waste of neighbors while the heat is collected and then supplied to the district heating facility. It is a unique and rare occurrence to have landfill gas collection, domestic waste incineration, and district heating facilities all in one ecological park.

Figure 6. Mapo Resource Recollection Facility
(Source: https://seoulsolution.kr)

Fourthly, the awareness of citizens regarding waste management has changed as the abandoned landfill has been transformed into a park. The Nanjido landfill site was constantly negatively seen as a source of both environmental pollution and odor. But the waste handling facility was transformed into a resting place for citizens, which is now widely known as a shining example of excellent representative environment management on the part of Seoul.

4. Relevance with Other Policies

The Nanjido Ecological Park project was connected with the Sangam New Millennium Town project and New Han River Development projects.

1) Sangam New Millennium Town Project

Sangam New Millenium Town Project was a plan focused on developing the Sangam district from 1998 to 2000. It contained long-term plans to shape Sangam as a future city as well as a new sub-center of Seoul. The first phase connects the Nanjido landfill stabilization and re-development with surrounding facilities and development plans. The slogans and ideas behind the plan include ‘Gateway City for reunified Korea’, ‘Information City for 21st century’, and ‘Eco City for coexistence of humans and the environment’. The objectives included planned development for transfer station construction and sphere development of the Gyeongui line, Yeongjongdo New Airport Railway, and Subway Line No.6; scenario developments and stage plan settings for the Nanjido landfill stabilization and future use; establishment of organization plans aligned with the city development for a successful World Cup; suggestion of ecological city design guidelines for Samgam Millennium City; and planned responses to high-speed trains.

Figure 7. Sangam New Millennium Town and Nanjido Ecological Park

(Source: https://seoulsolution.kr/)

Additionally, the land was divided into various sections (Digital Media City, an eco-friendly housing complex, and World-cup Park) to help shape Sangam as a new city combining downtown functions, distribution, housing, with parks and green fields.

2) New Han River Development

This project aimed at developing a space for the coexistence of humans and the environment: where the Han River is made fascinating with water purification, ecosystem recovery, and leisure facilities for citizens and tourists alike. Located along the Han River, the Nanjido Ecological Park was developed for landscape and water quality improvement of the Han River. The Nanji-Han River Park is the second biggest park around the Han River and provides natural purification and leisure to the citizens using the wetland developed for 2002 World Cup. For the New Han River Development, the framework plans were developed in the first half of 1999 and it got underway in 2000 with the addition and maintenance of facilities, preservation and recovery of historic sites as well as the development and promotion of green fields.

5. Policy Objectives

The millennium park framework plan for the Nanjido Ecological Park development consisted of the following political objectives: (1) to recreate the landfill as an eco-friendly space; (2) to shape the surroundings of the 2002 World Cup stadium; and (3) to contribute to developing an eco-friendly city with the open space and park functions of the Sangam New Millennium Town Arrangement project.

Nanjido, however, raised different issues – including air and water pollution, odor, harmful insects, and safety for the surroundings as an insanitary landfill for 15 years. As addressed before, discussions took place to relocate the waste and use the land for new purposes, or

stabilize the waste and avoid its short-term use for the future. Finally though, a decision was made to build the Nanjido Ecological Park. By developing the ecological park, the abandoned land was recycled as an eco-friendly space for the new millennium suggesting future-oriented environmental alternatives and representing proud cultural characteristics.

The second political objective was to improve the surroundings of the Sangam World-cup Stadium by developing the Nanjido Ecological Park. Korea was selected as a host for the 2002 World Cup and Sangam was the site for main World-cup stadium in Seoul. But the surroundings were poor. It was vital to address the mountains of waste at the Nanjido landfill site, polluted streams, and housing for the poor. So, the ecological park development project was responsible for the large-scale environment rearrangements for the surroundings.

Thirdly, Seoul tried to transform Sangam into an eco-friendly town in order to to address the rapidly increasing demand for housing in the 1990s. Seoul actively developed housing sites because of the increasing demand for development and housing in the 1990s. Sangam was no= exception as it had detached houses, settlements, and faming land. Thus, it was planned to build housing to transform Sangam into a sub-center while developing a large park in Nanjido to improve the life quality of citizens and build the Sangam New Millennium Town as an eco-friendly city serving as a supporting green field.

6. Main Policy Contents

Seoul concentrated its full organizational capabilities so as to finish the Nanjido Ecological Park Development project before the World Cup. To shorten the project period, 8 projects - landfill stabilization. Pyeonghwa Park, Haneul Park, greening of surroundings, Heemang Forest, Noeul Park, Nanjicheon Park, and Najni Han River Park - were carried out at the same time. 6 departments of Seoul were engaged in the design while 5 departments took part in order placement and supervision. Moreover, many private businesses participated: 9 designers, 23 constructors, and 6 supervisors.

The Nanjido Ecological Park development consists of the landfill stabilization and park development and cost 232.2 billion KRW (140.5 billion KRW for the stabilization and 82.7 billion KRW for the park development). The expenditures were covered with the general funds of Seoul.

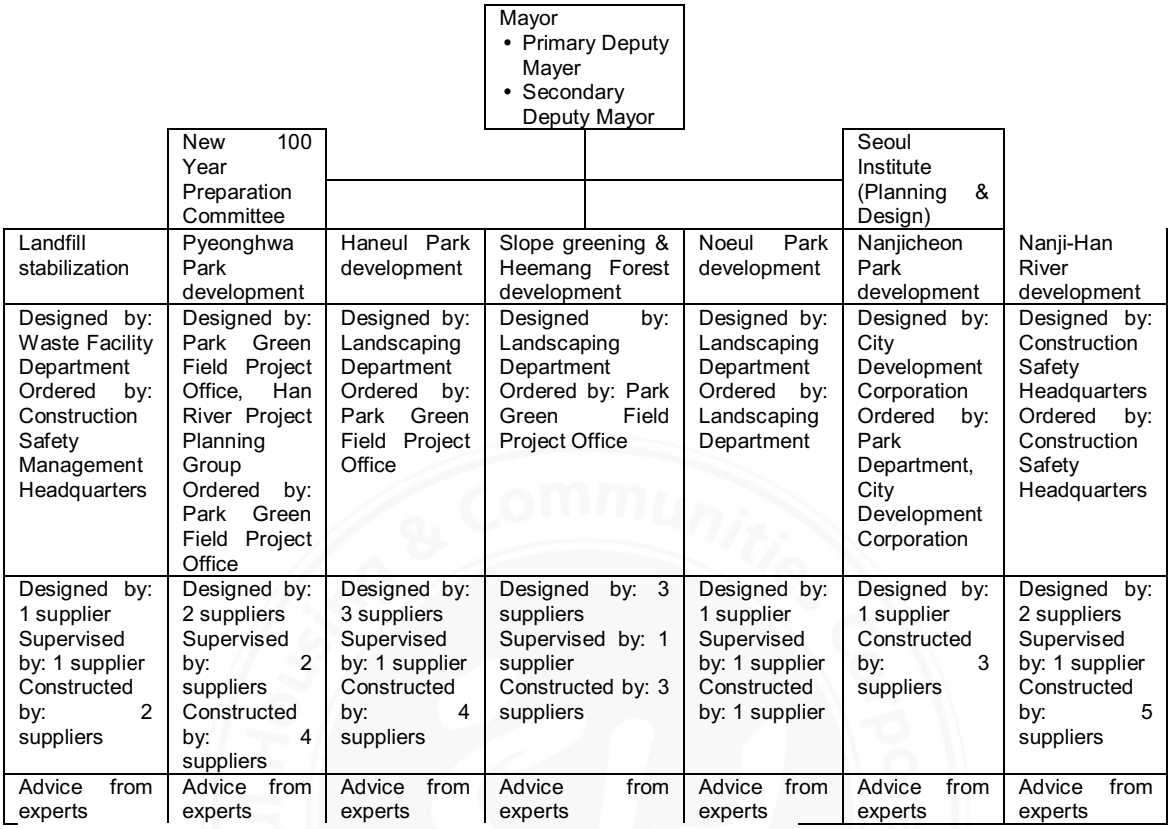


Figure 8. Organization for Nanjido Ecological Park Development project
Source: Seoul Institute, 2014, "2014 Economic Development Experience Modularization Project: Recovery of Nanjido Ecological Park"

1) Nanjido stabilization

With the landfill finished, Nanjido is expected to be stabilized until 2020. The landfill stabilization is a process in which the organic matter is degraded for a long time and discharged as landfill gases or leachate; inorganic matter and heavy metals are leachated with the ground subsiding. Finally, it returns to its original state. The insanitary landfill was carried out for a long time so Nanjido produced leachate, odord, and harmful gases resulting in water and ground pollution around the Han River and thus serious destruction of the local ecosystem. The Nanjido stabilization aimed at addressing the environmental pollution and preparing for eco-friendly park development. The stabilization consists of leachate handling by installing barrier walls for the leachate, top molding processes to develop grass fields; gas collection and handling; and slope stabilization to prevent collapse by adjusting its incline and developing the area for the return of green space.

2) Ecological park development

The Nanjido Ecological Park has 5 parks - Pyeonghwa Park, Nanjicheon Park, Haneul Park of Landfill No.1, Noeul Park of Landfill No.2, and Nanji-Han River Park - covering approximately 1.05 million pyeong (about 318.182 m2). They were designed to be integrated and organized

while having independent characteristics. The planning concept was the 'Mutual Coexistence and Symbiosis' for the coexistence of nature and human culture; a symbiotic relationship between environment preservation and human development, and a harmony of artificial structures and natural landscapes. In addition, the drainage and earthwork plans were reflected to prepare for the subsidence of landfill layers and observe them.

Figure 9. Bird's-eye view of Nanjido Ecological Park
Source: http://worldcuppark.seoul.go.kr

3) Sustainable waste management

Along with the Nanjido Ecological Park development, the Mapo Resources Recollection Facility was built between the Noeul Park and Haneul Park. It is an incineration facility that handles 750 tons of domestic waste daily from Mapo, Yongsan, and Junggu. It was built from June, 2000 to December, 2003. The Nanjido Ecological Park came to have comprehensive resource recycling functions with the newly-built resources recollection facility, district heating facility, leachate treatment plant, and landfill gas collecting facility. In addition, the resources recollection facility is serving as an environmental education space by operating site visit programs for citizens and designing symbolical building for the futuristic ecological city.

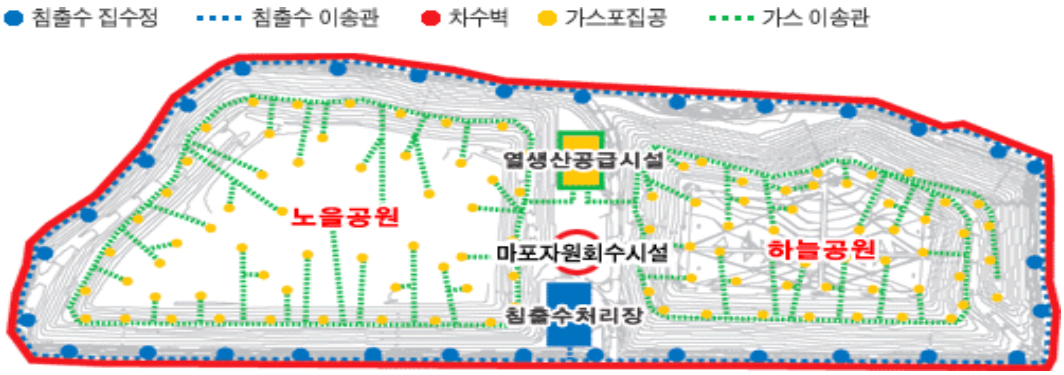
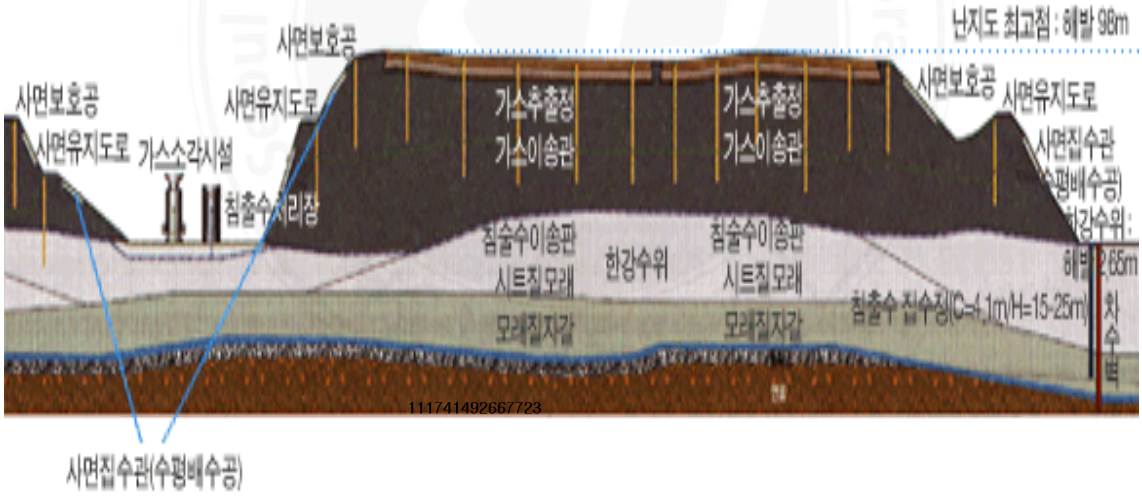


Figure 10. Resources collecting and related facilities
Source: http://worldcuppark.seoul.go.kr

7. Technical Details

The Nanjido ecology recovery project consists of landfill stabilization and ecological park development.

1) Stabilization



The stabilization aims at isolating the waste accumulated for 15 years and thus restoring the surrounding environment. The stabilization consists of barrier wall installation and leachate processing to prevent water pollution, landfill gas collection and processing, stabilization of the slope, and top molding for grass fields.

The leachate facility has intercepting and processing equipment. The intercepting equipment (barrier walls and collecting wells) isolates the leachate and keeps stable levels of leachate in the landfill to prevent collapse of the slope. 31 horizontal-drainage collecting wells were installed to 3m depth of the bottom layer with the Caisson method. This method is especially good with underground water level control and low costs. The barrier wall isolates the leachate

and was installed at a depth of 19-48m at 6,235m distance by combining the S.S.P Wall and C.B.S Wall. The leachate is stored in the collecting wells; from there it is sent to the leachate treatment station and the Nanji Sewage Treatment Plan using pumps. Finally, it is discharged into the Han River.

The landfill gas produced with the biodegradation of waste is collected and then processed. The average production of Nanjido landfill gas is 432KNm³/day, which is mainly composed of methane (51%) and carbon dioxide (46%). To prevent odor diffusion and any risk of explosion of landfill gases, the top of landfill was covered with a blocking layer. The landfill gas processing collects and processes harmful gases in a safe manner and provides habitats for plants. The reflected collection of landfill gas was 300Nm³/min through 55 and 51 vertical collecting wells installed at 120m intervals on both the top and slope, respectively. The gas is collected at the landfill gas processing facility for district heating while the remaining is burnt. The landfill gas collecting and processing facilities are managed by the Korea District Heating Corporation.

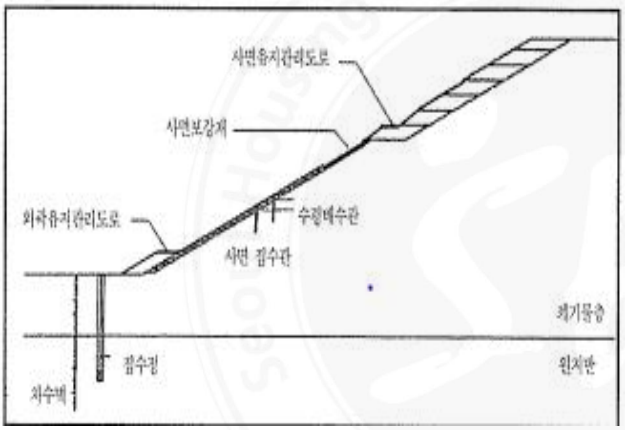


Figure 10. Design concept of slop stabilizing facility for Nanjido Landfill Stabilization

Source: Yeong Kuk Lim, 2006, Nanjido Landfill Stabilization

The slope stabilization is to prevent its collapse while minimizing rainwater penetration. Any slope with a inclination under 1:2 was maintained while those over 1:2 were adjusted with a 9m protection installed. The maintenance stage performs continuous slope inspection, waterway repairing, and maintenance to prevent slope loss. Lawn and Leafy lespedeza was planted on any vegetation-vulnerable slope for better stability. Any potentially collapsing slope was covered with tent fabrics to prevent further damage from occurring. Additionally, regular safety inspections were performed biennially by external experts, including professional engineers.

The top arranging and molding work installed water shields (HDPE) to prevent rainwater penetration and covered the top with earth to encourage the growth of plants. The molding consists of a 50cm supporting layer, 1.5mm shield layer (HDPE), a 30cm drainage layer, filtering felt, a 30cm vegetation layer, and a 30cm surface layer in the order to create a 1.4m depth on average. The top is arranged to have an approximately 4% slope to easily avoid rainwater and encourage plant growth. The future subsidence was estimated with the hyperbolic

method of the Gibson &Lo Model and Power Creep Law and then reflected on the top arranging and molding. Maximum subsidence was estimated in the center by over 3.6m for 20 years.

Table 1. Details of Nanjido Ecological Park project

Classification	Project details
A. Top arranging and molding	
1) Purpose	·Top: Minimized rainwater penetration and thus leachate production, prevention of surface gas leakage, and vegetation ·Slope: Maintenance of currently stable slopes while recovering vegetation and installing protection on surrounding sections and banking around the outskirts and slope maintenance roads
2) Arranged inclination on top	·About 4% of arranged inclination for good rainwater avoidance
3) Cross section of top molding layer	·Top molding layer (1.4m): Surface (30cm), vegetation (30cm), drainage (protection, 30cm), blocking (HDPE 1.5mm), and supporting (50cm) layers ·Dynamic compaction for landfill gas collecting well, pipelines, and roads
B. Blocking of leachate	
1) Purpose	·To prevent diffused leachate pollution in the adjacent Nanji Stream, Bulkwang Stream, Han River, and others
2)Installation section & method	·Barrier walls were fully-installed around the landfill with Coment Bentonite Slurry Wall and Steel Sheet Pile.
3)Installation depth & distance	·Depth: Penetration of 1m and 0.5m into weathered rock and soft rock, respectively ·Distance: 6,235m (S.S.P : 3,320m, C.B.S : 2,915m)
C. Intercepting and processing of leachate	
1) Purpose	·Optimized intercepting and processing of leachate from the slope and foundations 111741492667723
2) Slope collecting facility	·Slope collecting pipe: 6,003m, MAT type pipe: 3,622m ·Horizontal drain: 667 holes
3) Intercepting facility	·Horizontal draining type collecting well: 31 points, Horizontal strainer: 9,300m (186 holes)
4) Transfer facility	·Non-pressure flow pipe (MDPE): 5,186m, Forced flow pipe (PEM): 2,035m ·Intermediate pumping station: 3 points
5) Processing facility	· On-demand pretreatment and then transfer to Nanji Sewage Treatment Station for the separate processing ·Process: Flow Control+Collection & Precipitation+Penton Oxidation ·Capacity: 1,860 tons/day
Classification	Project details

D. Collection and processing of produced gas	
1) Purpose	·Collecting and processing of gas (375N㎥/min) produced during degradation of wastes
2) Collecting facility	·Extracting well: 106 points
3) Transfer facility	·Transfer pipe (HDPE): 13,250m
4) Processing facility	·Blower: 5 EA
E. Slope stabilization	
1) Purpose	·To prevent collapse of slopes and minimize rainwater penetration
2) Horizontal drain facility	·Length: 9m , Installation: 667 points
F. Sewage sludge processing	
1) Purpose	·To eliminate hazards by processing and disposing the landfill sludge (565,882㎥) and thus increase the recycling and land utilization
2) Method	·Banking material for landfill bottom arrangement: 202,210㎥ ·Utilization of sludge-mixed earth and sand as molding material: 16,890㎥ -Supporting layer: 91,570㎥ -Vegetation layer: 77,320㎥ (top+slope) ·Soil-like: 194,700㎥

Source: Yeong Kuk Lim, 2006, "Nanjido Landfill Stabilization"

2) Ecological park project

① Pyeonghwa Park

The Pyeonghwa Park was built on a plane surface, which had an area of 440,000㎡, between the World-up Stadium and Gangbukgangbyeon-ro, at an altitude of 10-15m altitude on a 10m-high waste pile. Its concept is the peace that is related to the Mutual Coexistence and Symbiosis theme of the World Cup Park. It was specifically designed to reflect the themes of global harmony and peace kept in mind for the World Cup. The Pyeonghwa Park was designed by the Han River Project Planning Group, and was working-designed and constructed by the World Cup Park Project Group, Park Green Field Management Office. It consists of the UNICEF Square, Nanji Pond, Pyeonghwa Garden, Picnic Square, and Nanjido Story (Exhibited in World-cup Park). The waterside trail was developed on the water's edge using a 50cm-high wood deck. Water was brought from the Han River to the Nanji Pond in the center with cattails, baby lotuses, water lilies, scouring rush, and Russian irises planted for water purification.

Figure 13. Framework plan for Pyeonghwa Park
Source: http://www.lafent.com

② Haneul Park

This grass field park consists of a 190,000㎡ area on Landfill No.2. It has the poorest soil quality of the entire Nanjido Landfill site so it was designed to show how nature can still be reborn on poor land.

The master plan was established by the Master Plan Commission for Millennium Park; the landscaping and working design was performed by Yooshin Corporation Co., Ltd. and Pyeonghwa Engineering Co., Ltd.; the construction was performed by Bando Environment Development Co., Ltd., Imwon Development Co., Ltd., and Dongil Construction Co., Ltd. A total of 25.6 billion KRW was spent on the Haneul Park development. It was built with to a concept of a vast grass field and separated into 4 zones – with the ridge formed for drainage and the high grass field developed in the South-North section and low one in the East-West section. The South-North section had silver grass and the equivalent perennial grass field while the East-West section had mainly wild grass and some naturalized grass fields to demonstrate the stages of succession between them later. The entire area has drainage gradient of 4-8% with the cross management roads. For stabilization, the available vegetation depth was only 60cm on top of the water blocking layer and the ground was unstable so the planting of trees and installation of structures was prevented. Haneul Park has vast grass fields and the Silver Grass Festival is held there every October.

③ Noeul Park

This site was developed with about 340,000㎡ area at the location of Landfill No.1. Initially, there were plans to develop a public golf course with 57% of the area and civil leisure facilities and vegetation area with the rest. This initial plan was put forward but it, ultimately, did not succeed. There was serious disagreement concerning the golf course so the plan was changed to build family and sculpture parks in 2008 and 2009. Currently, it is used as a family park with

cafes, playgrounds for children, park golf courses, and a family camping area.

④ Nanjicheon Park

This location was built in the lowlands with a 70-250m width between the waste layer (Haneul and Noeul Parks) and Sangam Area. It had suffered from serious water pollution because of leachate from the Nanjido Landfill. Some of the waste had been buried in the center and the stream was affected severely. The plan, therefore, was to develop the Nanji Stream and park around it in order to show the ecological recovery of the polluted stream and transformation into a natural one.

The Nanjicheon Park was developed for residents in the Sangam New Millennium Town - especially the disabled, old and infirm, and youth. Thus, a lawn picnic field was built sloping down toward the pond with special and natural playgrounds using natural materials and topography. The trail and stepping stones were installed around the pond so that family visitors can have the opportunity to study the wetland ecology. Furthermore, the Nanjicheon Park has sports and game facilities for the residents. It caters especially for the disabled and old, with sports facilites arranged in small groups along the road in the forest to alleviate desolateness. Curved trails were installed between the sports facilities and stream to improve accessibility to the stream's edge and different types of wild plants.

⑤ Nanji-Han River Park

This is the second biggest park among the 13 Han River parks. The Nanji-Han River Park is a neighborhood park for the recreation of residents offering sports and game facilities, picnic places, and trails and required functions for the smooth operation of the World Cup. Considering the site conditions, the land use plan of the Nanji-Han River Park was divided into a dock, camping, central square, sports facilities, and waterside ecological park zones.

Figure 14. Pyeonghwa Park
Source: http://worldcuppark.seoul.go.kr


Figure 15. Haneul Park
Source: http://www.lafent.com

Figure 16. Noeul Park
Source: http://worldcuppark.seoul.go.kr

Figure 17. Nanjicheon Park
Source: http://worldcuppark.seoul.go.kr

Figure 18. Nanji-Han River Park
Source: http://hangang.seoul.go.kr/archives/3021

8.Policy Effects

1) Environmental effects

After the ecological park development project, the ecosystem and surroundings of Nanjido have considerably improved. Over 1 million trees and herbaceous plants have been planted. It was reported that there were 89 types of 24 families of plants in 1994, which is only 1 year after the last landfill had taken place. Within 3 years, grass and trees had covered the slopes of the waste piles and the plant species had extended to 271 types of 60 families compared to 1994. These continuously extended to 502 types of 95 families until 2010. The plant species were naturally

extended with different types of naturalized plants. Naturalized plants were brought in and adapted to the poor environment during the landfilling so 50% of naturalized plants in Korea were found there. This formed a very unique and notable ecosystem. Currently, only 22% of naturalized species have survived because of succession. The inhabitation of birds, insects, amphibians, fishes, and mammals has also increased. Before the park was developed, 167 types of animals had been reported to live there; this was increased to 731 types after the Nanjido Ecological Park was developed, which is a sign of healthy ecology. A continuing increasing number of birds inhabit the Han River, Nanji Pond, Nanji Stream, and mountains. It was also found that endangered species are now living there: narrow-mouthed toads and wildcats.

Figure 19. Narrow-mouthed toads found in the Nanjido

Source: http://worldcuppark.seoul.go.kr

Figure 20. Acacia flows found in the Nanjido

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Source: http://worldcuppark.seoul.go.kr

Moreover, the Nanjido Ecological Park development contributed greatly to improved biodiversity and water quality. Seoul investigates the environment around the Mapo Resources Recollection Facility at 3 year intervals. These have shown that all environmental criteria are met for the air quality, noise, water quality, and soil. There are no residents around the Mapo Resources Recollection Facility so the investigation range is extended to a 2km radius, which includes the entire Nanjido Ecological Park.

2) Economic effects

The stabilization and park development created economic effects through the landfill gas

collection and housing site developments. The Nanjido Ecological Park installed landfill gas collecting wells on the top and slope of Haneul Park and Noeul Park and connected pipeline to collect it. This is then used as boiler fuel at the Korea District Heating Corporation. From 2002 to 2013, a total of 232,592,000m3 of landfill gas had been used for boilers amounting to 6.86 million KRW of annual savings. The Korea District Heating Corporation processes the landfill gas for heating the World-cup Stadium, neighboring apartments, and office buildings. The landfill gas production is decreasing as the landfill is stabilized.

The surroundings of Nanjido were left undeveloped before the World-cup Park was developed because there of odor and environmental pollution and thus the demand for housing was low. However, the surrounding ecosystem and environment were considerably improved with the ecological park development and Digital Media City plans and this resulted in increased land prices. The competition rate of subscription was very high for the Sangam Housing Site Development Zone in 1999 with a land price of 900,000 KRW per 1㎡ in 1996 increased to 1,200.000 KRW to 1,500,000 in 1999. This was aided by the announcement thatthe Sangam area would be transformed into a special housing area (21C New Seoul Town) with leisure, shopping, and cultural facilities, Nanjido Ecological Park and water park, as well as different types of amenities and sports facilities. The housing site development area was 1,450,000 ㎡, which exceeded the side of one of most popular districts, Yongin & Suji District (1,350,000 ㎡).

3) Sociocultural effects

The Nanjido Ecological Park has become a representative eco-friendly project of Seoul and been annually visited by about 9.8 million citizens and foreign visitors. The representative camping ground of Seoul, Noeul Camping Ground was visited by 52,000 people in 2013 compared to only 21,000 people in May, 2010 (the first year) and the continued annual growth is promising. Popularity has increased to the extent that first-come-first-served reservations are often finished in 5 minutes through the Internet. It is also full of visible and enjoyable delights – including park golf, the silkworm ecology experience center, natural playgrounds, the firefly eco center and habitat, and the urban farmers' garden.

Additionally, Seobu Park & Green Field Office, Green City Division, Seoul is operating monthly firefly eco center description programs, silkworm ecology tours, and different programs using natural objects for the citizens to experience the Nanjido Ecological Park. The environment programs are free for children and families, and more families are applying for the environment experience as eco-friendly education becomes more and more popular.

Table 2. Ecology program of World-cup Park

Program name	Day	Time	Workforce	Subject	Description
Kindergarten Let's play in the forest!	Tue-Thu	10:00-12:00	20	6 to7-year-old groups	▯ To know seasonal changes ▯ To walk in the park the things that disappear in winter ▯ To share the dreams of children
Korean paper experience	Sat-Sun	10:30-11:20 14:00-14:50	20	Families	▯ Explanation of process from paper mulberry to paper ▯ To recognize the importance of Korean paper by making Korean-paper post cards by themselves
Wood handcrafts	Sat-Sun	13:30-14:50 10:30-11:50	20	Families	-To make creative pieces using waste wood ▯ Importance of natural recycling
Firefly description program	Tue-Fri	10:00-12:00 14:00-16:00	20	Anyone	▯ Description about fireflies at the eco center ▯ Description of the ecology of firefly, and observation of larva and imago

Source: http://worldcuppark.seoul.go.kr

The Nanjido Ecological Park draws high attention from other countries. It is an excellent and exemplary landfill recovery and development project. It has been benchmarked by developing countries such as Indonesia and Cambodia, and serves as a stepping stone for Korea to enter environment markets of other countries. Pleasingly, it receives high attention from municipalities of developing countries for the sustainable urban development.

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9. Challenges & Solutions

One of the difficulties for the Nanjido Ecological Park project was to find new housing for the urban poor who were living in Nanjido. The waste collecting workplace of Nanjido residents was closed as the Nanjido landfill was closed in May, 1993. However, they wanted the land where they were living to be granted so that they could stay. If they had stayed at the location, the entire ecological park development – including the landfill stabilization and park development – would have been hindered and their safety continually threatened by the mountains of waste as high as 100m. Seoul, therefore, gave purchase rights for permanently rented apartments and private ones to many of about 1,000 households so that they could populate the region. However, about 400 households refused to move until Nanjido was confirmed as the World Cup site and construction began. The roofs and walls of structures were

seriously corroded and catastrophic disaster was more and more likely if the banks of the landfill were to collapse due to heavy rain. Seoul gave them jobs through job placement and job-producing projects and provided rights of residence for rented and sold apartments as well as relocation expenses support to demolish the temporary housing. Meanwhile, 400 employees of 61 waste collecting centers who were living in prefabricated housing complexes were given a chance to move to the Sihwa Industrial Complex while 3 aggregate providers in the northern part of Landfill No.2 were also relocated.

Another challenge of the Nanjido Ecological Park development was the purpose issue of Noeul Park. Noeul Park was originally planned as the Nanji Golf Course. The Korea Sports Promotion Foundation was eventually selected as an investor in March, 2000 so it invested 14.6 billion KRW to develop a 9-hole golf course in Noeul Park and open it in October, 2005. However, the land owner, Seoul City Government and Korea Sports Promotion Foundation had conflicting ideas concerning the operation method and management rights so they undertook legal proceedings. Furthermore, Seoul amended the ordinance to transform the golf course into a park and the Korea Sports Promotion Foundation opened the golf course for free. Finally, Noeul Park was turned into a real park and Seoul compensated the Korea Sports Promotion Foundation with 18.5 billion KRW, including the Nanji Golf Course development expenses. The Korea Sports Promotion Foundation transferred the ownership of the golf course to Seoul. Seoul then spent an additional 4 billion KRW installing new trails, water supplies, drinking fountains, toilets, shade canopies, and benches while trying to retain as much of the lawn field of 9-hole golf course as possible so as to renovate it as a family park and thus invite more visitors.

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『The 1st Special Measures for Seoul Metropolitan Air Quality』seeks to secure the degree of visibility of the open sea of Incheon from Namsan on a clear day. Towards this end, an about 4 trillion won budget from both the national treasury and the local funds had been used for 10 years (2005-2014). Ninety percent of the total budget was allotted for the old-diesel-vehicle exhaust gas reduction project, and an action plan was formulated and implemented to turn old diesel vehicles into low-pollution ones. The improvement target was set to 40μg/m3 PM10 (Tokyo) and 22ppb NO2 (Paris).

『The 2nd Special Measures for Seoul Metropolitan Air Quality』 seeks to realize a healthy 100-year-old era with clean air, and efforts were set to be made to achieve the goal from 2015 to 2024. The improvement targets were set to 20μg/m3 PM2.5, 30μg/m3 PM10, 21ppb NO2, and 60ppb O2, and the focus was expanded to include gasoline and gas cars, in addition to diesel vehicles.

In the case of specific diesel vehicles, cars whose emission warranty period has expired in accordance with Article 46 of 『Clean Air Conservation Act』; light cars and passenger cars whose emission warranty period has expired in accordance with No. 3, Annexed Table 5 of 『Enforcement Regulations of Clean Air Conservation Act』; and vehicles whose emission warranty period has expired in accordance with No. 5, Title 4 are excluded from the implementation of 『Clean Air Conservation Act』, as shown below.

Table 1. Enforcement Regulations of the Clean Air Conservation Act [Annexed Table 5]

Specific diesel vehicles		Specific diesel vehicles (excluding some vehicles)	Excluded vehicles	
No.1 Until December	No.2 January 1, 2000- June 30, 2002	111741492667723 No.3 On and after July 1, 2002	No. 4 On and after Jan	No.5 On and after Jan
All diesel vehicles	All diesel vehicles	**<Exclusions>** - Light cars (less than 800cc) - Passenger cars weighing less than 2.5 tons and with less than 8 passengers	All diesel vehicles	All diesel vehicles

Annex Table 18 of the Enforcement Regulations of the Clean Air Conservation Act regulates the exhaust gas application period depending on the production period of the diesel vehicles.

Table 2. Enforcement Regulations of the Clean Air Conservation Act [Annex Table 18]

Production period	Application period	Vehicle type				
On and before December 31, 1997		**Passenger car**	**Small truck**			
	February 2, 1991-December 31, 1992					
	January 1, 1993-December 31, 1995	5 years, 80,000km				
	January 1, 1996-December 31, 1997	5 years, 80,000km	40,000km			
January 1, 1998-December 31, 2000		**Light car**	**Passenger car**	**Small truck**	**Heavy-duty vehicle**	
	January 1, 1998-December 31, 1999	60,000km	5 years, 80,000km	60,000km	-	
	January 1, 2000-December 31, 2000	5 years, 80,000km	5 years, 80,000km	5 years, 80,000km	2 years, 40,000km	
January 1, 2001-June 30, 2002		**Light car**	**Passenger car**	**Multi-purpose car**	**Mid-sized car**	**Large car**
	January 1, 2001-June 30, 2002	5 years, 80,000km	5 years, 80,000km	5 years, 80,000km	5 years, 80,000km	2 years, 80,000km
July 1, 2002-December 31, 2005		**Light car**	**Passenger car 1/ passenger car 2**	**Passenger car 3/ truck 1/ truck 2**	**Passenger car 4/ truck 3**	**Construction machinery**
	July 1, 2002-December 31, 2002	5 years, 80,000km	5 years, 80,000km	5 years, 80,000km	2 years, 80,000km	
	After January 1, 2003	5 years, 80,000km	5 years, 80,000km	5 years, 80,000km	2 years, 160,000km	1 year, 20,000km
January 1, 2006-December 31, 2008		**Light car**	**Small passenger car**	**Small truck/mid-sized passenger car/truck**	**Large/ ultra-large passenger car/truck**	**Construction machinery**
		5 years, 80,000km	5 years, 80,000km	5 years, 80,000km	2 years, 160,000km	1 year, 20,000km
On and after January 1, 2009		**Light/small/mid-sized passenger car/truck**	**Large passenger car/truck**	**Ultra-large passenger car/truck**	**Construction machinery motor**	
		10 years, 160,000km	5 years, 80,000km	6 years, 200,000km	7 years, 500,000km	1 year, 20,000km

On and after January 1, 2013		10 years, 160,000㎞	6 years, 300,000㎞	7 years, 700,000㎞	10 years, 8,000 hours	
On and after January 1, 2016		10 years, 160,000㎞	6 years, 300,000㎞	7 years, 700,000㎞	10 years, 8,000 hours	

3. The Importance of the Policies

The rapid increase of automobiles accounts for 52% of the air pollution, and automobiles are considered the main source of air pollution. The fine dust, excluding the inflow from outside, is generated mostly from operating diesel vehicles. The more fuel an automobile consumes, the more the air pollutants that it releases into the air, which will adversely affect the air quality of Seoul. The air pollutants from the transport sector account for more than 70% of the total emission of air pollutants, and among such air pollutants, those coming from automobiles are increasing gradually.

Air pollution deteriorates people's health and damages properties and ecosystems. The damages caused by increased air pollutant emission are accumulated. As this problem is not contained in an individual city but spreads to the surrounding areas, its seriousness is increasing. It is natural for the number of automobiles to increase as the people's income and the goods transport increase, but Disel Particulate Filters (DPFs) must be attached to diesel vehicles to significantly reduce the emission of air pollutants from such vehicles.

The air quality of Seoul has improved substantially considering that the concentration of PM10 decreased from 60 ㎍/㎥ in 2004 to 45 ㎍/㎥ in 2015. Since recently, however, it has been increasing slightly due to the influx of air pollutants from the city's neighboring countries in Northeast Asia. The NO2 concentration has decreased slightly or has shown no change since 2008. The implementation of Phase 1 of the Seoul Action Plan on Air and Environment Improvement is considered to have lowered the pollution level near the city streets, and to have expanded the visibility distance.

The visibility distance data show much improvement owing to the better PM10 concentration in Seoul's air. The visibility distance improved from 12.3 km in 2004 to 13.1 km in 2013 on average. The number of days with an over 20 km visibility distance also partially increased from 76 days in 2007 to 202 days in 2010, 274 days in 2012, and 205 days in 2013.

Seoul, however, still needed to make the owners of diesel vehicles follow the emission reduction plan. Since January 2011, authorities have implemented administrative measures such as imposing fines on diesel vehicle owners who have not followed the plan 6 months after the notice was given, with the intention of inducing their participation in the effort.

4. Results of the Project in terms of Spreading Diesel Emission Control Devices

1) Promotion of the pilot project

Seoul carried out the In-Use Diesel Vehicle Emission Reduction Pilot Project in 2004. The city installed 280 DPFs and 150 DOCs (diesel oxidation catalysts) in its official vehicles and public transit buses, and remodeled 450 vehicles into LPG (liquefied petroleum gas) vehicles, for a total of 880 units. The expenses for DPF installation were fully shouldered by the government, and those for DOC installation and LPG remodeling were shouldered evenly by the government and the city.

2) Full-scale implementation

After the pilot project period, the full-scale project began in 2005. With 50% of the project expense shouldered by the government and 50% shouldered by the city, the project has covered a total of 12,130 diesel vehicle units to date: 7,789 DPF installations, 1,490 DOC installations, 2,814 LPG remodeling cases, and 37 early vehicle disposals. Since 2006, 70-95% of the installation costs has been supported.

3) Mandatory installation

In 2008, the city made it mandatory to install low-emission devices in over-7-year-old diesel vehicles weighing over 3.5 tons. It supported 70-95% of the installation costs, 50% from the government and 50% from the city.

In 2009, the city extended the coverage of the In-Use Diesel Vehicle Emission Reduction Project to over-7-year-old diesel vehicles weighing over 2.5 tons. It shouldered 70-95% of the installation costs, 50% from the government and 50% from the city.

5. Policy Objectives

The objective of the In-Use Diesel Vehicle Emission Reduction Project is to protect the health of the over 10 million Seoul citizens from air pollution, and to provide a more pleasant environment for them by installing low-emission devices in diesel vehicles, remodeling such vehicle's engines into LPG engines, and encouraging the owners of old diesel vehicles to dispose of their vehicles early. The city plans to complete the project by 2019, and to maintain a safe air quality level by completing the installation of low-emission devices or carrying out other measures on the about 380,000 diesel vehicles in this city that were manufactured before the year 2005.2

Table 3. Seoul Air Quality Improvement Targets

Division	2014	2024

[2] In-Use Diesel Vehicle Emission Reduction Project, Seoul Urban Solutions Agency (2014)

PM_{10}	40μg/m^3	30μg/m^3
$PM_{2.5}$	-	20μg/m^3
NO_X	22ppb	21ppb

Remarks: The target year for ultra-fine dust ($PM_{2.5}$) was set to 2018 to achieve the target earlier.

6. Main Policy Contents

As of 2015, the city, through its In-Use Diesel Vehicle Emission Reduction Project, has installed low-emission devices like DPFs in 150,948 diesel vehicles.

According to the Special Act on Seoul Metropolitan Air Quality Improvement and local by-laws, the city made it mandatory starting on January 1, 2008 to install low-emission devices in over-7-year-old diesel vehicles weighing over 2.5 tons whose low-emission guarantee period (2 years for vehicles weighing over 3.5 tons, and 5 years for vehicles weighing under 3.5 tons) has expired. The government and the city shouldered 83-96.5% of the installation cost. Likewise, the aforementioned devices had to be installed in over-7-year-old diesel vehicles weighing between 2.5 and 3.5 tons starting in January 2009.

In particular, between 2013 and 2014, the city installed PM-NOx simultaneous-reduction devices in 106 large diesel buses as part of the Nitrogen Oxide (ultra-fine-dust inducer) Reduction Demonstration Project. After analyzing the results of the demonstration project, the city started expanding the project implementation.

Although the long-term effectiveness of the Diesel Vehicle Emission Reduction Device Installation Project has yet to be evaluated, it can be said that the air quality in Seoul has been improving based on the data obtained so far, such as a decrease in the number of days with 100 μg/m3 or more ultra-fine dust in the air and an increase in the number of days with no more than 30μg/m3 ultra-fine dust. Moreover, the 111741492667723 number of high-emission-vehicle reports, which indicates the citizens' perception of the air pollution level in the city, has dramatically decreased.

The Diesel Vehicle Emission Reduction Device Installation Project was planned to be implemented from 2005 to 2024 for improving the air quality in the capital area. Since 2009, it has so far been implemented in five other metropolitan cities: Busan, Daejeon, Daegu, Gwangju, and Ulsan.

It is very important to make sure that the installed emission reduction devices are working as intended. Recognizing the importance of the inspection of such devices, the city has encouraged the manufacturers to inspect the devices regularly and set up the city's own inspection team. The team has been examining the vehicles with an installed emission reduction device, and has been issuing device improvement or disposal orders to the people whose vehicles failed in the

inspection.

The owners of the vehicles with an installed emission reduction device can receive free after-sale (A/S) services during the 3-year warranty period (3 years or 160,000 km for DPF, 3 years or 80,000 km for DOC or for the LPG remodels). Also, the owners of vehicles with a class 1 emission reduction device can receive free filter cleaning per year at more than 40 cleaning centers in the capital area.

According to the Special Act on Seoul Metropolitan Air Quality Improvement, vehicles with an installed emission reduction device should be operated for at least 2 years after the device installation, excepting unavoidable situations like a natural disaster, a fire, or a theft. Moreover, the vehicle owners are required to return the device to the Korea Automobile Environmental Association when they are to dispose of their vehicles.

If an owner removes the device without any valid reason before the mandatory operation period, or fails to return it, the owner has to return the subsidy.

To handle the complaints regarding the installed emission reduction devices, the manufacturers of the devices operate their own A/S call centers and cleaning centers. If any dispute between an owner and a manufacturer occurs, the city will act as the arbiter.

The primary reason that DPFs are disqualified on account of their under-performance, and become subject to a removal order, is operating the vehicle under a severe environment falling outside the certification criteria. Other reasons are the lack of post-management by the manufacturer and the vehicle maintenance failure of the vehicle owners. Theoretically, the DPF can reduce the amount of exhaust emission by more than 80%. Therefore, vehicle owners should do their best to maintain the device's optimal performance level.

Once a vehicle owner removes the device from her or his vehicle, she or he is no longer qualified to receive the corresponding benefits and subsidies. Thus, the car owner is obliged to pay the environment improvement charges and to regularly subject her or his vehicle to an exhaust emission test. Moreover, the manufacturer has to return the subsidy.

Realizing the broad characteristics of air pollution, Seoul, Incheon, and Gyeonggi provinces decided to cooperate with one another starting in 2010 to maximize the improvement of their air quality, after collecting various opinions from experts and citizens. The subject vehicles are diesel vehicles weighing over 2.5 tons, that are over 7 years old, and that have not taken any corrective measure within 6 months after receiving Seoul's emission reduction order or that does not pass the total emission gas test. Any of the three aforementioned local governments can impose a 200,000 KRW fine after a one-month warning period on the owners of vehicles without an emission reduction device found in their respective jurisdictional roads. Moreover, they have set up an unmanned enforcement system using CCTVs on their main roads (e.g., Olympic Expressway), and have tightened the control over the vehicles without emission reduction devices.

• Current status of the installation of the Driving Restriction Monitoring System (operated since March 2012)

- 24 camera installations on 7 different spots on Seoul's main roads

• Implementation of the Driving Restriction Monitoring System (2014)

- Caught 746 vehicles, issued a warning to 679 vehicles, and imposed a fine on 67 vehicles

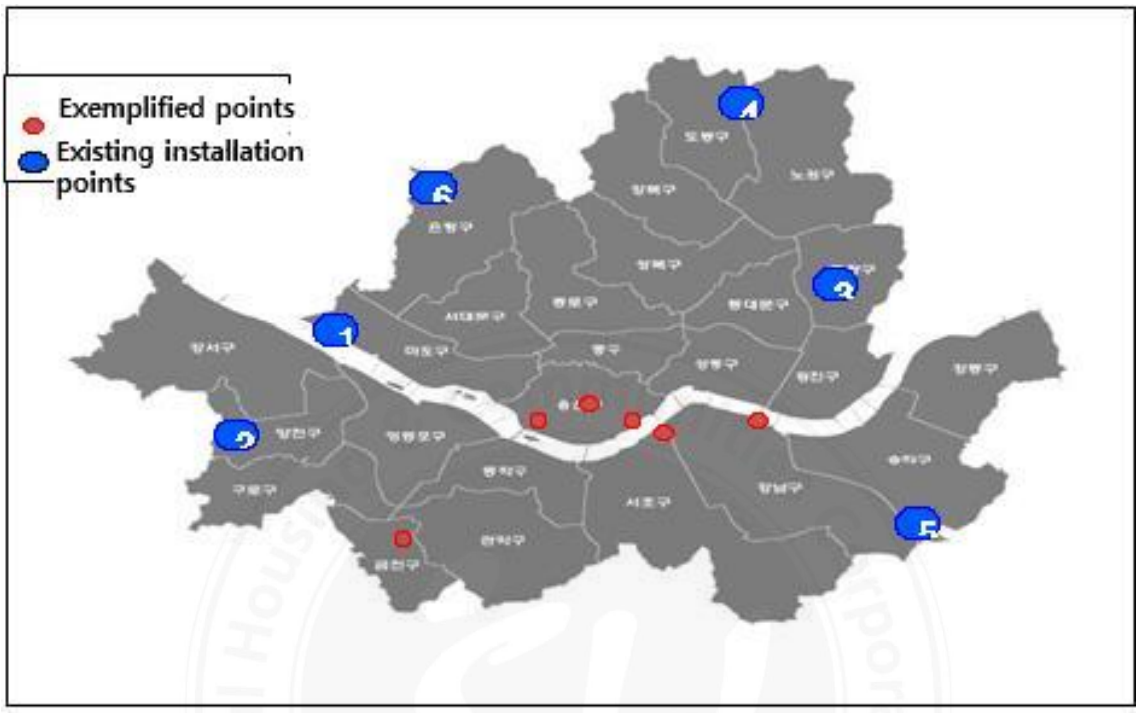

Figure 1. Status of vehicle travel restriction system installations

DPF is installed in mid-sized and large diesel vehicles, and can eliminate more than 70% of the exhaust gas by collecting pollutants like PM, depositing them in the catalyst-coated filter, and then converting them to CO2 or vapor. Partial diesel particulate filters (p-DPF) is installed in mid-sized and small diesel vehicles (weighing no more than 3.5 tons), and its catalysts convert pollutants to hazardless materials without a collection process, which relieves p-DPF of any post-management measure. DOC was installed in small diesel vehicles, but its installation has been suspended since 2010 due to its low cost-to-benefit ratio of 10:20% performance in reducing ultra-fine-dust emissions. Since the full-scale implementation of the emission reduction project with focus on the public transit buses and business vehicles in 2005, DPFs have been installed in 89,423 diesel vehicles, and they are expected to be installed in 6,600 vehicles per year until 2019. According to the Special Act on Seoul Metropolitan Air Quality Improvement and local by-laws, the owners of diesel vehicles weighing over 2.5 tons, are over 7 years old, and whose low-emission warranty period (2 years for vehicles weighing at least 3.5 tons; 5 years for vehicles weighing less than 3.5 tons) has expired can obtain subsidies from the government and the city for 90-95% of the implementation cost for any emission reduction measure, such as the installation of an emission reduction device.

Table 4. Status of DPF devices and subsidy (amount, effects)

Division			Government fund (1,000 won)	Deductible (1,000 won)	Target	Emission reduction effects	
						PM (HC)	NO_x
DPF	Natural large		5,575	511	Large: More than 11,000 cc Mid-sized: 6,000-11,000 cc Small: Less than 3,000 cc	More than 80%	-
	Natural mid-sized		5,232	477			
	Complex large		10,056	959			
	Complex mid-sized		7,809	737			
	Complex small	Van	3,672	401			
		Truck	3,764	330			

The city inspects diesel vehicles frequently to see if their emission reduction device is working properly and if their emission level is within the normal range. If any abnormal vehicle is found, the city orders correctional measures and monitors their fulfillment. If any device is found to be no longer usable, the city provides a free refurbished device in an attempt to promote the continuous use of the emission reduction device and to maintain the vehicle's optimal performance.

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The diesel vehicles registered in Seoul and the metropolitan area (excluding compactcars and passenger cars) whose low-emission guarantee period has expired under the Clean Air Conservation Act are designated as "specific diesel vehicles" and are monitored with stricter emission standards rather than with the general emission standards for in-use vehicles.

A specific diesel vehicle is allowed to operate only if it passes the detailed inspection and is within the specified emission level range. If it does not satisfy the standard, the owner of the vehicle must install an emission reduction device (DPF, p-DPF, or DOC), must remodel its engine into a low-emission model, or must dispose of the vehicle.

When installing an emission reduction device on a specific diesel vehicle, its smoke concentration has to meet the certification criteria of an emission reduction device. If the device does not meet the standard, it is allowed to be installed only after fixing and re-testing the

device to ensure that it meets the standard. Only vehicles whose smoke concentration meets the in-use vehicle emission standard are allowed to be disposed of early .

Generally speaking, DPFs are installed in mid-sized to large vehicles; p-DPFs are installed in mid-sized vehicles, or such vehicles are remodeled into vehicles with LPG engines; and DOC is installed in small vehicles, or such vehicles are remodeled into vehicles with LPG engines. Since 2010, however, DOC installation has been suspended, and instead, small p-DPFs have been installed in small vehicles since then.

The Korea Automobile Environmental Association kept the maintenance expenses out of the subsidies.

When the manufacturers submit an application for reimbursement of the maintenance expenses along with supporting documents to the association, the association screens the applications and then releases the funds to the device manufacturers.The maintenance cost shouldered by the association includes a 300,000 KRW annual cleaning cost for 3 years for DPF during the warranty period, and a 10,000 KRW monitoring cost.

Benefits such as exemption from the environmental improvement charges and from undergoing the precise emission test are granted to the vehicle owners who joined the low-emission initiative. The only compulsory condition for receiving the benefits is that the vehicle should be operated for at least 2 years after the installation of any emission reduction device.

The post-management of the installed device is also very important. Since the initiation of the project, the city has realized the importance of post-management and has thus encouraged the manufacturers to also focus thereon. The city has carried out inspections of the vehicles with an installed emission reduction device by organizing an inspection and monitoring team for such purpose. The team has also issued correctional or removal orders whenever needed.

7. Technical Details

As mentioned earlier in this paper, DPF stands for “diesel particulate filter.” This device traps the particulates discharged from the vehicle engine at its filter, and then burns them (recycling) in the engine. Through the repetitive trapping and recycling of particulates, the device can eliminate more than 80% of the vehicle emission and thus has an excellent advantage over the other devices in terms of performance. DPFs, in most cases, are installed in mid-sized to large vehicles. For small vehicles, DPFs were not available until 2007 due to the technological limitation of such devices. The four technologies presented below are the internationally accepted post-treatment technologies, whose reliability, durability, and cost effectiveness have proven that they are practical to use in reducing the air pollutant emission of modern diesel vehicles.

Technology trapping the particulates (e.g., soot) from the vehicle exhaust and eliminating them through a burner and/or heater

Continuously regenerating trap (CRT) to be continuously cleaned or “regenerated” above a certain temperature with the catalyzed diesel particulate filter (CDPF)

Diesel oxidation catalyst (DOC), which oxidizes the gaseous matters in the exhaust gas (e.g., hydrocarbon [HC], CO, NOx) and the particulate matters (PMs) in the exhaust gas (e.g., soluble organic fractions [SOFs]) using catalysts; works similarly as the three-way catalytic converter in a gasoline engine

The technology that oxidizes harmful exhaust gas and PMs by systematically controlling the engine control technology, the catalyst post-treatment technology, and the additive technology

Table 5. Type of diesel emission control devices

Division	**Pollutant reduction efficiency of the device**	**Warranty period**	**Target pollutants**	**Remarks**
First-class	More than 80%	3 years or 160,000 km	Particulate matter (PM_{10}), nitrogen oxide (NOx)	Diesel particulate filter (DPF)
Second-class	More than 50%	3 years or 80,000 km		Partial diesel particulate filter (pDPF)
Third-class	More than 25%	3 years or 80,000 km		Diesel oxidization catalyst (DOC)

1) First-class emission control device (DPF: diesel particulate filter)

DPF traps the PMs in the exhaust gas at the catalytic filter and eliminates them by burning them at a temperature of over 550oC. It reduces the soot found in the exhaust gas from a diesel engine. Soot consists of carbon and is produced by the incomplete combustion of coal, oil, wood, or other fuels. If it is excessively accumulated, it can reduce the fuel efficiency and performance of the vehicle. DPFs are categorized in terms of the way that heat for burning PMs is provided.

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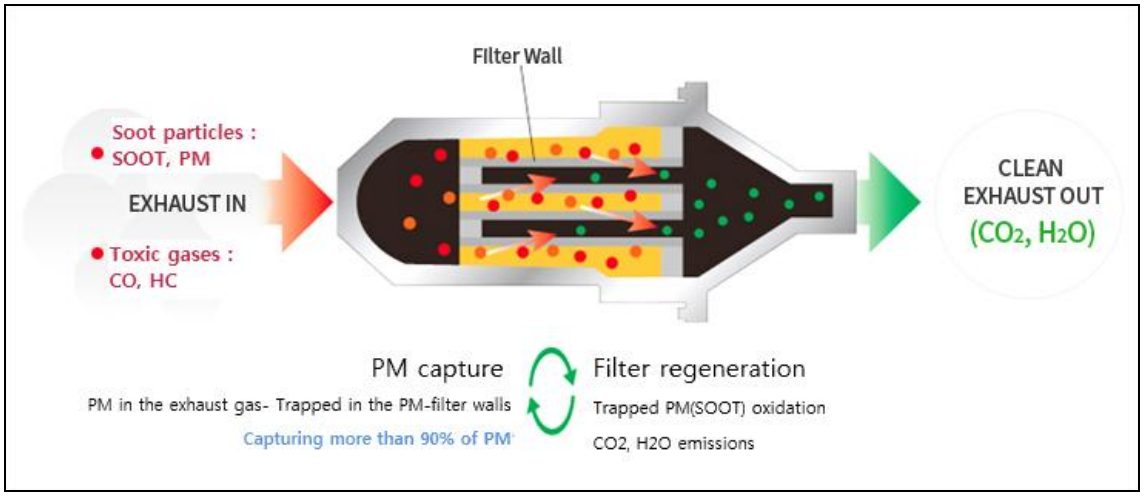

Figure 2. How DPF works?

(Source: Korea Automobile Environmental Association,

http://www.aea.or.kr/main_business/technology.php)

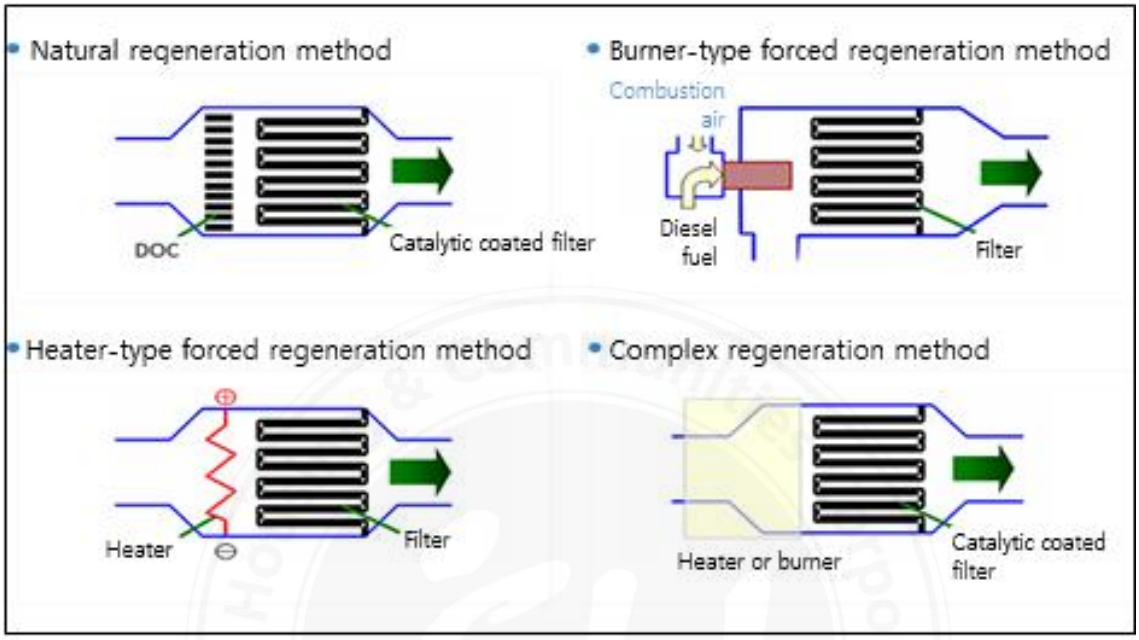

Figure 3. DPF regeneration method

(Source: Korea Automobile Environmental Association,

http://www.aea.or.kr/main_business/technology.php)

PMs are classified according to the heat supply system required for the combustion, as shown below.

Table 6. Heat supply system by generative method

Type	Heat supply system	Applicable vehicles
Natural-regeneration	Engine exhaust heat	High-speed vehicles
Forced regeneration	Electric heater or auxiliary fuel injection	Low-speed vehicles
Complex regeneration	Mixed use of the natural- and force-regeneration methods	Low- and high-speed vehicles

The exhaust gas is burned again by the oxidation catalyst located at the opening of the DPF,

which decreases the size of the PM. These small PMs penetrate the filter and are released to the air, but other PMs that are still big are trapped in the filter and are accumulated on it through the repetitive process until the engine control system sprays the fuel to be burned in the DPF. This burning fuel increases the temperature in the DPF, and the heat burns the accumulated PMs again to make them smaller.

The process of spraying fuels to make the big PMs small is called "regeneration." There are different ways of setting the timing of the regeneration. One is through the pressure differences between the front and back of the filter (pressure difference sensor). Every vehicle manufacturer has a different set point for the pressure difference. Some check the engine performance regularly based on its mileage to see how negatively the PMs affect the engine performance due to the filter clogging and the resulting increased pressure in the exhaust system. Once it detects a certain level of engine underperformance, it sprays fuel into the DPF. Other manufacturers use an extra equipment (scanner) to set the regeneration timing. The pressure difference sensor and mileage methods are applied differently according to the engine control system type, vehicle type, and DPF manufacturer.

The ways of increasing the temperature in the DPF to a point that is sufficient to burn the PMs accumulated on the filter are most important and vary. Some spray extra fuels into the PDF, some use additives, some use an electric heater, and others use an extra burner. Due to the cost issue, the most common method is spraying extra fuel into the DPF to increase the temperature to over the regeneration point while checking the temperature with an exhaust gas temperature sensor. Some manufacturers, however, are using additives for such purpose.

Although DPF reduces the PM emissions into the air, it increases the costs, decreases the fuel efficiency, and has short durability, which are the limitations of this emission reduction device. Many studies have pointed out that the average lifespan of the fuel-spraying DPF in terms of mileage is around 100,000 km.

2) Second-class emission control device (p-DPF: partial diesel particulate filter)

Rolled like a cylinder with a paired layer of flat foil and corrugated foil, p-DPF has a partially open structure. Therefore, the exhaust gas passes through the space between the flat foil and the corrugated foil. p-DPF does not reduce the engine power or fuel efficiency because it does not accumulate any PM on the filter, unlike the wall-flow-type filter. Moreover, it does not need periodic management of the filter because ashes do not stay thereon.

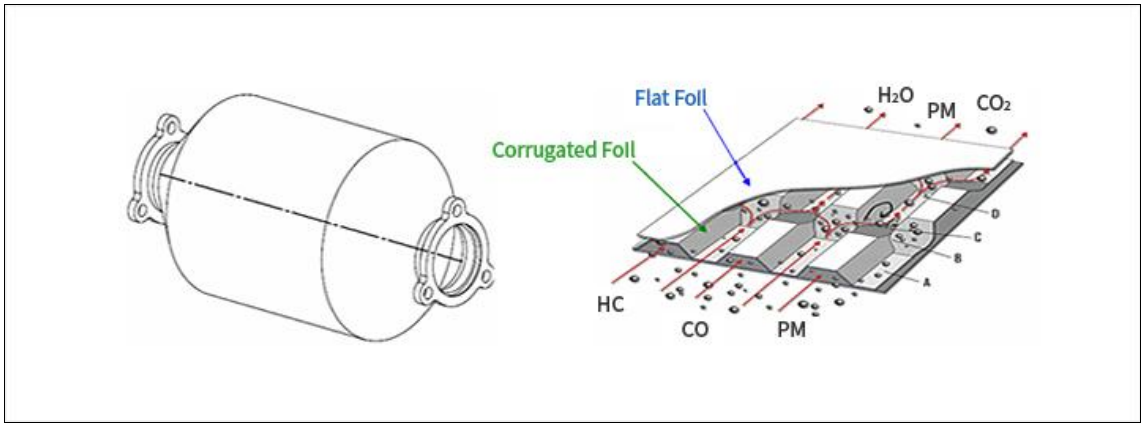

Figure 4. p-DPF structure

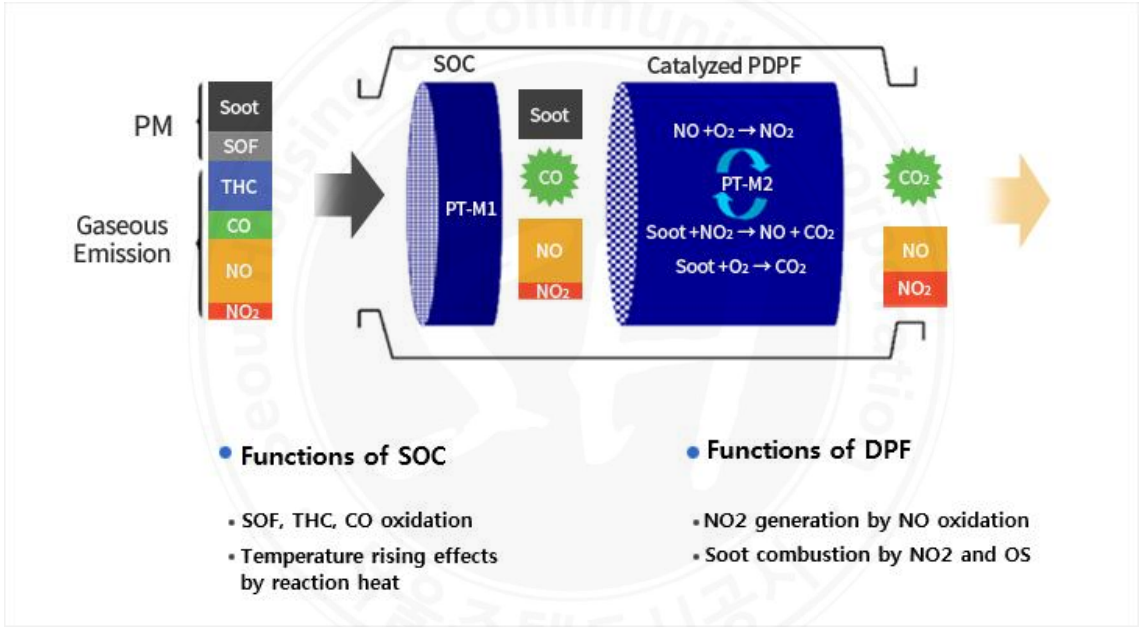

Figure 5. How p-DPF works?

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3) Third-class emission control device (DOC: diesel oxidation catalyst)

When exhaust gas passes through the DOC, it reacts with the catalyst. The DOC, in this catalytic reaction, purifies the exhaust gas by oxidizing the gaseous matters (e.g., HC, CO) and the PMs (e.g., lubricant components, incompletely combusted fuels, SOFs).

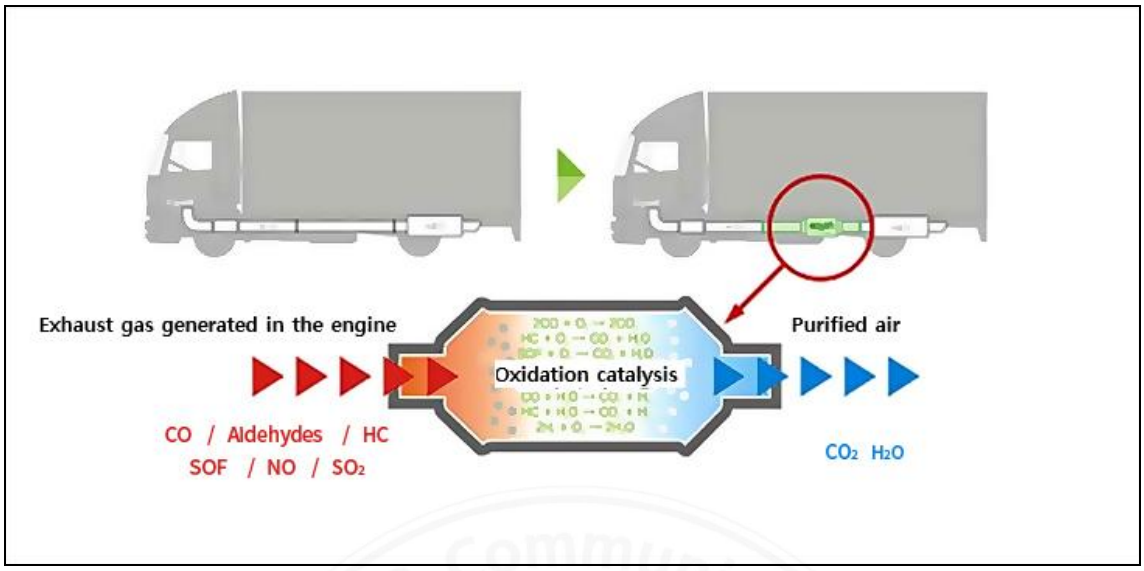

Figure 6. How DOC device controls emission

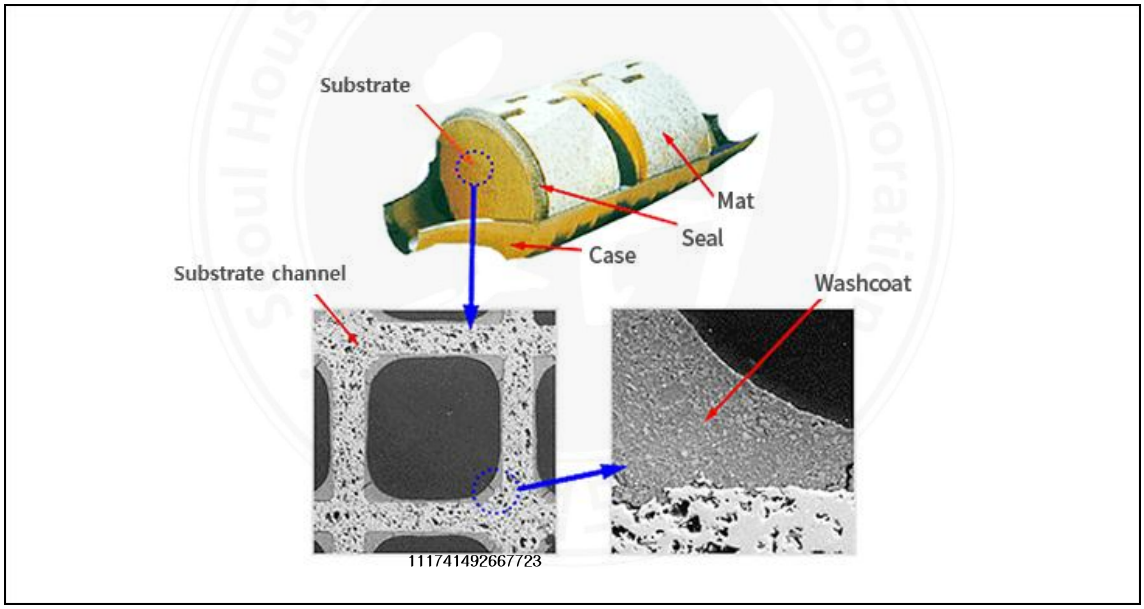

Figure 7. DOC structure

8. Policy Effects

The low-pollution vehicle project that has been implemented since 2000 has demonstrated the effect of reducing the PM10 emissions of the vehicles in Seoul by 4-22%. The concentration of PM10 measured from an air quality measurement network at the roadsides of Seoul has continuously been reduced through the years since 2005, up to 53 μg/m3 in 2014. This is almost similar to the annual environmental standard of PM10 (50 μg/m3), and as such, it can be seen

that the environmental standard was met not only in the general air quality measurement station (45.8 μg/m3 in 2014) but also in the roadside air quality measurement station. In addition, the number of days when a high density of more than 100 μg/㎥ occurs has decreased, and the number of days when a low density of more than 30 μg/m3 occurs has increased. Therefore, the pollution from fine dust in Seoul has decreased, and the number of reported vehicles discharging exhaust fumes has been sharply reduced. It of course cannot be concluded that these improvements were obtained only through the low-pollution vehicle project, but this project has been evaluated to play a big role in achieving such results.

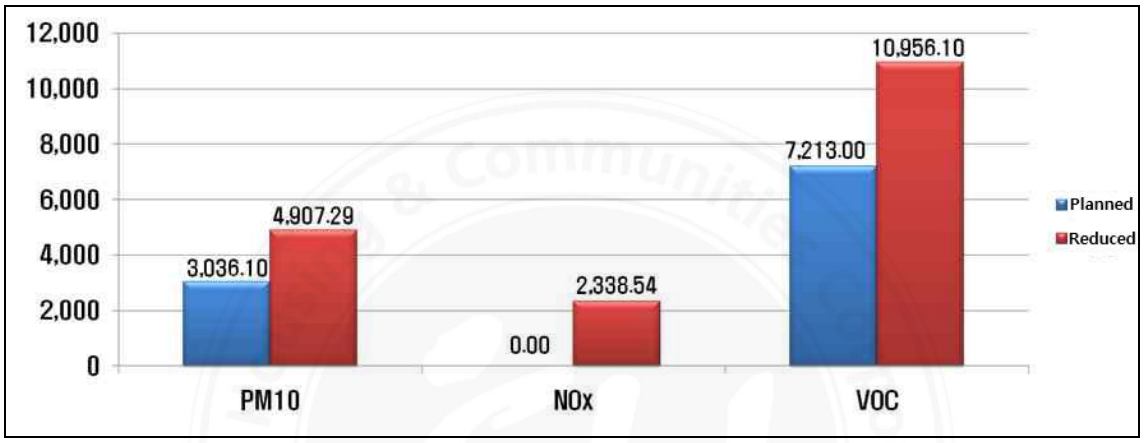

Figure 8. Reduction of pollutants by emission control devices (2007-2009) (Unit: ton)

Source: Analysis of the air quality improvement effects of pollution control measures (2011)

To reduce the NOx in the air, the Seoul metropolitan government implemented the pilot project of attaching a NOx reduction device to 444 vehicles, like the attachment of a PM-NOx simultaneous-reduction device to old construction machinery and large trucks from 2013 to 2017, to verify the feasibility of such measure, and expanded the project implementation to beyond 2015.

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Table 7. Average exhaust gas reduction ratio through the implementation of the NO_x reduction pilot project

Project title/exhaust gas	**CO reduction**	**NO_X reduction**	**PM reduction**
Three-way catalytic converter	82.2%	88.4%	60.1%
PM-NO_X simultaneous-reduction device	85%	70%	80%

9. Challenges and Solutions

The project of attaching an emission control device to diesel vehicles has been carried out for the purpose of reducing fine-dust emissions, and it was evaluated to be somewhat effective in reducing diesel vehicles' fine-dust emissions. The carbon dioxide (CO2) pollution level in Seoul, however, has exceeded the environmental standards and has not shown a clear improvement trend. Given that a significant portion of the NOX emissions in Seoul is discharged from diesel vehicles, there is a need for the low-pollution diesel vehicle project to take into account the reduction not only of fine dust but also of NOX.

In this regard, the Seoul metropolitan government proceeded with the project of attaching PM-NOX simultaneous-reduction devices to 444 vehicles in 2013, including old construction machinery and large trucks, and since 2015, it has been expanding and promoting the project after the verification of its effects.