AIR QUALITY

OUTLOOK REPORT

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Ministry of Higher Education and Science Denmark

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PREFACE

This outlook provides an insight into South Korean Air Quality market and strategies. The outlook demonstrates that the state of South Korea's ambient air quality can be seen as a clean air business and R&D opportunity.

Improving air quality should be seen through the lens that society can profit from less air pollution. Cleaner air benefit both people and the planet – and makes perfect economic sense as well as it strengthens South Korea's innovative approaches toward improving air quality in Korea.

The objective of this Outlook report is to inspire Danish researchers and R&D-intensive companies to identify potential opportunities for collaboration with South Korea in ambient air quality research, management and showcase that tackling the air quality challenges in South Korea not only saves money but also creates new business opportunities and jobs.

The Outlook report stresses that more action is needed to implement measures that reduce dangerous emissions and foster further innovation as well as stimulating potential test and demonstration of new air quality management systems between Denmark and South Korea.

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INTRODUCTION

South Korea has a long history with episodes of air pollution peaks. Annual dust storms have been blowing over from China and Mongolia every spring for over a millennium, with the earliest record of "Yellow Dust" on the peninsula being made in AD 174[1].

In recent history, rapid industrialization in South Korea starting in the 1960's led to an increase in energy consumption followed by the adoption of nuclear and coal power plants. The intensifying manufacturing factories and massive construction projects accelerated the emission of air pollution, as well as an economic boom that put an unprecedented number of cars on the streets as well as ships in the ocean. A plethora of other factors also aggravated the already delicate issue of air pollution which today most Korean people claim to be their number one complaint about their country.[2]

To quote an official from the Air Quality Policy Division at the Ministry of Environment; "The worst part of air pollution for Koreans is the high concentrations of fine dust. And as fine dust occurs due to a complex range of influences including weather conditions, local emissions, and entry of dust from outside the country, we absolutely need to encourage a decrease in emissions by strengthening domestic policies and encouraging a decrease in overseas factors through international cooperation."

The South Korean focus on ambient air quality is of rising interest among Danish stakeholders within the field. As the 4th largest economy in Asia, the largest ship building nation in the world, and with an ambitious focus on the green and digital transformation in general, South Korea is an attractive collaboration partners as well as market for many Danish researchers and companies.

Please contact ICDK Seoul if you have an interest in further discussing air quality technologies or learning more about possibilities of future R&D cooperation, test, and demonstration of air quality technologies with Korean partners.

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[1] Bulletin of the American Meteorological Society (2008)
[2] Seoul Institute of Technology (2021)

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CLEAN AIR FOR ALL

Clean air is an essential need for all. Our health, our environment and even the global economy depend on clean air. We need to tackle air pollution as a joint effort, as air pollution does not respect borders.

Centre for Research in Energy and Clean Air estimated in 2020 that 4.5 million people died in 2019 due to exposure to air pollution from fossil fuels. On average, each death was associated with a loss of 19 years of life[3].

Furthermore, fossil fuel PM2.5(atmospheric particulate matter that have a diameter of 2.5 micrometres or less) pollution was responsible for 1.8 billion days of work absence, 4 million new cases of child asthma and 2 million preterm births, among other health impacts that affect healthcare costs, economic productivity, and welfare.

The economic costs of air pollution from fossil fuels are estimated at US$2.9 trillion in 2018, or 3.3% of global GDP, far exceeding the likely costs of rapid reductions in fossil fuel use. The cost per capita in South Korea are estimated to be $1100 in South Korea, or equal to 3.4% of South Koreas GDP.

These costs show the increase in economic productivity and welfare that can be achieved by eliminating air pollutant emissions from fossil fuel use - gains that are likely to far exceed the costs of such a transition, given the increasing cost competitiveness of clean energy.

It is evident that society can also profit from reducing air pollution. Tackling the air quality challenges not only saves money, but it also creates new business opportunities and jobs.

Cleaner transport such as electric cars or buses and retrofitting polluting vehicles and ships, harnessing renewable energy sources like wind and solar, boosting energy efficiency by refurbishing building and implementing cleaner industrial processes as well as replacing energy hungry appliances such as old stoves, boilers, refrigerators or converting fossil fuel power plants into biobased or renewables are all examples of clean air business opportunities.

Our global food supply chain is also by many organizations highlighted as a global air pollution challenge. Better livestock feed and low-emission mineral fertilizer, manure storage, and spreading techniques as well as food logistics and handlings are sectors where clean air business is secondary, but still can create significant improvement for the greater society.

All the above are green growth examples which can lead to global R&D and business collaboration, which can create jobs, investment, and resource efficiency.

[3] Centre for Research on Energy and Clean Air “Quantifying the Economy Costs of Air Pollution form Fossil Fuels” Feb. 2020

1. AIR POLLUTION IN SOUTH KOREA

Ambient air pollution is a serious issue in South Korea — the country has the highest share of population exposed to excessive PM2.5 concentrations among all OECD nations, with Seoul doubling the WHO guidelines and levels of other major cities in developed countries.[4]

In 2005, the Korean government had legislated a Special Act to improve Seoul's air quality to the level of Tokyo and Paris by 2014. Despite years of efforts to improve Seoul's air quality, including successful performance of comprehensive reduction plans for nitrogen dioxide (NO_2), particulate matter (PM), and volatile organic compounds (VOCs) emissions from major primary sources, such as mobile and large-scale industrial sources, the city was unable to reach the planned levels[5].

Under the former administration of president Moon Jae-In's, South Korea has taken aggressive measures to cut down on fine dust levels. According to the Ministry of Environment, nationwide concentration levels of both PM-10(atmospheric particulate matter that have a diameter of 10 micrometres and smaller) and PM-2.5 have been "trending strongly downward," recording 33 μg/㎥ and 19 μg/㎥ in 2020, respectively.

Pollutants

The Clean Air Conservation Act of Korea defines an air pollutant as gas or granular matter. There are a total of 64 air pollutants prescribed by the Act, including particulate matter, carbon monoxide, nitrogen oxides, suadministrlfur oxides and dioxin.

According to the OECD, "Over the past 15 years, concentrations of sulfur dioxide (SO_2), PM10, and Pb have been continuously decreasing". This appears to be the outcome of the government's air quality management policies, including improvement of Seoul Metropolitan air quality, as well as increased supply of clean fuels such as low sulphur oil and liquefied natural gas (LNG), supply of lead-free gasoline, and tighter emissions regulations.

Regarding fine dust - a pressing concern in Korea - the table below illustrates average daily fine dust in Seoul and show that PM2.5 and PM10 levels have been trending downward over the past decade.

Table 1: Average Daily Fine Dust in Seoul[6]

	2021		2022	
	PM2.5	**PM10**	**PM2.5**	**PM10**
Spring	24 μg/㎥	56 μg/㎥	20 μg/㎥	40 μg/㎥

[4] Policies, Regulatory Framework and Enforcement for Air Quality Management: The Case of Korea (2020)
[5] National Institute of Environmental Research, MAPS–Seoul (2015)
[6] Seoul Metropolitan Government's air quality website, based on the Ministry of Environment's numbers

Summer	16 μg/m³	26 μg/m³	12 μg/m³	22 μg/m³
Fall	16 μg/m³	29 μg/m³	- μg/m³	- μg/m³
Winter	25 μg/m³	42 μg/m³	28 μg/m³	42 μg/m³

Seasonal variations

South Korea shows distinct seasonal variations in ambient air pollution. Numbers spike in winter and spring, while summer air is relatively fresh due to a predominantly southeasterly wind.[7] Other seasons typically feature a strong westerly wind, which carries air pollutants from China, Mongolia, and North Korea. Migratory high pressure systems then drop in to stagnate the polluted air over South Korea, resulting in smog and even springtime dust storms known as the "Yellow Dust" phenomenon.

Sources of Pollution

Some of South Korea's air pollution inarguably emanates from China, but how much is a subject of much debate and political controversy. Various studies found China to be responsible for between 32 %[8] to 50 %[9] of South Korea's air pollution. Meanwhile, Greenpeace claims South Korea is responsible for as much as 70% of some types of their own pollution. Likewise, speaking to local media, University of Suwon's environmental engineering professor Jang Yeong-gi has argued that it is clear that Korea produces much of its own fine dust, though putting figures on how much that comes from overseas and how much is produced locally is difficult.[10]

Regarding this discrepancy, an official from the Air Quality Policy Division at the Ministry of Environment explained: "Each instance is different. When there are high concentrations of dust in the air, there are times when overseas influence is dominant and times when local influence is dominant due to air stagnation." To illustrate this point, overseas influence was 69-82% in January 2019, while just two months earlier in November 2018, overseas influence was just 28-34%.[11]

1.1 Political Trends

Air quality as a political issue

Air quality is a growing political issue in South Korea. A recent survey of Seoul citizens found that their biggest complaints within civil society is related to episodes of high air pollution, especially related to visual fine dust and air pollution peaks.[12]

[7] Yonhap News, "'Fine dust season' has come...It seems to get worse until next March" (2019)
[8] National Institute of Environmental Research, Joint Research Project for Long-range Transboundary Air Pollutants in Northeast Asia (2019)
[9] Nature magazine (2016)
[10] Yonhap News (2019)
[11] Ministry of Environment and others, Comprehensive Plan to Manage Fine Dust 2020-2024 (2019)
[12] Seoul Institute of Technology (2021) G

The South Korean government officially announced its revised Nationally determined contributions (NDC) goal to the international community at the 26th United Nations Climate Change Conference (COP26) in 2021. Subsequently, the former President Moon Jae-In decided to revise Korea's 2030 greenhouse gas emission reduction target to 40 percent from the previous goal of 26.4 percent to speed up South Korea's carbon neutral push on a pledge to reach zero net carbon emissions by 2050.

Under president Moon Jae-In's administration, South Korea has taken aggressive measures to reduce the days of high air pollution levels and activities accelerating fine dust levels. National mandates has been given specifically to reduce air pollution from the national energy production infrastructure. The table 1-1 below show Korean Government clean air initiatives and targets for reducing air pollution by 22% from existing coal-fired power plants.

Table 2: Government Mandates on Coal fired Power Plants

2018-2019	Closure of 16 plants
From Nov. 2019	Remaining 44 plants to run at 80% capacity or less
by 2034	Closure of 6 obsolete plants, conversion of 24 plants to LNG

Korean Green new deal

In July 2020, the Korean government announced a Korean New Deal with the aim of providing 1.9 million jobs by 2025. The Korean New Deal consists of almost KRW 160 trillion (EURO117.2 billion) worth of total fiscal investment in two main policies –the Digital New Deal and the Green New Deal – and an overarching policy to strengthen the employment and social safety net.

The Korea Green New Deal include 5 key areas of investment: Green Smart Schools, Smart Green Industrial Complexes, Green Remodeling, Green Energy, and Green Mobility. Of the KRW 74 trillion (EURO 542 billion) of total capital investment under the Green New Deal, the largest portion, KRW 20 trillion (EURO 146 billion), will be used for green mobility, particularly hydrogen projects.

Changing leadership, new president Yoon

South Korea had the 20th presidential election in March 2022. Yoon Suk-yeol from the conservative People Power Party was inauguration as president of South Korea. The Yoon administration has not announced an environmental policy roadmap yet. However his environmental pledges from last election delivers a rough idea of the direction of his environmental policy.

President Yoon promised to expand the country's power generation based on renewable energy sources and nuclear power, and to reduce the operation of fossil fuel-based power plants, which currently constitute 60 percent of the country's overall energy mix, to 40 percent within his term. He also pledged to install air purifiers in all elementary, middle and high schools, as well as nursing homes, and lower the PM 2.5 concentration standard in public areas with high human traffic volume from 50 micrograms per cubic meter to 40.

President Yoon has also emphasized his promise to modify gas stations and liquefied petroleum gas (LPG) filling stations by installing battery chargers there and mitigating safety regulations for stations used by both gas and electric cars, so that people can recharge their electric cars there.

1.2 Clean air Business & Technological Trends in Korea

Korean Green New Deal

Among the 5 key projects of the Green New Deal, clean air benefits are especially associated in relation to building smart and green industries and to stimulate green transportation and logistics on land and sea. The Korean government intends to use technology to stimulate clear air which includes:

- Build smart energy platforms which control energy generation and consumption in real time
- Build 100 eco-factories, which produce a minimum level of pollutants through recycling, as well as 1,750 clean factories
- Promote industrial symbiosis and recycling between manufacturers within an industrial complex (81 by 2025)
- Help 9,000 small manufacturers with installing fine dust reduction systems
- Set up smart industrial complexes (15 by 2025) with simulation centres to test manufacturing processes and adopt air quality management and remote monitoring systems against the releases of toxic chemical substances, which use AI and drones

Air pollution control systems

The global market size for air pollution control systems is expected to reach EUR 82.44 billion by 2025, registering a 5.0% CAGR.[13] The Korean domestic market is forecasted to grow from KRW 6.22 trillion (EUR 4.64 billion) in 2016 to KRW 7.98 trillion (EUR 5.95 billion) in 2021, growing by 5.1% year on year.[14]

While large corporations make up only 9% of the companies active in the Korean air pollution control system market (22 companies overall), they account for 78% of total sales. Small and medium-sized companies account for 91% of the companies active in the area (225 companies overall), but account for just 22% of sales, with the average company making less than KRW 3 billion in annual sales.

The Korea National Environmental Information Center cites POSCO ICT and KC Cottrell as two major players in the fine dust response industry, particularly in terms of overseas activities[15].

With fine dust growing as a concern, air purifier sales have been booming[16]. South Korea's local air purifier market in 2021 is estimated at 3.5-4 million units, a growth of over 500,000 units from last year. Korean companies such as Coway, Samsung and LG offer stiff competition in this sector. A 2019 study found that

[13] Grand View Research (2018)
[14] Small and Medium Enterprises Technology Roadmap (2018-2020)
[15] Korea National Environmental Information Center, "Fine Dust Response Industry Benchmarking and Overseas Expansion Strategy" (2019)
[16] Maeil Gyeongje, "Not Just Samsung and LG, How About This Air Purifier?" (2021)

60% of Korean homes have air purifiers[17], though a poll taken the same year showed nearly half of workplaces lack air purifiers.[18]

While South Korea has been catching up with leading countries in terms of most technologies, its fine dust response technology was still 7.5 years behind world leaders as of 2018, according to a report.[19] That said, major Korean companies have been securing practical technology in the materials and process development sector, scrubbers, and ICT-based air pollution management. In particular, academic and corporate researchers are focusing their efforts on obtaining original technology in materials, as well as obtaining key technologies pertaining to materials and processes.

Additionally, as is the case in other industries, IoT technology is making an impact in the air quality industry in the form of sensors, apps and systems. This trend is likely to accelerate with the wider adoption of 5G technology. Patents for fine-dust related technologies are skyrocketing, with a growing number incorporating IoT, AI and other so-called "Fourth Industrial Revolution Technologies."[20]

1.3 Air quality Scientific Trends

National research institutions account for most of the research into air pollution in South Korea, with the Ministry of Environment accounting for 45 fine dust-related R&D projects since 2019. Other organizations that have led 10 or more projects include the Korea Disease Control and Prevention Agency, the Korea Forest Service, the Ministry of Health and Welfare, the Ministry of Science and ICT, and the Ministry of Trade, Industry and Energy. An overview of government funding can be seen in the table below.

Table 3: Government Funding on Fine Dust-Related R&D[21]

			Notable Projects			
Year	**No. of Projects**	**Funding**	**Project**	**Ministry**	**Registering Organization**	**Project Funding**
2019	44	KRW 10.99 billion (EUR 8.19 million)	Technology to control fine dust in schools	Ministry of Science and ICT/Ministry of Education	National Research Foundation of Korea	KRW 4.65 billion (EUR 3.46 million)
2020	56	KRW 9.54 billion	Technology to minimize fine dust	Ministry of Environment	Korea Environmental	KRW 1.2 billion

[17] Airlab, "What Air Purifier Would Be Best in an Office?" (2019)
[18] Chosun Ilbo, "54% of Workplaces, 43% of Schools Have Air Purifiers" (2019)
[19] Biotech Information Portal, "Fine dust technology trend report" (2018)
[20] Today Economic, "Measuring fine dust with AI, IOT, and 5G technology" (2021)
[21] National Science and Technology Information Service (2021)

		(EUR 7.11 million)	emission control blind spots		Industry and Technology Institute	(EUR 894 thousand)
2021	27 (to April)	KRW 5.17 billion (EUR 3.85 million)	Advancement of air environment standards to improve fine dust management	Ministry of Environment	National Institute of Environmental Research	KRW 600 million (EUR 447 thousand)
			Air pollution exposure assessment in established elderly cohorts	Korea Disease Control and Prevention Agency	Korea National Institute of Health	KRW 614 million (EUR 457 thousand)

In addition, an overview of scientific papers and patents can be seen in the following table. Scientific papers registered from 1960 through April 2019 were searched on the SCOPUS database, excluding "policy and information services" which is not a technological field. The WIPS-ON database was used to search US patents registered between 2009 and April 2019. There were no registered patents for the following categories: "indoor air quality management," "human risk epidemiology," "ordinary and concentrated measurement" and "identifying fine dust generation and conversion mechanisms."

Table 4: South Korean Scientific Papers and Registered Patents in the Field of Fine Dust Response Technologies from 1960 to 2019

Focus of Scientific Papers	**% of Papers**	**Focus of Registered Patents**	**% of Patents**
Health impact assessment	21.5%	Reduction of secondary pollutant generation at stationary pollution sources	26.4%
Fugitive dust reduction	15.8%	Road fugitive dust reduction	21.5%
Diagnosis, measurement and analysis	14.5%	Climate impact assessment Modeling	9.6%
Atmospheric air quality modeling	11.6%	Reduction of primary pollutant generation at stationary pollution sources	9.2%
Stationary pollution source	10.7%	Human exposure assessment	6.9%

emissions reductions			
Cause investigation studies	10.4%	Indoor fine dust detection	4.6%
Fine dust exposure reduction technologies	6.2%	Measuring/analysis technologies	4.2%
Mobile road pollution source emission reductions	4.9%	Primary vehicle emissions reductions	3.1%
Non-road mobile pollution source emission reductions	4.3%	Others	14.4% total

According to the research, over 20% of Korean scientific papers on fine dust focused on the health impact, followed by fugitive dust reduction (15.8%) and diagnosis, measurement and analysis (14.5%). Meanwhile, nearly half of patents focused on reducing secondary pollutants at stationary pollution sources (26.4%) and reducing fugitive dust from roads (21.5%).

In recent years, South Korea's patent office has received a growing number of applications for technologies related to fine dust. While in 2010 it received only eight patent applications related to monitoring fine dust, it received 212 in 2019[22]. Of particular note is the growing number of applications for dust monitoring technologies involving so-called "Fourth Industrial Revolution" technologies such as AI, IoT and bioengineering. The Korean patent office received 43 such applications in 2019, up from just 14 in 2015.

2. CLEAN AIR COLLABORATION PLATFORMS

Boosting Danish-Korean collaboration, partnership and exports requires a joint effort. Companies, researchers, and authorities must cooperate on profiling and marketing both countries individual strongholds within relevant business sectors like clean shipping, smart agricultural clean cities, renewable energy and utilization and clean production.

The driver to strengthening collaboration around air quality depends on innovation partnerships, exports and global market shares which needs to be monitored, and joint export promotion initiatives must be launched to stimulate concrete test and validation of clear air technologies. Such collaboration with specific innovation platforms seem to have the most impact and be the most successful ones.

2.1 Innovation Platform: Magok Urban living lab for improving Ambient Air Quality

The following section focuses on the case study of Magok Smart City - an urban living testbed with a special focus on improving local ambient air quality in Seoul that can be used as a testing and demonstration platform for relevant technology and solution providers.

[22] Kharn, "Active Grafting of AI, IoT to Fine Dust Monitoring" (2021)

Launched by the Seoul Metropolitan Government in 2018, the Magok Smart City project brings together residents, experts, and companies to turn the city's Magok district into a testbed for resolving urban problems using Fourth Industrial Revolution technologies.

Magok is located 2km north-west of Gimpo International Airport, commonly known as Gimpo Airport, which is serving between 22-25 million passengers yearly. Gimpo Airport is identified as a significant source of increasing the local air quality background concentration. The chemical emissions that causes the greatest concern close to airports include; Nitrogen Oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO) and particulate matter (PM).

Magok Smart City are working closely with Gimpo airport to test and validate mitigation measures which can improve air quality in and around Gimpo which could include testing of photocatalysis, onto concrete, asphalt and other surfaces where the pollution occurs from airplanes and ground vehicles.

At the heart of the project is the Magok Smart City Living Lab initiative, in which the city annually selects proposals submitted by companies to test new technologies in the district.

In 2019, the city selected five proposals, including one by the startup Dash Company and the research institute Impact Research Lab to install recharging stations for IoT kickboards at strategic locations throughout the district to reduce air pollution. The other four projects selected for the smart city initiative include a community mapping program for foul odors, an app for detecting fire in local apartments, a delivery program using self-driving robots and a smart moss project.[23]

Seoul Housing & Communities Corporation Supervisor Jeon Gang-min explains the IoT kickboard project: "In Magok Smart City, there is a lot of space between blocks, and there are a lot of short-distance routes not covered by public transportation. If you activate mobility between major strong points and connections with public transportation like subways and buses, you can improve the air quality even within a limited geographic space."

With automobiles emitting nearly 40% of the air pollutants in Seoul, Magok city's kickboard project is aimed at getting more people to use renewable energy for last-mile personal mobility. The installation of fixed stations can also lower social costs by 50% over existing kickboard sharing services. It can reduce traffic jams, reduce costs of kickboard collection, replacements by up to 70%, and remove urban blight by getting rental kickboards off the curbside. Reducing air pollution from transportation requires that Magok focus on changing the mobility patterns of its citizens by e.g. improving access to public transportation and encouraging the use of electric vehicles.

In January of 2021, Seoul Housing & Communities Corporation unveiled the so-called Smart Moss Wall[24], an innovative solution co-developed with local startup Realtek. The installation uses moss to separate and absorb fine dust, consequently purifying the air. The solution is currently undergoing a trial program near Magoknaru Station.

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[23] Smart City Korea, "Seoul City Unveils Results of Magok Smart City Living Lab's Five Projects" (2019)
[24] Today Energy, "SHC to Simultaneously Solve CO2 and Fine Dust through Smart Green Tech" (2021)

Authorities believe Magok's Smart Moss Wall can reduce annual fine dust by 12 kg and Carbon dioxide (CO_2) by around 240 tons. A similar solution by Germany's Green City Solutions can reportedly reduce fine dust by 30% and CO_2 by 10% within a 50 meter radius, cleaning enough air for 7,000 people to breathe every hour. This allows it to do the work of 275 wooden trees.

In particular, the Smart Moss Wall developers incorporated a zero energy strategy using solar panels and an automated irrigation system powered by rain water. And true to its name, the wall is smart, using sensors to connect with the SH Smart City Innovation Center for monitoring and analysis.

In fact, last year Seoul Housing & Communities Corporation unveiled a similar solution, the so-called Moss Tree, which does the work of 85 trees by reducing CO_2 by 50kg a year[25].

Realtek, the Moss Wall's private sector designer, also installed modules to monitor atmospheric conditions in real time in 21 spots in Magok in 2020. The modules can monitor CO_2, humidity, temperature, NO_2, wind strength and direction and PM10 and PM2.5 levels.
The local clear air initiative however needs to monitor the performance of the air cleaning potential, and further environmental sensing for emission monitoring and reporting is needed to be integrated as part of the urban living lab.

Seoul Housing & Communities Corporation has also built a cloud-based monitoring and management system connecting the Smart Moss Wall, Smart Moss Tower and Smart Green Stations.

The strengths of the IoT kickboard project explained above makes it a prime example of a strong initiative. The project ran into initial difficulties due to legal and cost issues regarding power supply, but authorities have since obtained power-sharing agreements with local businesses, and full-scale trial operations will begin in the spring of 2021.

Many further opportunities in this space are already being addressed. A battery swapping program for electric mopeds is in the planning stage. Technology is under development to recharge electric bikes at charging stations too, with the goal to commercialize this in 2022.

Likewise, the Smart Moss Wall and the Smart Moss Tower project is also in its infancy. However, in this case, it appears Seoul Housing and Communities Corporation has benchmarked similar efforts in Germany, particularly those provided by Dresden-based startup Green City Solutions. Should the project prove viable during its trial phase, authorities plan to build more moss walls and work with nature based solution to reduce air pollution throughout Magok, particularly roadside locations where fine dust and CO_2 are major concerns. As noted above, planners have also linked the wall and tower into an IoT-based monitoring and management system.

[25] DongA Ilbo, "Moss Tower Cleans Air, Kickboard Recharging Station…" (2020)

The Seoul Housing & Communities Corporation in partnership with Korea University and Innovation Centre Denmark in Seoul has paved the way for greater international cooperation. Such collaboration might involve activities concerning both domestic and foreign interests across a range of possible activities, including: smart city projects, professional exchanges, educational and research programs, seminars, lectures, academic conferences and networking meetings. Magok Smart City's Living Lab Innovation Centre, which can act as a testbed for smart city trial projects, recruits projects to support on an annual basis. Applications are restricted to entities located in Seoul and consortiums led by Seoul-based entities, though consortium partners may be located outside of Seoul and even outside Korea.

2.2 Innovation Platform: Green Smart School

When former President Moon Jae-in announced the "Green Smart School" project to educators in August 2020, he called it one of 10 major tasks of his landmark "Korean New Deal" initiative.[26] The Ministry of Education later detailed the initiative worth KRW 18.5 trillion (EUR 13.78 billion), focusing on 2,835 outdated school buildings nationwide. The project, at least as it is promoted, aims to create "Green Smart Schools" that not only incorporate eco-friendly technologies but also reflect the latest trends in digital and environmental education. The project aims to reduce greenhouse gas emissions by 190,000 tons of total carbon dioxide (TCO_2) a year and create 150,000 jobs. Moreover, the incorporation of green building strategies such as window replacements, efficient insulation, weather barriers, light colored roofs, solar panels and improved geothermal heating systems will make the buildings much more energy efficient, reduce power consumption and, likewise, reduce demand on Korea's largely coal-powered energy sector. In regions of the country with many coal plants such as Chungcheongnam-do Province, this could improve air quality significant.

In Moon's address to educators, the former president called for a digital-based convergence education system with smart classrooms, praising Korea's "unmatched, internationally competitive ICT and excellent teachers." He suggested that by combining these capabilities, Korea could realize education "in a new era that goes beyond the walls of classrooms, schools and the school system."

He also demanded that green schools serve as places and resources for environmental education. He said zero-energy green schools will be put in place by utilizing solar power generation and eco-friendly building materials, which could turn the Green Smart School project into a unique educational platform for Korean school children to learn about their own environmental and energy footprints and how technology can reduce energy consumption and lead to a reduction in air pollution from the energy production sector.

Though the Smart Green School initiative is largely a national initiative, the central government is working with local governments and local departments of education to pursue its aims. This has led to some interesting opportunities for international companies.

[26] Korea.net, "Remarks by President Moon Jae-in during Visit to Middle School Emerging as Green Smart School" (2020)

In September of 2020, Chungcheongnam-do Province concluded a deal with the Danish embassy, Israel's Yozma Group and several local organizations to implement "Danish-style" eco-friendly education spaces that offer students hands-on educational opportunities with renewable energy, ecosystems and other environmental subjects[27].

Introduced to Chungcheongnam-do Province by the Danish embassy in Korea, Seoul-based design firm IntEGrA has been assisting local authorities in researching the feasibility of implementing lessons learned in Danish schools at two provincial schools. Korean-American architect Brian Koh, IntEGrA's founder, said they hope to "use green technologies as part of their education material… We want to use building design features as part of the climate crisis education." Chungcheongnam-do Province will include IntEGrA's suggestions in its design guidelines for school renovations.

The government hopes that the project will have a sizable impact on TCO_2 emissions in South Korea. As one of 10 major initiatives under the "Korean New Deal" plan, it is obvious that the former administration invested significant financial and political capital, giving the Smart Green School project a better chance of yielding significant results and achieving this emissions goal.

However, this is not the first attempt to turn Korean schools into eco-friendlier places, a point noted by critics who express concern that the initiative is essentially a make-work construction project masquerading as an exercise in environmental protectionism. Previous projects have come up short. One school, for example, invested KRW 430 million to install solar panels in 2010 that generated only 0.5% of its energy costs, and then had to remove them due to typhoons during summer.

With so much money and political capital going into this project, producing and promoting results is key. Foreign partners that offer better means toward this end could find themselves in a good position to capitalize on the initiative. Firms aspiring to involve themselves in the project should be aware of possible regulatory barriers. During his feasibility study, Brian Koh found particularly promising software for Danish building energy management. To use it in Korea, however, would require language localization and integrating it into Korean equipment according to Korean standards.

On the bright side, Korea is a party to the World Trade Organization's Government Procurement Agency protocols, with non-discriminatory government procurement procedures. Tenders are made through the Public Procurement Service[28], though bid applications must be in Korean. The U.S. government recommends[29] that firms should "maintain a reputable representative or agent in-country to carefully monitor PPS tender opportunities."

One excellent collaboration opportunity seems to be the environmental education aspect of the project which the Korean government has been accused of neglecting. They are turning schools into eco labs and obviously a half-baked approach will not go unnoticed. As such, innovations in the field of environmental

[27] Yonhap, "Chungnam Adopts Trial Program for Danish-style Eco-Friendly Education Spaces" (2020)
[28] Public Procurement Service
[29] Export.gov, "Korea - Selling to the Government" (2019)

education may be very well received. Storm-proof solar panels might be another technology they would be interested in.

2.3 Innovation Platform: Zero Emission Shipping and Hydrogen industry

With air quality being a primary public concern in South Korea, the country is pursuing numerous strategies and projects to address this issue. The following chapter focuses on South Korea's Zero Emission and Hydrogen industry include Zero emission shipping and Carbon capture, utilization and storage (CCUS).

Zero Emission Shipping
Korea being the world-leader in shipbuilding, and Denmark being the world's number one shipping nation, the Zero Emission Shipping agenda is identified as a key innovation platform for the two countries in order to take on joint responsibility and for collaborating closely towards the future of a zero emission shipping industry.

International shipping emits 2-3 percent of global greenhouse gas emissions, transporting close to 80 percent of global trade by volume. To curb the emissions from shipping, the International Maritime Organization (IMO) has agreed on an ambition to reduce greenhouse gas emissions from shipping with at least 50 percent by 2050, but is facing significant technological as well as regulatory challenges to meet the required 2030 and 2050 goals.

The Getting to Zero Coalition is a partnership between the Global Maritime Forum, the Friends of Ocean action, and the World Economic Forum. It brings together decision-makers from across the shipping value chain with key stakeholders from the energy sector as well as from governments and Inter-Governmental Organizations (IGOs). Korea and Denmark are two of the supporting countries for accelerating maritime shipping's decarbonization with the development and deployment of commercially viable deep sea zero emission vessels by 2030.

This will require both developing the vessels as well as the future fuel supply chain, which can only be done through close collaboration and deliberate collective action between the maritime industry, the energy sector, the financial sector, governments and IGOs.

Therefore, it is worth highlighting that the Ministry of Economy and Finance of Korea in June 2021 announced that Korea will build 28 green vessels and sharply raise its 2021 growth outlook for Korea's economy against the backdrop of robust exports around green shipping.

Although shipping is a sector that is hard to decarbonize, research and development see promising developments in green shipping. The world's biggest shipping company, Maersk, is working to become carbon neutral by 2050 and recently ordered the world's first container vessel fueled by carbon neutral methanol from Hyundai Mipo with delivery in 2024. This is one of many exciting developments happening right now in the partnership between Denmark and South Korea.

Back in 2019, the Danish Maritime Authority hosted the first meeting with South Korean Green Ship Expert Committee (GSEC). This collaboration originates from the strategic partnership between Denmark and Republic of Korea that was formed during the 60-year anniversary for the dispatch of the hospital ship M/S JUTLANDIA. GSEC are the framework for collaboration on new technology and sustainable solutions for shipping and is a cornerstone for accelerating the development and deployment of zero emission vessel by 2030.

It is evident that with the combination of expertise within shipping, ship building as well as development and production of maritime equipment, Denmark in partnership with Korea are well matched to find global green solutions to the challenges of future shipping.

The Korean government revealed during the World Ocean Forum and KorMarine in May 2021 that it would focus on supporting digitalization and carbon neutrality with policy measures to boost domestic demand, establish smart yards and ship data collection and utilization platforms. The government plans to develop carbon-zero ship technologies fuelled by hydrogen and ammonia ship by 2031. The Korean government is furthermore to establish onshore and offshore testbeds for self- driving technology, such as intelligent navigation and engine automation.

This could lead to cooperation around exploring methanol as a fuel type. Methanol as a ship fuel is interesting for ship operators because it does not contain sulphur and is liquid in ambient air conditions, which makes it easy to store onboard ships. For ships operating in International Maritime Organization (IMO), emission control areas (ECA), methanol could be a feasible solution to meet sulphur requirements. Furthermore IMOs tough emission limits of SOx and NOx Emission Control Areas (ECAs) pose difficult challenges for ship owners and operators.

From the IMO’s ballast water management legislation to the Energy Efficiency Design Index for new ships (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), shipowners need to be ready to drastically cut energy consumption and emissions. Vessel and equipment producers have risen to the challenge and devised tools and strategies from new, energy-saving hull paints to higher-capacity container ships. Collaboration around energy effective pump solutions are lifting the green ship business cases and could support positive cash flow for ship-owners which are struggling to comply with EEDI.

While the business opportunities in shipping may be a few years ahead, the energy transition in other sectors of the economy is imminent. Therefore, it is important to explore synergies with other sectors such as land-based transport. Determined collective action in shipping can increase confidence among suppliers of future fuels that the sector is moving in this direction. This will translate through the supply chain into increased demand for zero emission fuels. It could also be an important point of leverage for change across other hard-to-abate sectors, thus accelerating the broader energy transition.

Carbon Capture, Utilization & Storage

CCUS plays an important part in South Korea's strategy to become carbon neutral by 2050. A 2020 government strategy paper states: "CCUS is an essential option to reduce CO_2 emissions and achieve our NDC and 2030 emissions reduction target. Government-funded R&D projects are underway to build an

infrastructure for developing and demonstrating technologies that can reduce nearly 10 million TCO_2 by 2030. For a wider use of CCUS technology, further technology development is needed to achieve carbon neutrality of the power sector."[30]

In South Korea, development of CCUS technologies has been underway since 2010, when a comprehensive national plan to promote technological development was announced. However, the plan has not been effectively implemented due to changing local and international conditions.[31] Nevertheless, a number of large scale pilot projects have demonstrated promising results and are worthy of further examination, including:

- Korea Electric Power Corporation's (KEPCO) Boryeong 10 MW KoSol CO_2 Capture Pilot Plant[32] (operation start 2013) with a post-combustion capture technology, 200 TCO_2/d capacity, and more than 90% CO_2 capture rate and 99% purity using a proprietary solvent KoSol-4 developed by KEPCO Research Institute.

- Korean Southern Power Co.'s (KOSPO) Hadong 10 MW Dry Sorbent Capture Pilot Plant (operation start 2013) with a post-combustion capture technology, 10 TCO_2//d capacity, and more than 80% CO_2 capture rate and 95% purity using a Fluidized-bed process developed by Korea Institute of Energy Research (KIER).

- Korea Carbon Capture and Sequestration R&D Center's (KCRC) 300-500 MW Korea CCS 1&2 Pilot Plants (operation start 2016) with a oxyfuel or post-combustion (integrated gasification combined cycle) capture technology with the aim of significantly reducing operating costs of large scale CO_2 emitters.

The government has been engaged in a number of large-scale test and demonstration projects since 2010. Furthermore, the Korea Institute of Energy Research developed the KIERSOL CCUS method in 2012, which uses the 20% more energy efficient solvent potassium carbonate. This method was transferred to Hyundai KIA Motors. South Korea has world-class wet and dry-method CO_2 capture technologies that are deployable now, a big draw in contrast with other efforts to reduce greenhouse gasses, such as renewable energy, which still require technological development to boost their efficiency and economic feasibility. This is particularly the case with wet-method CO_2 capture technology, which is a relatively mature technology that the oil and gas industry has been using for quite some time.

Further to this, the Korean government also has a history of getting things done once they declare an initiative, alongside strong human capital to draw upon within the nation.

Despite these advances, storage technology is still lagging behind, with South Korea's CO_2 storage potential currently sitting at around 15-18 tons.[33] The government has pushed the development of land-based and

[30] Carbon Neutral Strategy of the Republic of Korea (2020)
[31] Korea Research Institute of Chemical Technology, CCU Technology White Paper (2020)
[32] MIT, "Boryeong Station Fact Sheet: Carbon Dioxide Capture and Storage Project"
[33] Monthly Hydrogen Economy, "Entrust Carbon Neutrality to CCUS Technology" (2021)

sea-based storage technologies, but those efforts have come to nothing due to local opposition at potential storage sites.

There are also a number of other clear opportunities in the CCUS field within Korea. CCUS is ideal to helping the country transition to renewable energy and a hydrogen economy, with the use of CCUS being likely to increase as South Korea builds hydrogen production facilities. South Korea plans to build 40 small-scale hydrogen production facilities by 2025, with six currently under construction.

3. SWOT ANALYSIS AND STRATEGIES

The following is a SWOT analysis of the general state of ambient air quality management in South Korea, based on the findings of this report from the data collected over the past few years, followed by strategy suggestions for international collaboration on air quality improvement initiatives on the peninsula.

Table 5: SWOT Analysis

Strengths	**Weaknesses**
Air Quality: Levels of most pollutants have been steadily decreasing in recent years, including PM10 and PM2.5 fine dust, though as the threat section notes, South Korea still has much room for improvement, with fine dust levels still among the worst in the OECD. **Political**: The Korean government has been very committed to combating air pollution, having allocated a massive budget toward related projects. The Korean government has a reputation for competency when it comes to industrial projects, and there is strong public support for reducing fine dust. **Scientific**: Some 676 of air quality monitoring stations are in place around the country. There is a lot of strong research support from local universities and research institutes. Electric vehicles are starting to grow in popularity. **Business**: South Korea is a vibrant market with interesting opportunities for local as well as international stakeholders	**Air Quality**: Fossil fuels are still widely used with electric vehicles still in early stages of public adoption. The government has been unable to lower NO_2, NOx, SOx and O3 levels sufficiently. Dependency on coal plants. **Political**: A new administration has taken office in the Korean government, and it is unclear whether the new administration will be as proactive against air pollution. Though the public supports improving air quality, specific policies can and do run into public opposition at the national and local level. **Scientific**: Monitoring of some pollutants began only recently, resulting in insufficient data. Comparison with worldwide data is difficult due to the Ministry of Environment's preference for annual mean data. **Business**: Underdeveloped market for carbon utilization needs to be addressed. In terms of opportunities for international stakeholders, there is a need for local contacts or/ and consortiums to gain access.

Opportunities	**Threats**
Air Quality: Ongoing projects have a significant chance of successfully improving air quality on the peninsula. **Political**: The former President Moon's administration has allocated billions of Euros to projects aimed at combating fine dust, leaving a lot of room for collaboration. Likewise, there is growing concern on the part of the public regarding air quality. **Scientific**: Many research projects are still ongoing or starting up soon, offering many avenues for collaboration. Unique technologies have been developed that could be incorporated internationally, particularly in relation to CCUS. Forty hydrogen production facilities planned or under construction, as well as conversion of 24 coal power plants to LNG. **Business**: The Korean government is highly interested in improving air quality, with a history of funding related projects. The Korean market for air pollution control system is expected to hit KRW 7.98 trillion (EUR 5.95 billion) in 2021, growing by 5.1% year on year. A massive underdeveloped market opportunity exists for carbon utilization, as well as carbon storage in the East Sea field project. Zero emission shipping and CCUS opportunities in general are expected to increase within the coming decade. Likewise, the retrofitting of Korean schools offers opportunities in green construction and environmental and digital technology.	**Air Quality**: South Korea has some of the worst fine particulate numbers in OECD, particularly in the Seoul area, where fine dust levels are double WHO recommendations. Combatting the seasonal "Yellow Dust" is very complex, as it emanates from outside Korea. Increased industrialization in the region may escalate the fine dust problem out of control. **Political**: Opposition from both right and left-wing parties could endanger the former administration's air quality improvement initiatives. Korean public sentiment towards China is worsening over air pollution and other matters. The former President Moon's Green New Deal initiative is a massive undertaking, and has been criticized for not being well-planned in certain areas. **Scientific**: Government funding for air quality improvement projects could be unstable as political changes take place. **Business**: High competition from companies in other countries. For instance, the large US and Canadian oil and gas industries have helped give those countries an edge in commercialized CCUS technology. Moreover, large corporations dominate the South Korean economy, making it tough for smaller players to get a foothold.

4. RECOMMENDATIONS: CONNECTING DANISH AND SOUTH KOREAN CLEAN AIR STAKEHOLDERS

Korea feel the economic impacts from all sources of air pollution, including lost productivity; increased healthcare costs; decreased quality of life; stunted crops, plants, and trees and discolored and damaged outdoor structures and materials – all of which costs Koreans and the Korean economy trillion of KRW per year.

As indicated by the SWOT and the overall findings in the report, South Korea is an interesting and increasing marked for both import and export of ambient air quality solutions. As ambient air quality is high on the South Korean agenda both in terms of political, scientific and research and business commitment, many different opportunities can be identified for international and not least Danish stakeholders.

Ambient air pollution, in general, is a transboundary problem that is closely tied to the challenges of climate change and global health. In Denmark, air quality has improved during the last decades and is today above the European – and worldwide average due to the country's 50 years of efforts in mitigating ambient air pollution through technological development.[34]

However, air pollution is still a major challenge in Denmark. The latest Danish calculations (August 2019) show that air pollution in Denmark in the period 2016-2018 was the cause of an average of 4,200 premature deaths annually. 3,000 of those premature deaths are apparently due to sources of air pollution abroad, while 1,200 cases are due to Danish sources. On the other hand, Danish sources also contribute to approximately 1,200 premature deaths annually in Europe. The number of premature deaths annually due to air pollution in Denmark has fallen approximately 38% since 1990[35].

Since 1982, air pollution has been monitored in Denmark through a nationwide air measurement program. The results show, at least for most pollutants, that levels are declining. However, research also shows that exposure to the air pollution that exists today can give rise to negative health effects in the population.

Whilst Denmark is fighting its own air pollution challenges, the country is at the same time eager to play an active part in helping to solve global challenges such as ambient air pollution by sharing experience and solutions with others around the globe[36].

Based on desktop research, conversations, and interviews with selected Danish stakeholders such as CLEAN (Environmental Cluster Denmark), The Danish Clean Air Vision (Luftvisionen), DMT (Danish Environmental Technology Association), FORCE, The City of Copenhagen, The Danish Technological Institute, Copenhagen Solutions Lab and Aarhus University and The Technical University of Denmark (DTU) the following recommendations and scenarios have been built:

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[34] State of Green (2020)
[35] Sundhedsstyrelsen (2021)
[36] State of Green (2021)

Overall recommendations – barriers and drivers for Danish stakeholders

A major obstacle for Danish stakeholders to enter the South Korean Ambient air quality market is simply a lack of knowledge about concrete business and cooperation opportunities in South Korea. A natural first step is therefore to create more awareness of the South Korean market opportunities and entry points: including details on more concrete projects, access to funding as well as networking and partnership opportunities with relevant stakeholders in South Korea. Also, the potential consequences of a new administration taking office in South Korea - and hereby the investments in the green transformation, including the ambient air quality agenda - needs to be addressed further when reaching out to Danish stakeholders.

Overall drivers

The existing declarations, partnerships and cooperation between Denmark and South Korea are already important drivers for cooperation between the two countries. A lot of effort has already been placed on building fruitful relations between the two countries.

The case of Magok City and similar projects are in general appealing to Danish stakeholders. It contains the possibilities of testing, building concrete partnerships with local stakeholders as well as potential access to funding opportunities. Also, projects that invites to triple helix (public-private-academia) partnerships across the borders, is identified as a clear advantage in terms of applying to some of the big funding calls, such as EU's Horizon Europe programme. Living Labs such as the Magok City project are immediately a very recognizable set up for Danish stakeholders as it is seen in Living Labs around the country as well as at Copenhagen Solutions Lab in Copenhagen.

Denmark and Korea recently strengthened a unique and very strong Green Growth Alliance covering relevant sectors incl. offshore wind, biogas, and the maritime sector. When it comes to hydrogen, referred to as Power-2-X in Denmark, our two countries are also among the world-leaders. Later in 2022, the new Korean government will most probably announce its 2nd Hydrogen Economy Roadmap which is expected to put forward detailed plans and incentives for speeding and scaling up hydrogen production. It is important that the shipping industry is included in the hydrogen transition, and all actors in decarbonizing shipping ecosystem receive the proper international support, so that they will be able to realize the climate target, by setting up a national strategy, a regulatory framework and learn from best practise and global marked barriers.

The political commitment to the ambient air quality agenda in South Korea is a great driver combined with the massive community investments. Also, South Korea's reputation as a country producing quality both in terms of new technologies as well as concrete products is an incentive for cooperation as sharing knowledge and know-how is viewed as an important factor and foundation for creating new partnerships and further cooperation for many Danish stakeholders.

Overall obstacles

Access to funding is always a major concern when considering new projects and partnerships. Besides the funding opportunity within Magok City, applying for funding is a very time-consuming and uncertain process. The interest of getting involved in local South Korean projects is therefore directly linked to an assessment of the real possibilities for obtaining funding.

Also, the concern of identifying local consortium partners in order to become part of a project, such as the Magok Smart City's Living Lab, is considered a very time consuming and uncertain process.

Danish technologies are often considered expensive especially outside the EU. This indicates a need for R&D projects, where local demands are taken into account throughout the process. The involved Danish stakeholders all have essential experience in matchmaking and mediation between both commercial and R&D stakeholders.

Scenarios for further cooperation between Danish and South Korean Stakeholders within the field of Ambient Air Quality

<u>Scenario 1 – Initiate partnerships on joint challenges</u>

There is an interesting potential in establishing larger Danish-South Korean partnerships and consortiums to ensure a broad network base. A broader and more formalized partnership between private, public, and academic stakeholders might ensure a better anchoring for the involved partners in terms of obtaining long term results.

The Danish Air Quality sector is on a rise and more companies and stakeholders in general are coming together in professional networks and clusters such as DMT, The Danish Air Vision and CLEAN, who recently launched an Air Quality network for their member companies (summer 2021). Based on Danish competencies and joint challenges between Denmark and South Korea, interesting topics for joint projects could be within:

- **Coating / Reduction of NOx**.
  Working with surface coating on tiles, house surfaces etc. The surface coating can remove NOx and other harmful particles through an active catalysis process. In Denmark, there has been successful projects in Roskilde, at Frederiksberg swimming pool and at Kastrup Airport.

  Motoring / Transportation.

- Denmark has many competencies within motoring / transport, e.g., in relation to filters on cars. There are generally many stakeholders, both SMV's, start-ups but also larger Danish companies within this field.

- **Air Quality portfolio from Copenhagen Solutions Lab.**
  Copenhagen Solutions Lab has a wide range of partnerships and projects with stakeholders outside the City of Copenhagen. A lot of these projects are funded externally and can be used as inspiration both in terms of relevant project topics and in terms of project/stakeholder set-up.

Scenario 2: - Matchmaking in terms of applying to relevant funds

Funding is crucial for engaging stakeholders in new markets. Therefore, it seems obvious to provide targeted advice to Danish stakeholders about gaining access to South Korean partners in terms of applying to different funding opportunies.[37] Relevant Danish stakeholders can be reached through CLEAN, The Air Vision, the Danish Technological Institute as well as DMT (Danish Environmental Technology Association).

The Danish collaboration model often means a close cooperation between the private sector, public authorities, and academia. The involved Danish stakeholders all have interest and experience in engaging stakeholders in joint applications for funding. However, the overall experience is that joint projects should be initiated by the companies in order to succeed.

In terms of connecting South Korean stakeholders with Danish researchers, government bodies and companies should share knowledge and create innovative solutions on ambient air pollution as well as smart cities and green urban transition. One way is to engage the local companies directly. Danish companies are often signed as subcontractors in foreign markets and will only engage if there is a realistic potential to commercialize. This approach can directly match and showcase Danish know-how, expert level and relevant stakeholders in order to connect, co-create and potentially commercialize.

Scenario 3 – Extended Student and University cooperation through DTU and KAIST

The strategic Partnership between DTU (the Technical University of Denmark) and KAIST (Korea Advanced Institute of Science and Technology) is based on sustainable solutions within research, education and innovation. The alliance with KAIST aims to utilize complementary competencies to carry out research and technology development within green technologies. An interesting future project could be engaging students from both universities within joint challenges on air quality. This could result in establishing formal partnerships and knowledge sharing between subprojects in for example Magok City and Danish living labs involving students from DTU and KAIST as well as South Korean and Danish companies.

Education is another important part of the collaboration between KAIST and DTU. Since 2009, six Dual Degree collaborations have been established at master's level. The alliance also has links to the national

[37] For example the Magok City Funding

"Green Growth Alliance", which aims to promote Denmark's and Korea's political, commercial and technological collaborations in green technology and growth.

It is the immediate assessment from DTU that a collaboration within clean air / air pollution could easily be initiated. However, it depends on whether additional financing can be found. The experience is that the collaboration between DTU and KAIST is constantly evolving.

In terms of funding, EUREKA or Horizon Europe (where South Korea is to become associated partner) could be further investigated. EUREKA is a network organization where national research and innovation programmes can be coordinated into joint projects. EUREKA's primarily focus is on TRL (Technology readiness level). It consists of 40 member countries within and around Europe. However, some countries outside Europe are participating as associated members including South Korea.

Scenario 4 – Work on top of existing partnerships and bilateral ties

As mentioned, many bilateral ties have already been established between Denmark and South Korea. Using the frame of these existing partnerships such as city-to city cooperation, C40 networks and declarations, close bilateral ties and signed agreements should be taken into account, when initiating new projects and partnerships.

On a city level, both Copenhagen and Seoul have signed the C40 - Clean Air Cities-declaration during the C40 Mayors Summit in Copenhagen in 2019. In September 2021, Mayors from 15 cities including both Copenhagen and Seoul joined the C40 Renewable Energy Declaration to power their communities with renewable energy and expand access to clean, affordable electricity for millions of urban residents. The City of Copenhagen is in general interested in long term collaboration focusing on green initiatives and mutual knowledge sharing. An important factor for Copenhagen when entering partnerships is creating concrete value for other Danish stakeholders such as companies, knowledge institutions etc. External funding is also an important keystone for the city to engage. National initiatives and export/ market focus also influence Copenhagen's focus areas. The same goes for the C40 city network where some of Copenhagen's international work has been initiated[38].

Also, Esbjerg has partnerships with Jeollanamdo and Ulsan and work together within the World Energy Cities Partnership. The strategic partnership DTU and KAIST as mentioned above is also an obvious building stone. P4G, The Green Growth Partnership and CLEAN's City Solutions Platform are also well-established platforms for existing and potential further cooperation.

Scenario 5 – Focus on Danish strongholds and key story

The Danish political target of becoming fossil-free in 2050 as well as the overall storytelling about Denmark as a green frontrunner is often mentioned as an important export driver.[39]

[38] Interview: The City of Copenhagen
[39] State of Green

INNOVATION
CENTRE
DENMARK

Danish solutions and technologies are often expensive seen in an international perspective and based on local demands and legislation. This can complicate sales abroad. Focusing on the storytelling of long-term investments in tomorrow's green technologies can help solve this issue. Both State of Green and especially The Danish Air Vision are important stakeholders and can present the overall storytelling of Danish strongholds within Air Quality.

Denmark is aiming to become one of the frontrunners in zero emission and green transition industry. Denmark is like Korea a windy country and has many years of experience with and development of wind energy. Therefore, Denmark and Korea have favourable conditions to become a frontrunner in the transition to Power2X. Large Danish companies like Haldor Topsøe and Green Hydrogen System already work with the technology and the Danish large wind power/renewable energy developer Ørsted and CIP is developing the needed energy infrastructure.

On the business side, the largest market opportunity may be in Power2X and CCUS, technologies Korea is lacking in, yet sorely needs. The country's strong human capital makes it easy for them to fill most of their own business needs, yet with such a generous government budget dedicated to the fight against air pollution there must be a reasonable market opportunity in other collaborative ventures as well. This is especially true with strong competition from other countries pressuring Korean companies to perform.

ANNEX 1: KOREAN CLEAN AIR STAKEHOLDERS

According to the Ministry of Environment, South Korea is working with other countries “to pursue bilateral and multilateral cooperation to improve air quality in Korean as well as in the entire Northeast Asia." Following is a list of stakeholders in this space.

Table 6: Major Korean companies in the air pollution control space

Industry	**Korean companies**
Desulfurization Processes	Doosan Heavy Industries, Hyundai Heavy Industries, Samsung Heavy Industries, Daewoo Heavy Industries, STX Heavy Industries, KC Cottrell, Panasia, Techwin, Seoul Sharp Heavy Industries, ENCOCO, Daewoo Engineering
Denitrification Process	KC Cottrell, Panasia, Blue Bird, Daeyoung C&E
Particulate Removal Processes	KC Cottrell, Sinsung Plant, Aerix, J-E TECH, Clean ENG, Samyoung, Clean Air Tech, Beltran Korea
VOC Processing	Techwin, DAEYANG E&I, Key Engineering, Ecopro, Devocs, Teso Engineering
Odor Processing	BNETECH, ECOSolutions, Exen, Wooyang Engineering, AB-Tech
Adsorbent Materials	DY Carbon, Yuhan-Kimberly, Songwon, Lotte Fine Chemical, Taekyung BK
Catalysts	Nano, Heesung Catalysts, Ceracomb, Ordeg, Cosmo Fine Chemicals
Filler Materials	BoMyung Clean & Clean
Filters	Hwa Shin Special Textile Filter, Korea Filter, BoMyung Clean & Clean
Separating Membranes	Philos, Pure Envitech, Woongjin Chemical, AIRRANE

Table 7: Stakeholders, Innovation platforms

Magok Smart City	
Projects	**Stakeholders**
Government stakeholders:	Seoul Housing & Communities Corporation, Seoul Metropolitan Government
Non-government stakeholders:	Dash Company, Impact Research Lab, Air Order, Community Mapping Center, Digital Seoul, Team Interface, Robotics, Inc.
Green Smart School	
Government stakeholders:	Ministry of Education, local departments of education
Zero Emission and Green transition industry	
Joint project for CCU chemical conversion to produce chemicals & fuels	SNU, Korea University, Aju University and other universities and research institutes, Hyundai Oilbank, SK Innovation and Lotte Chemical.
CCU biological conversion project to produce chemicals and fuels	Korea District Heating Corporation
CCU project for mineral carbonation to produce construction materials	Pohang Research Institute of Industrial Science and Technology, Sungshin Cement, Daewoo Construction and others
Developer of the KIERSOL method, which uses potassium carbonate to extract carbon dioxide combustion gas released at industrial plants	Korea Institute of Energy Research
Advancement of CCU technology	Ministry of Science and ICT
Commercialization of advanced mineral carbonation technologies	Center for Carbon Mineralization of the Korea Institute of Geoscience and Mineral Resources
Non-government stakeholders:	Construction companies, students, school parents, green power technology companies, teachers, teachers unions, edtech companies

Table 8: Stakeholders, other

Government	Non-Government
- Ministry of Environment - Ministry of Science and ICT - Ministry of Trade, Industry and Energy - Ministry of Education - Ministry of Land, Infrastructure and Transport - Ministry of Foreign Affairs (international cooperation) - KEPCO - Government think tanks: National Institute of Environmental Research, National Science and Technology Information Service, etc - Local governments such as Seoul Metropolitan Government	- The tax-paying public - National research universities - Environment-related civic groups and organizations - Almost every major Korean manufacturer, including POSCO, Hyundai and Samsung - Car manufacturers like Hyundai and Kia - Korean shipbuilders like Hyundai Heavy Industries and Daewoo. - Major transportation and shipping companies such as Korean Air and Hanjin. - Major petrochemical companies such as LG Chem - Major trade unions - Major business groups such as the Federation of Korean Industries - SMEs, especially those involved in the environmental, manufacturing, materials and transportation industries