

STATE OF GREEN
WHITE PAPERS
FOR A GREEN TRANSITION

CLEAN AIR

Sharing Danish experience and solutions
for the benefit of people and the planet

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Improving urban air quality

Tackling air pollution at sea

Monitoring air pollution at sea

Reducing ammonia emissions from agriculture

Limiting air pollution from industry production

CLEAN AIR

Sharing Danish experience and solutions for the benefit of people and the planet
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AIR POLLUTION IS A MAJOR ENVIRONMENTAL CHALLENGE OF OUR TIME

Clean air is a source of better living and welfare. Unfortunately, filling our lungs with clean air can by no means be taken for granted. Danish expertise and clean air solutions are ready at hand to reduce ambient air pollution worldwide.

Minister for Environment, Lea Wermelin



Studies show that nine out of ten people in the world are exposed to levels of air pollution that exceed limits recommended by the World Health Organisation and have a substantial negative effect on both living conditions and the environment worldwide. Consequently, one of the UN Sustainable Development Goals for 2030 is to reduce the number of death and illness caused by air pollution (SDG 3.9).

By sharing our experience and solutions with others, Denmark wishes to play an active part in helping to solve global challenges, including ambient air pollution.

Working in partnerships to improve air quality

In Denmark, we have worked on improving air quality since the 1970s and we have brought down air pollution from industrial and energy production to a low level compared to global standards. Beyond the health and environmental benefits to the Danish society, this development has also

fostered a cleantech sector that is leading in developing, supplying and utilising solutions to reduce air pollution.

Since 2018, a partnership between Danish business organisations, companies in the field of clean air solutions and the Ministry of the Environment and Food has worked together in The Danish Clean Air Vision to develop and deliver solutions aimed at providing cleaner air nationally as well as globally. Solutions that will benefit the environment, human health, growth and employment.

Existing technology can help reduce global air pollution

The problems related to air pollution are often seen in relation to the world's cities and have been intertwined with the increasing urbanisation – a trend that shows no sign of decline.

However, air pollution is not only a city phenomenon. It originates from almost all

types of industries from rural agriculture to international shipping, just to mention a few.

The good news is that solutions to help us combat the negative effects of air pollution already exist.

In Denmark, we have a long tradition for being at the forefront of developing and implementing green solutions and green technologies. Due to the Danish tradition for solution-oriented cooperation between companies, research facilities and authorities, Denmark has fostered a range of solutions to reduce air pollution.

This white paper highlights some of the best practice examples for clean air solutions. Even though these solutions have been created within a Danish context, they are scalable and relevant on a much broader scale and ready at hand for a global audience.

I hope you will feel inspired.

ABOUT THIS WHITE PAPER

Ambient air pollution is a global health challenge causing premature deaths of millions each year as well as a very high cost to societies globally. Technological innovation is key in battling air pollution and at the same time maintaining economic growth. Here, industries play a crucial role in terms of innovating and developing new efficient solutions that can reduce air pollution. Solutions that often need to be incentivised through taxes, regulation and other initiatives as a driver for the market.

A long-term focus on improved air quality

For many years, Denmark has been focused on developing clean air technologies and solutions to those sectors that represent a significant source of air pollution, including shipping, industrial production, agriculture, transportation, heating and power generation. Coupled with strict environmental legislation and air quality monitoring, this sector-focus has helped to significantly reduce ambient air pollution in Denmark's urban and rural areas.

Find inspiration for your own clean air projects

This white paper features lessons learned from Denmark's 50 years' of experience with fighting ambient air pollution. Through state-of-the-art case examples in cities, shipping, agriculture and industry production, the white paper illustrates how implementing clean air solutions is viable to societies and offers benefits to both people's health and the environment. It is meant to serve as inspiration and a tool to reap the benefits of implementing clean air solutions across sectors.

We hope you will be inspired.



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1. CLEAN AIR IS A MATTER OF GLOBAL HEALTH

Globally, ambient air pollution is a major health challenge that causes 4.2 million premature deaths every year due to strokes, heart diseases, lung cancer and chronic respiratory diseases. Around 91 per cent of the world's population lives in places where air quality levels exceed limits recommended by the World Health Organisation (WHO). The major outdoor pollution sources include vehicles, power generation, heating, agriculture, waste incineration, shipping and industry.

The economic rationale in fighting air pollution

The economic impact of air pollution, from e.g. loss of workdays and direct healthcare, is far higher than the investments needed to reduce air pollution. Calculations made by the European Commission show that in

the European Union, the expected benefits to society are more than 20 times the cost of implementing the legislation. Globally, there is an economic rationale to act and cost-effective solutions already exist to address the challenge of air pollution. Policies and investments supporting cleaner transportation, power generation, industry, energy-efficient housing and better municipal waste management can effectively reduce key sources of ambient air pollution.

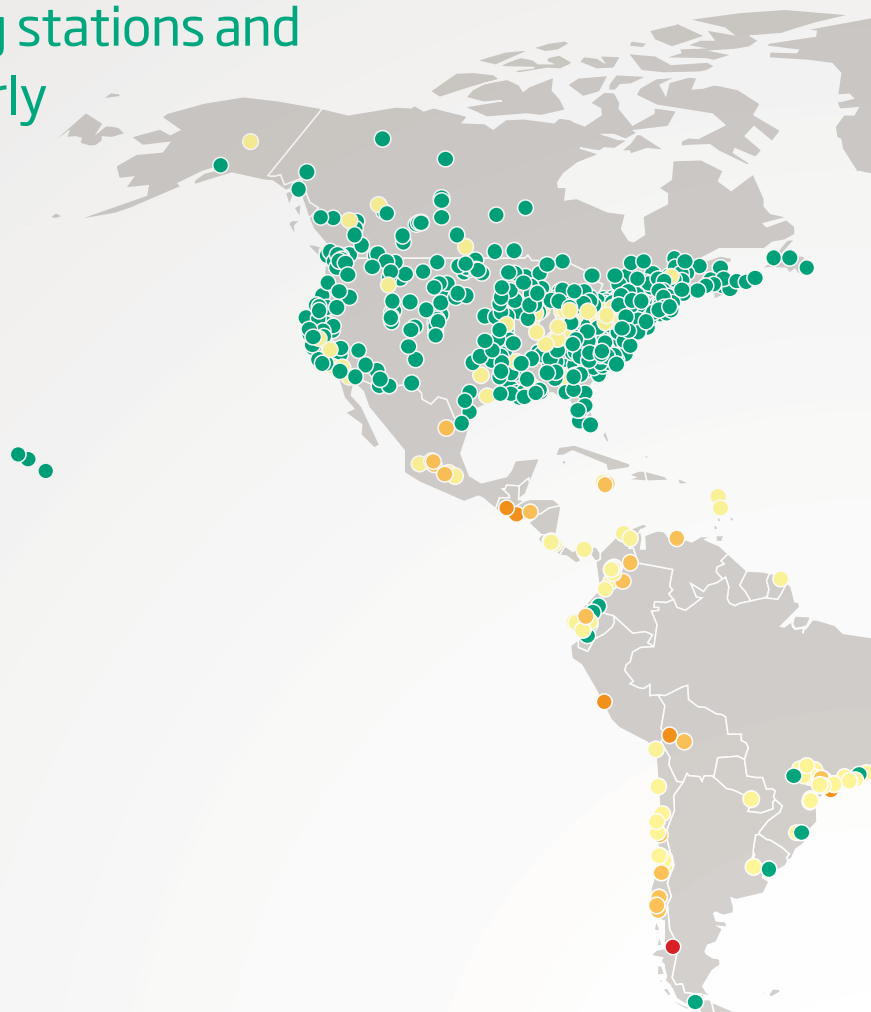
Air pollution is closely linked to the challenges of climate change and biodiversity. Combustion of fossil fuels is a major contributor to both air pollution and greenhouse gases. Policies to reduce air pollution therefore often offer climate benefits as well as benefits for ecosystems and health.

Existing solutions and technological development must go hand in hand

Technological innovation is key in beating the challenge of air pollution without hampering the economic growth and welfare of societies. Here, the private sector plays a crucial role in terms of finding and developing new efficient solutions that can reduce air pollution. Solutions that often need to be incentivised through public taxes, regulation and other initiatives once they enter the market.

However, many solutions to fight air pollution already exist and are available in transportation, urban planning, power generation, local heat production, industry, shipping and agriculture. Adoption and adaptation of existing clean-tech innovations

Location of the monitoring stations and PM_{2.5} concentration in nearly 3000 human settlements, 2008-2015



Annual mean PM_{2.5} (µg/m³)

- <10
- 10-19
- 20-39
- 40-59
- 60-99
- ≥100

PM_{2.5}: Fine particulate matter of 2.5 microns or less.

Source: [World Health Organisation](http://www.who.int)

from other countries is a central input to a successful policy and implementation.

Cross border collaboration is needed to fight the challenge of air pollution

While the preconditions to fight air pollution might differ from region to region across the globe, it is still essential to share experiences between countries and regions to ensure an efficient and cost-effective response to the challenges of air pollution worldwide. The UNECE Convention on Long-range Transboundary Air Pollution has been providing a legal and organisational framework for the exchange of knowledge and joint commitment since 1979. In addition, the clean-tech industry plays a vital role in the exchange of experiences and technologies between countries and regions.

The aspect of regional and inter-regional cooperation and the exchange of experiences was a main theme at the third United Nations Environment Assembly in 2017 as well as central at the WHO Global Conference on Air Pollution and Health in 2018. Furthermore, at the C40 World Mayors Summit in Copenhagen in 2019, 35 city mayors signed the C40 Clean Air Declaration, agreeing to coordinate and integrate policy strategies for improving air quality as well as share experiences.

Achieving a sustainable and healthy future for all requires action on air pollution

The UN Sustainable Development Goals on health (SDG3), energy (SDG7), sustainable cities (SDG11) and climate change (SDG13) provide a massive opportunity for addressing the challenge of air pollution and the related burden of disease.

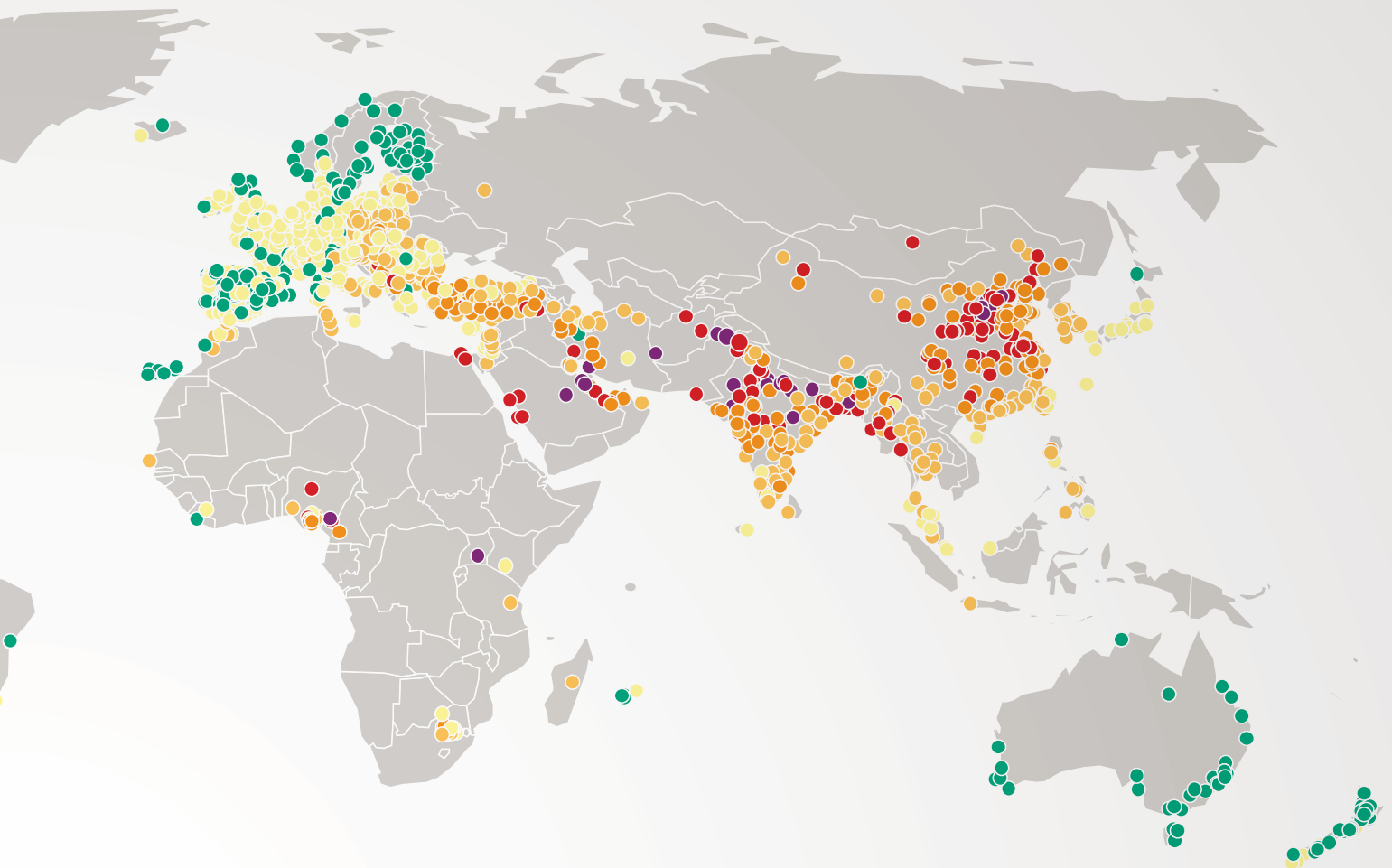
The list of targets with relevancy to indoor and ambient air pollution includes:

SDG target 3.9, which calls for a substantial reduction in deaths and illnesses from air pollution

SDG target 7.1, which aims to ensure access to clean energy in homes

SDG target 11.2, which aims to provide access to safe, affordable, accessible and sustainable transport systems for all

SDG target 11.6, which aims to reduce the environmental impact of cities by improving air quality



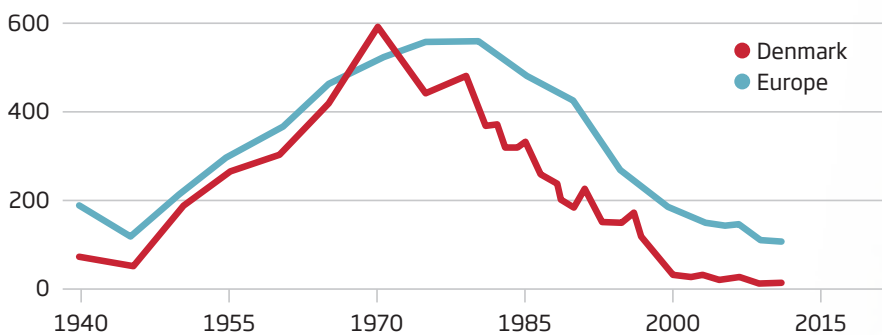
2. CLEAN AIR IN DENMARK - DEDICATED EFFORTS SINCE 1970

During the past five decades, the regulation of air pollution in Denmark has been founded on a long tradition of high environmental concerns, and the regulatory framework has been a combined effort of Danish initiatives, the implementation of regional conventions and directives from the European Union.

Establishing national and EU regulation to reduce air pollution across sectors

Already in the late 1960s, sulphur dioxide (SO₂) was recognised worldwide as an air pollutant with a series of negative impacts on human health and the environment. In 1972, this led to regulation of the sulphur content in fuel oils in Denmark.

Emission of SO₂ (1000t/year)



Through the Danish Environmental Protection Act of 1974, the authorities were now empowered to restrict air emissions from the industry and energy sectors. The Act proved to be an efficient instrument for reducing local emissions of pollution and associated health risks.

During the 1980s and 1990s, Denmark was a frontrunner in establishing national and EU regulation to reduce air pollution and improve air quality in cities, developing and introducing regulation or standards for vehicle emissions as well as emission control requirements to urban power and heat production. Denmark was one of the first countries in the world to require catalytic converters in cars from 1990.

In 1990, the Danish Ministry of Environment issued a comprehensive set of guidelines for industrial air pollution control (these were revised in 2001). In parallel, the EU introduced emission limits for large combustion plants and the EU directive on Integrated Pollution Prevention and Control (IPPC) for large combustion sources as well as other major polluting industries imposed Best Available Technology (BAT).

Denmark is a large agricultural producer with a very extensive primary food production, which constantly has to be balanced with concerns towards human health and environmental impact. Accordingly, agricultural production in Denmark is extensively regulated to lower the ambient impact while still maintaining a strong sector. Like in any other industries, large farms are required to obtain an environmental permit for operation that ensures a safe level of emissions and the application of BAT.

In 2008, the Danish Environmental Protection Agency issued the world's first statutory order that included emission limit values for new wood stoves.

As a significant player in the global shipping industry, Denmark has been pushing for more global regulation of emissions from shipping. At the same time, Denmark has been a main driver for establishing sulphur emission control areas in the Baltic and North Seas since 2015 and similar NO_x control areas for new ships from 2021.

High environmental standards as a driver for private sector innovation

The environmental regulation in Denmark has always been founded on the capability of the industry to find new technologies and innovative solutions in response to the environmental needs, using both push and pull incentives. The high political ambition in Denmark in terms of environmental protection has been a major driver of this, pulling a continued development and marketing of new innovative solutions and techniques.

At the same time, dedicated public funds for research, development and testing of new clean techniques have been pushing the development.

The clean-tech sector is today one the fastest growing sectors in Denmark, and it is regarded as one of Denmark's important research and industry strongholds.

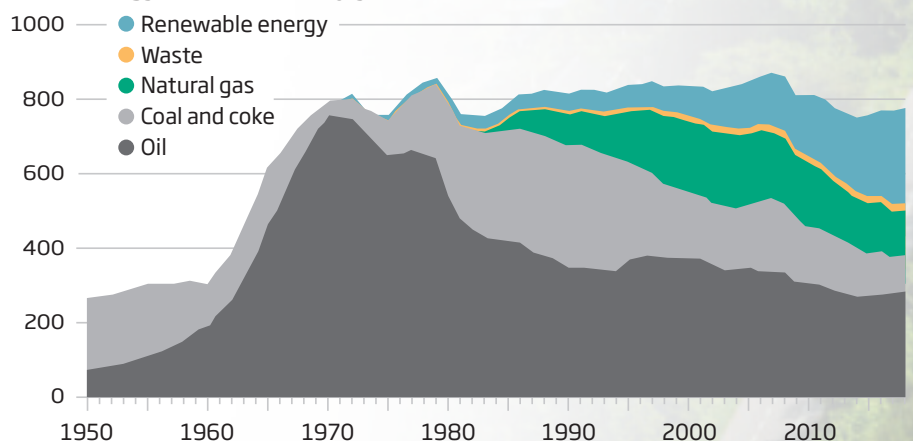
Energy and climate change synergy

An active Danish energy policy focusing on energy efficiency, energy diversification and developing renewable energy has resulted in a resilient and sustainable energy system in Denmark, with co-benefits for the levels of air pollution. As seen in the figure, the major changes of energy sources from oil to coal to natural gas to renewable energy - have also lead to reductions in air pollution.

An early decision in Danish energy policy was to place energy savings high on the agenda, pushing the industry to prioritise energy efficiency and promote energy savings in buildings.

Today, the main climate driver in Denmark is the target to be independent of fossil fuels by 2050.

Gross energy consumption (PJ/year)





3. IMPROVING URBAN AIR QUALITY

Air pollution is one of the most significant environmental challenges affecting people's health - particularly in urban areas. Just within the EU, air pollution costs are over EUR 4 billion in healthcare, EUR 16 billion in lost workdays and 400,000 premature deaths every year, according to the latest estimates from the European Commission. Globally, urbanisation is increasing rapidly, exposing billions of citizens to air pollution and urging the need for local authorities to address air pollution and encourage behavioural change to help improve air quality in the cities.

A growing number of cities worldwide are working together to coordinate and integrate policy strategies for improving air quality as well as share experiences. The C40 Clean Air Declaration, which was signed at the C40 World Mayors Summit in Copenhagen in 2019 by 35 city mayors, shows the relevance of setting goals together and cooperating on implementation.

For many decades, Danish cities have been frontrunners in addressing urban air pollution. Already in the late 1960s, sulphur dioxide was recognised as an air pollutant with various negative impacts on health and the environment. In 1972, this led to regulation of the sulphur content in fuel oils in Denmark. Through the Danish Environmental Protection Act of 1974, the authorities were empowered to restrict, for instance, air emissions from the industry and energy sectors, and the Act proved to be an efficient instrument to reduce local air emissions and associated health risks.

Public concern leading to regulation of transport emissions

Transportation is another key reason for poor urban air quality. During the 1970s, awareness concerning the negative health impacts of transport emissions started to increase in Denmark. This concern began

with the disclosure that lean in transport emissions could affect the human nervous system, which led to increased pressure for regulation of the use of unleaded petrol.

In 1990, Denmark introduced strengthened emission requirements, forcing all new cars to be fitted with catalytic converters in order to reduce emissions of carbon monoxide, volatile organic compounds and nitrogen oxides. The EU introduced a similar regulation in 1993.

Fuel quality requirements, taxation, vehicle emission standards and urban vehicle access restrictions have been central to improve urban air quality in Denmark and foster local businesses to develop solutions to meet the new requirements.

Reducing air pollution from the urban heating supply

Integrating local heating needs into the wider energy system has also been a central tool to improve air quality in Danish cities. Shifting from individual domestic heating using coal or oil, to the use of district heating based on surplus heat from conventional power plants, industries and waste incineration has increased efficiency, reduced the carbon foot print and air pollution from the urban heating supply.

Much of the development has been achieved through the large scale transition to district heating networks, which is an important infrastructural premise that must be present to broadly integrate the energy systems. Today, two out of three households are supplied by district heating in Denmark, which allows for a more efficient heat supply if produced centrally in densely populated areas.

The use of wood stoves as an extra, secondary heating source is widely used in Denmark. Accordingly, it is also a major

source of particulate matter harming human health. The main approach in addressing the pollution problem from this local heating source has been to replace old stoves with modern, more energy efficient and cleaner ones.

Promoting eco-innovation in the design of new wood stoves

New Danish wood stoves are characterised by being much more efficient and cleaner than their European competitors and ahead of the coming EU eco-design requirements for wood stoves.

Back in 2008, the Danish Environmental Protection Agency issued the world's first statutory order that included emission limit values for new wood stoves. Over the years, these emission limit values have been revised and in 2017, the emission limit values were restricted to a level, which is below the EU standards that will enter into force in 2022.

In parallel, the promotion and use of environmental labelling have been used extensively for wood stoves. The Nordic eco-label, the Swan, has driven the market towards even more efficient and clean wood stoves. The Danish consumers have increasingly chosen new wood stoves with the Nordic Swan label. Back in 2006, only one manufacture produced such a wood stove, and when the use of the swan label peaked, 90 per cent of all new wood stoves were Swan labelled.

The environmental requirements from the authorities and the consumers have been a major driver for the innovation of cleaner products from the wood stove manufactures. At all price ranges, consumers are today able to buy a wood stove with lower emission levels than national or EU requirements.

RETROFIT OF AIR CLEANING SYSTEMS IN TRANSPORTATION

Reducing air pollution from busses, trains, trucks and mobile machineries in cities is often complicated because of the average long lifespan of the vehicles and machineries. Renewal of the entire fleet ahead of the normal retirement age is in most cases an economic burden on the operator and the city.

In 2014, when a decision had to be made on additional measures to comply with the EU limit value for NO₂ in Copenhagen, the choice fell on retrofitting 300 public busses running in the city centre. This solution was chosen because it was the most cost-effective way to reduce NO_x emissions from traffic in the city centre. Cleaning systems with integrated NO_x reduction (SCR) and particulate filters were installed in the busses, reducing up to 99

per cent of NO_x emissions and 95 per cent of particulate matter. In Denmark, a number of industries has over the years specialised in reducing NO_x and particulate matter from means of transportation and mobile machineries. Both as producers of systems for the vehicle manufacturers (OEM) and in terms of retrofit solutions for all kinds of combustion engines, vehicles and machineries, where there is a need to reduce emissions in urban areas. Retrofitting is both done on a large systematic scale, as it was the case with the city busses in Copenhagen, and on a more individual basis according to specific needs.

For more information on retrofit, explore the solutions from e.g. Purefi, Haldor Topsoe, Umicore and Dinex.



Photo credit: Ole Malling, Gottlieb Paludan Architects



What is the most efficient way to reduce emissions from wood stoves?

In Denmark, the biggest source of harmful particle pollution is wood stoves. Therefore, a large project funded by The Danish Environmental Protection Agency has been initiated to identify which initiatives and technologies are the most efficient for reducing emissions under real-life conditions.

A residential neighbourhood in Aarhus, the second largest city in Denmark, will be fitted with a network of sensors enabling real-time monitoring of the particle and NO_x concentrations in the local environment, both indoors and outdoors.

The project aims at testing the effects of automatically controlled stoves, low emission stoves, education and digital nudging tools

aimed at the users, draft boosters, filters and catalysts. By conducting various tests, the project will provide essential knowledge on which initiatives and technologies that have the largest emission reduction compared to the price.

A 50 per cent reduction of emissions related to wood stoves is expected in the test zone. If implemented nationally, this would correspond to a yearly particle emission reduction of 7,500 tonnes and a black carbon reduction of 2,000 tonnes.

Danish Technological Institute, Aduro, HWAM, Morsø, Heta, Schiedel, Exodraft, Blue Chimney, Leapcraft, Katzenmark, SBI, Danish Centre For Environment And Energy



The Swan label as a driver for more efficient and clean wood stoves

The Swan label is a Nordic eco-label, which has been a major driver for the development of new technologies for wood stoves. Supported by a dedicated support scheme for eco-innovation, the market has been able to meet the consumers' demand for cleaner wood stoves. A reiterative process between the producers and the ever more strict eco-labelling requirements has resulted in a manufacturing sector in Denmark, which is able to produce wood stoves with emissions far below both national and EU requirements.

A Swan labelled product is not exclusively for an up-scale market. The Danish companies are in general able to sell wood stoves complying with the Swan requirements at all price levels for wood stoves. Consequently, the common perception of a need for a high purchasing power in order to benefit from eco-labelling schemes has in the Danish case of wood stoves shown not to be true.

For more information on the Swan label, please visit Ecolabel.dk/en



Reducing particles from wood stoves with up to 95 per cent

The household wood stove has come under attack recently. The reason? Its emission of particles pollutes the air. Particularly the fine and ultrafine particles of flue gas contain microscopic elements or liquid droplets so tiny that they can penetrate our respiratory systems, reach our lungs and bloodstreams and cause various health problems.

This is the reason why exodraft has developed a highly effective electrostatic precipitator (ESP) for wood stoves in private homes. This wood stove filter reduces the number of particles by as much as 90-95 per cent as well as it reduces the total particle mass by 70-75 per cent.

The electrostatic particle precipitator is installed on top of the chimney and uses a high-voltage electrode to charge the particles in the flue gas and trap them inside the filter.

In addition to an integrated chimney fan, the precipitator comes with a self-cleaning function that causes some of the trapped particles to combust. The remaining particles are released into the chimney to be burnt off, thus minimising the need for manual cleaning of the filter.

Wood burning is CO₂-neutral and with an exodraft wood stove filter, it is also a clean way to generate heat and energy.

exodraft

4. TACKLING AIR POLLUTION AT SEA

Approximately 93,000 ships sail the oceans worldwide and that number is expected to increase along with the continued demand for international trade. The vessels carry the vast majority of all goods that are being transported across the world and they are an indispensable part of the infrastructure related to passenger transport. At the same time, cruise ships offer a relaxed way to spend a vacation while exploring multiple destinations, which has a broader appeal than ever before.

Increased shipping causes a threat to human health and the environment

However, the significant amount of ships is a challenge in relation to air pollution. The large exhaust on many vessels emit a number of harmful substances such as sulphur (SO₂), nitrogen oxides (NO_x), soot,

ammonia, particles, volatile organic compounds (VOC) and CO₂. Substances that have an adverse effect on people, the climate and the environment.

Pushing for a cleaner maritime industry

Luckily, the air pollution from the maritime industry can be curbed by using green technologies designed specifically for ships and the harsh conditions in which they operate. With the technologies available today, it is possible to address all the above-mentioned polluting components and thereby deliver massive benefits for public health and the environment.

The adoption of IMO's (UN's International Maritime Organisation) global sulphur-reducing requirements represent a significant

push towards a cleaner maritime industry. The requirements have boosted the demand for air cleaning and promoted the use of alternative fuels for shipping.

Danish solutions for the maritime industry are in high demand

From a Danish perspective, this development has not only been positive for reasons related to the environment and health. Denmark is a world leader within flue gas cleaning technologies, and Danish scrubber producers have seen an unprecedented surge in the demand of their products over the past fifteen years. In 2019, just three Danish scrubber producers covered approximately 15 per cent of the global market. In addition, minor Danish start-up companies are exploring alternative solutions in relation to sulphur removal.

MARINE SCRUBBERS

Since the IMO's sulphur-reducing requirements came into force, the global fleet of ships is left with two options regarding the use of fuel. Either to switch to a low sulphur fuel or to install a scrubber that cleans the ship's emissions before releasing it into the ambient air. If a scrubber is installed, the ship can continue the use of heavy fuel oil.

Exhaust gas cleaning or scrubbing technology is a well-known technology. For a long time, it has been used on land to clean emissions from land-based power plants. With the rising awareness of air pollution from shipping across the world, the systems have been adapted to the maritime environment.

Overall, a wet scrubber removes sulphur dioxide (SO₂) from the exhaust gases by washing it with an alkaline scrubbing material that neutralises the acidic exhaust gasses. However, there are different approaches:

Open loop systems utilise seawater to wash (scrub) the exhaust gasses. The water is discharged back into the ocean with the

natural chemical composition of the seawater being used to neutralise the results of SO₂ removal.

Closed loop systems utilise seawater treated with an alkaline chemical such as caustic soda or magnesium hydroxide used for neutralisation and scrubbing. The wash water is re-circulated and any losses are made up with additional seawater. A small quantity of the wash water is bled off to a treatment plant before it is discharged into the ocean.

Discharging of wash water is not permitted everywhere, which is the reason for the development of both closed loop and open loop scrubbers. Hybrid scrubbers that employ both technologies are available for vessels, which need to be able to accommodate all scenarios.

For more information on scrubbers, explore the solutions from e.g. ME, Puretec, and Alfa Laval.





Clean and silent ferry services

Denmark consists of many islands, which are mostly served by old, noisy and polluting ferries. As part of a state funded project, Exilator installed their exhaust cleaning system on both main engines and generators of the M/F Isefjord, and the results were remarkable.

Owners, captains, crew, passengers, the port, nearby restaurants and inhabitants were all surprised – most thought the ferry had been electrified as there was no smoke, no smell and no noise. The data from the official measurements revealed the following results: noise reduction exceeded 75 per cent, a particle matter (PM2.5) reduction of 99 per cent.

The conclusion: Exilator's award winning very compact exhaust cleaning system turned the ferry M/F Isefjord into a silent and clean one. The installation is now being used as a case study and demo ferry for other ferry owners and operators, and this has given Exilator a unique "showroom".

The project has been supported by Ministry of Environment and Food, Danish Technological Institute, Owners of M/F Isefjord, Assens Shipyard, Jeji, Landson Emission Technologies, Electro Performance and AKS



Shore Power cuts emissions from berthed cruise ships

Depending on their size, cruise ships consume power in abundance. As the power is generated by using marine diesel fuel, the emissions from the ships can have an impact on the environment and on human health. Lately, the severity of climate change and local health complications from air pollution have led the cruise industry to explore more sustainable shipping solutions. Due to the nature of maritime travel, much attention in the broader shipping industry has been directed towards finding the future clean fuels and technologies, but the technology for port calls is already here: it is called Shore Power.

The concept of Shore Power is simple: by providing electrical power from shore to ship, the ship's auxiliary engines can be turned off completely and the exhaust gasses from diesel fuel will cease, reducing emissions of NO_x, sulphur and particulate matter. This leads to immediate improved air quality in the port cities and in the close vicinity around the ship. PowerCon is building Europe's largest Shore Power facility in the Port of Bergen and upon completion three cruise ships will be supplied with renewable electricity from hydropower.

PowerCon, Port of Bergen, Plug



Battery-powered ferries save 65 per cent CO₂-emissions

The two ferries Aurora and Tycho Brahe, operated by ForSea, were once entirely dependent on diesel. Today, they have been rebuilt to battery-power. The ferries carries millions of passengers and cars a year across the narrowest part of the Oresund strait from the Danish town of Helsingør to Helsingborg in Sweden.

Four containers on the top deck contain the batteries, which are charged with electricity coming from renewables such as wind, hydro and solar. The ships can run on battery, diesel or a combined hybrid set-up and DEIF has supplied a power management system that can handle all three operating modes.

DEIF's power management system collects data from the batteries' management system (BMS) and calculates how much discharge capacity is available, and the max power needed to make sure the main propulsion is not overloading the system.

When the ferries run on battery power alone, they are nearly 100 per cent CO₂-free. In total, ForSea saves 65 per cent CO₂-emissions on its battery-sailed initiative. Further, the captains of the ships have stated that the battery power has had a positive impact on their work environment as it ensures a peaceful and quiet machine room.

DEIF, Forsea Ferries

5. MONITORING AIR POLLUTION AT SEA

It is crucial that environmental regulation within the global shipping industry is enforced as lack of compliance leads to a situation of unfair competition.

With the IMO's global requirements on sulphur reduction, the shipping industry has begun the transition from operating on Heavy Fuel Oil (HFO) to a wider use of fuel types with a maximum content of 0.5 per cent sulphur. Only ships with scrubbers installed are permitted to continue the use of HFO.

However, HFO is still the far cheaper alternative and this may create a foundation for systematic violations of the regulation. Large cargo ships, which operate between continents, can achieve a significant economic advantage operating on illegal non-compliant fuel compared to ships sailing in compliance with existing regulation. Enforcing the regulation is therefore just as

important as the regulation itself to achieve the full benefits related to the environment and human health.

Utilising sensor technology for monitoring of the regulation

Technology offers a solution to the difficult task of enforcing rules on open sea. Sealed online sensors placed in the ship's exhaust stack can monitor emissions on an ongoing basis and report back to both the ship itself and relevant authorities. This creates transparency and simplifies enforcement efforts. Furthermore, it creates a set of indicators for the ship itself by providing information that may be valuable for maintaining the ship - ensuring that engines and scrubbers operate in the most optimal way.

Air pollution monitoring in Danish waters

Since 2005, the waters surrounding Denmark have been appointed as a low

sulphur emission zone (SECA-zone). Accordingly, the Danish authorities have launched a monitoring system using airborne mounted sensors (helicopters in the Danish case, but drones could also be used) to detect ships with sulphur emissions above the thresholds allowed by law. Denmark also has a sniffer in place on the Great Belt Bridge (in Danish: Storebæltsbroen), which is covering the main traffic route in and out the Baltic Sea. These efforts have proven efficient to monitor compliance with the regulation.

The sensor technology is widely accepted as a strong indication of non-compliance. However, it is not legally valid as final evidence for enforcement. The sensor technology serves as grounds for targeting a specific ship for port state control to board the ship and draw fuel oil samples as the basis for legal sanctions.



New technology for monitoring emissions

For several years, MOL Nordic Tankers, Dania Ship Management and Danfoss IXA have been cooperating on testing new innovative technology for monitoring emissions from vessels on an ongoing basis. The result is a front-runner solution to ensure global enforcement of the IMO's requirements for sulphur emissions.

To test the solution, the sensor equipment from Danfoss IXA was installed on the chemical tanker Nordic Mari that shuttles between Europe and the USA. The sensors measure the emissions of SO₂, NO_x and NH₃, while a cloud solution makes data accessible to both the ship's owners and the authorities.

The innovative technology makes it possible to document how much the ship is emitting worldwide, and send the data ashore. Consequently, the technology enables the ship's owners to prove compliance with the IMO's requirements for sulphur emissions on an ongoing basis.

Besides monitoring emissions and proving compliance, the sensors also enable Dania Ship Management to track how the engines are performing by reading out the data from the vessel.

Danfoss IXA, MOL Nordic Tankers,
Dania Ship Management



Taking to the skies to monitor maritime emissions

Since 2017, the Danish Environmental Protection Agency has used a combination of airborne surveillance and the innovative mini sniffer technology to monitor compliance with the international maritime emissions limits in Danish waters. The initiative follows a push to ensure efficient enforcement of IMO's MARPOL Annex VI while also protecting a level playing field as the shipping industry adapts to stricter emissions rules at sea. Since then, the European Maritime Safety Agency has adopted the same technology and approach, taking to the skies with long-range 'sniffer drones' flying over European waters.

The architect behind the mini sniffer technology and the emissions surveillance operations, using both manned helicopters and drones, is the Danish tech company Explicit. Combining unique mini sniffer sensors, smart software and a dedicated Emissions Lab Service, Explicit enables authorities worldwide to easily and reliably survey maritime emissions from the air.

Explicit, Danish EPA, EMSA



Photo credit: Mike Hughes, DFDS

Project to forecast the future of exhaust monitoring

For a long time, monitoring of sulphur-reducing initiatives has been the focal point of the collaboration between European ferry and logistics provider DFDS and global instrumentations supplier Green Instruments. However, a constant strive to be on the forefront of development has enabled the Danish duo to team up in new ways.

A long search for ways of monitoring particle emission in mass and numbers initiated a pilot project, which is taking place on-board ARK Dania. The project goes beyond SO_x monitoring and seeks to measure the content of particles in exhaust gas, before and in immediate extension of the wet scrubber on-board the cargo ship.

Using Green Instruments' acclaimed opacity technology, originally developed to detect oil mist and monitor smoke density, the goal is to gain factual knowledge on actual particle-diminishing effects of scrubber systems.

Being able to document particle emission after a scrubber is so far unexamined area. However, the duo anticipates particle documentation to be the future of exhaust monitoring and clean air. Consequently, the project is expected to have a long-term and global potential.

Green Instruments, DFDS

6. REDUCING AMMONIA EMISSIONS FROM AGRICULTURE

Ammonia emissions affect eco-systems directly as well as human health through secondary formation of particulate matter from ammonia in the air. According to EU figures, up to 50 per cent of particulate matter in cities may originate from ammonia. 95 per cent of ammonia emissions derive from agricultural production, and about 80 per cent of ammonia emissions in the EU originate from just 4 per cent of the farms in Europe.

Danish efforts to reduce ammonia emissions

The Danish agricultural production is very intensive with large industrial farms and substantial animal production. Since the 1980s, Danish farmers have managed to reduce ammonia emissions per animal unit produced. Despite a 60 per cent increase in pig production from 1985 to 2005, ammonia emissions from Danish agriculture decreased by about 25 per cent.

From the 1990s to mid '00s, the reduction in ammonia emissions was mainly driven by a pressure to respond to the increasing awareness about eutrophication of aquatic environments. Later, ammonia became a concern of its own, resulting in the Livestock Act from 2007 targeted to reduce ammonia. The regulation has brought along a strong technology development within the Danish agricultural sector.

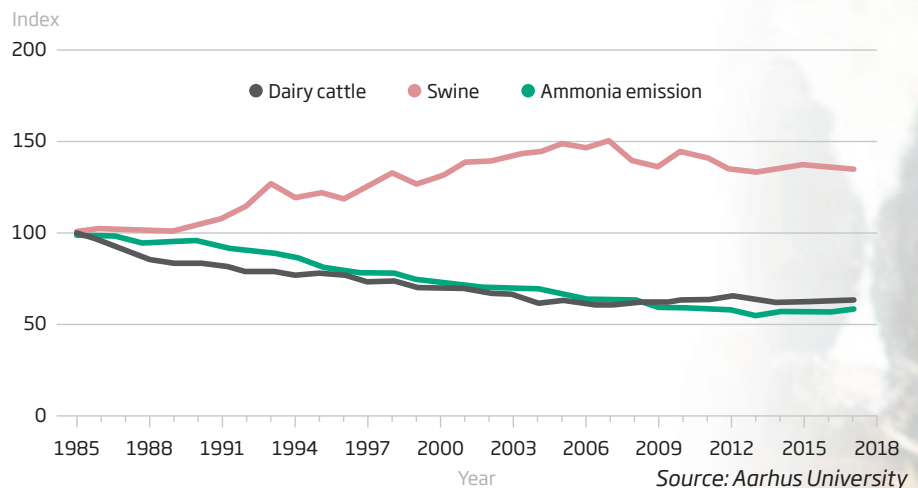
Today, all stages that leads to emissions of ammonia from the agricultural production are somehow regulated. Except for very small farms, all new stables need an environment permit to operate. To achieve this permit, the farm must take measures to reduce ammonia emissions by 30 per cent as a total for the farm, compared to a given reference system.

Already in the 1987, the first Danish Action Plan on the Aquatic Environment came, introducing many policies and measures on manure handling. In the 2000s, low-hanging fruits like a ban on broad spreading of

manure entered into force as well as a requirement to cover manure storages and restrictions to incorporate manure in the soil. It is essential to regulate the management of manure to balance the overall nitrogen uptake from crops and reduce emission to air and water.

Substantial efforts have been made by agricultural research institutes to develop the best available techniques for optimising manure management. A dedicated support scheme is available to promote the development, testing and demonstration of new solutions and techniques.

The development in swine production, cattle production and total ammonia emissions in Denmark



ACIDIFICATION OF MANURE

The emission of ammonia can be greatly reduced by lowering the pH value of manure. In stables, emissions can be reduced between 50-64 per cent, which improves the indoor climate and has a positive effect on animal growth. At the same time, the use of sulphuric acid also reduces methane emissions by up to 70 per cent.

Lowering the pH value can also be used when applying the manure on the soil (either in the storage or directly when applying the manure). This method is cheaper, but only reduces ammonia emissions by 40-50 per cent, while the methane synergy is absent.

Being a very efficient tool to reduce ammonia, and with many equally relevant positive side effects, research on acidified manure has been carried out for more than 15 years in Denmark.

Both in relation to developing and testing application techniques and in relation to safe use of sulphuric acid to lower the pH value.

Safety codes and checklists have been developed in cooperation between the acid suppliers and the agricultural sector to ensure a safe filling and handling of acid at the farm and with the mobile application. The result from intensive research on soil and crop effects from using acidified manure as a nutrient shows that in general there are no negative effects from using acidified manure as the main nutrient for crops, as long as extra limestone is added to the soil.





Ammonia reduction by slurry cooling

Cooling the slurry under the slats is not only reducing the ammonia emissions into ambient air, but also reducing smell and improving air quality for human and animals in the stable. Energy recovered from the slurry can also be used for other heating needs in the stable.

Scandinavian Farms is a large pig production company based close to Lianyungang in China. It is located in a climate with quite hot, but short summers. Scandinavian Farms builds and manages their farms completely after Danish standards. Scandinavian Farms installed

Slurry Heat Recovery system from Klimadan as the only heat source on the farm. The second objective was to reduce ammonia and the third to create a better workspace for their employees.

Return on investment was only 3.3 years from the saved fuel purchase. Ammonia emissions were reduced by approximately 30 per cent and smell reduced by 20 per cent.

Klimadan, Scandinavian Farms



Reducing ammonia emissions from livestock housing

Bregentved Estate produces 130,000 pigs/year. In order to reduce ammonia and odour emissions, investment was made in slurry acidification from JH Agro.

The JH Acidification NH4+ and JH SmellFighter solutions reduces ammonia emissions by 64 per cent and odour by 50 per cent. Methane gas emissions can be reduced by approximately 60 per cent.

The reductions are achieved by adding sulphuric acid to the slurry in a mixing tank, transforming ammonia to ammonium. The process is automatic and controlled by pH sensors. When reaching the desired

pH level, slurry is pumped back to the stable. A smaller amount of the slurry is pumped to the storage tank. The process is repeated, typically once a day. It is the only technology that reduces ammonia emissions from slurry in housing, storage, as well as when applied to the fields.

Besides the significant environmental advantages, Bregentved also benefits from better indoor climate for animals and employees, due to the much lower evaporation of ammonia. They also obtain a higher nutrient value of the slurry, when applied to the fields.

JH Agro



Ammonia reduction from application of slurry

BioCover has developed and demonstrated an efficient system to reduce ammonia emissions when applying slurry in the field. It currently treats more than 10 per cent of volume of slurry in Denmark. The system (Syren) automatically monitors and lowers the pH of the slurry by adding sulphuric acid to transform ammonia to ammonium. This result is an optimal nitrogen fertilizer for plants with minimal negative impact on the environment (air as well as water). Ammonia emissions are approximately halved compared to band spreading.

The system ensures up to 80 per cent nitrogen utilisation rate by the plants, as well as supplies sulphate for manure. The opportunity

to use band spreading instead of injection, with approximately the same ammonia reduction, allows for a larger working width, thereby ensuring a more efficient application with fewer damages to the soil. Additionally, the system also reduces odour and greenhouse gas emissions.

The system is designed with the highest safety standards in mind to ensure operation of the process without a risk to the operator and the environment.

BioCover

7. LIMITING AIR POLLUTION FROM INDUSTRY PRODUCTION

Through more than 40 years of active policies at national and EU level, industrial air pollution in Denmark is today largely controlled and mitigated.

Successful environmental regulation of Danish industries

The first actions to reduce industrial pollution were introduced with the Danish Environmental Protection Act that entered into force in 1974. The Act stated that all potentially polluting companies were to undergo an environmental audit and receive an environmental permit in order to continue their production. New companies could not start their production without such a permit. Until this point in time, problems related to industrial air pollution had mainly been solved by building higher chimneys.

These environmental audits and permits that outline terms of operation and emission limit values are at the core of Danish environmental regulation of industries,

and the effort has proven to pay off. In Denmark, conflicts between companies and neighbours are rare, and local authorities report on still fewer challenges related to industrial pollution. Today, few people in Denmark remember how it used to be like to live next door to a smelly, dusty and noisy industrial plant.

From national regulation to EU law - inspired by the Danish example

For many years, Denmark was a frontrunner in regulating industrial pollution. This has fostered a growing industry, which produces the solutions needed to comply with high environmental standards.

With the adoption of the Directive on Integrated Pollution, Prevention and Control (IPPC) in 1996, the EU lifted the environmental/industry regulation from the national level and created the framework for a common European approach and regulation. This approach and regulation

was to a large extent inspired by the Danish experiences.

European industry regulation today

The IPPC-directive introduced the principle of Best Available Techniques (BAT) that ever since has been a core principle in environmental law, stating that the polluter must comply with emission limit values equal to the utilisation of the most advanced and effective methods considered technically and economically feasible.

In 2010, the Industrial Emissions directive (the IE-directive) superseded the IPPC-directive. Today, the IE-directive forms the backbone of European industry regulation together with the Medium Combustion Plant Directive for installations from 1-50 MW, which entered into force in 2017. The two regulations cover emissions from combustion from energy production, industry and waste incineration.

INDUSTRIAL AIR FILTRATION

All over the world, industries are manoeuvring between maintaining an optimised and efficient production while curbing the environmental consequences and work hazards for employees. Although this is not an easy task, filtration of the polluted process air is the first and most important step.

Any kind of processing of materials will lead to a polluted work environment, though the challenges differ from one industrial sector to another. Where the feed industry e.g. struggles with fine dust particles; sand blasting leads to hard and abrasive dust particles; while minerals processing, building materials and metal-based industries might emit a wide range of particulates such as dust, fine metal shavings, cooling lubricants, VOCs, aerosols, etc.

The polluting components pose a threat to human health and the environment. Some of these are potentially explosive, and the damage they inflict on machines and equipment have consequences for companies' profitability. Luckily, solutions are ready at hand.

Several Danish companies deliver high quality fabric filters and electrostatic precipitators worldwide that alleviate the problems. They all draw on many years of experience, and they deliver a wide range of filtration solutions covering almost all industries and all types of air pollution.

For more information, explore the solutions from e.g. Nordic Air Filtration, Teldust, FLSmidth and Simatek.



Effectively reducing NO_x emissions in cement production

While CO₂ emissions from cement production are a global challenge, NO_x emissions are more of a local and regional challenge. NO_x-related issues, such as smog pollution, have a direct impact on public health for communities near cement facilities. Cement producers around the world are aiming to lower their NO_x emissions as local authorities are tightening health and environmental regulations.

FLSmidth focus on research and development efforts in collaboration with customers to find solutions to reduce NO_x emissions. These efforts have resulted in a new calciner (FLSmidth® InLine Low NO_x

Calciner) in which mixing of fuel and kiln gas is more effective. This improves ignition, combustion and NO_x reduction. Further, this calciner requires less ammonia injection or even makes it unnecessary. To test and evaluate the performance of the new calciner, FLSmidth collaborated with a cement producer in Southeast Europe. As a result, the plant has measured a significant decrease in NO_x emissions as low as 60 per cent below previously guaranteed levels. The technology is now being deployed globally.

FLSmidth



Waste-to-energy plant sets new environmental standards - and offers skiing with a view

Umicore has supplied a SCR DeNO_x catalyst to Copenhagen's state-of-the-art waste-to-energy plant, Amager Resource Centre (ARC).

Umicore is specialised in catalytic air emissions control and the company's catalysts are widely used in passenger cars, trucks and other vehicles as well as in more than 2,200 stationary plants worldwide.

ARC represents the first SCR DeNO_x installation in a Danish waste-to-energy plant. With the new catalyst, NO_x emissions from

ARC are significantly reduced. The catalyst is designed to reduce NO_x emissions by more than 96 per cent and dioxin/furan emissions by more than 98 per cent.

ARC sets new standards for environmental performance, energy production and waste treatment. The facility includes a roof-wide artificial ski slope open to the public. ARC is thus a multi-purpose plant, providing energy and waste treatment, as well as being a leisure facility and architectural landmark.

Umicore, B&W Vølund, Amager Ressource Centre



Catalytic industrial emission filters improve air quality

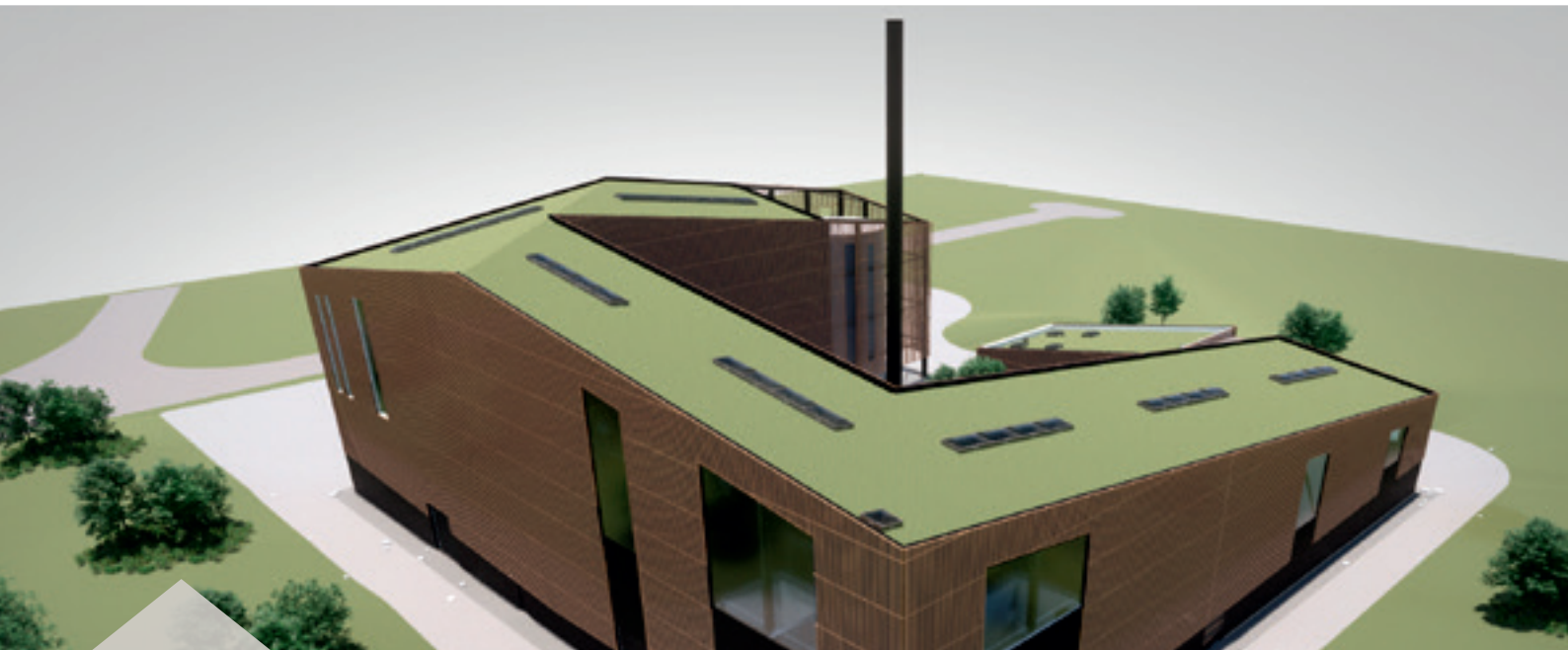
Industrial production around the globe must comply with increasingly strict emissions standards by filtering more gases and particles out of flue gases. This is challenging in high-dust production such as waste-to-energy plants, steel and cement plants, biomass-based power plants and many other industrial facilities.

At a medical waste incinerator in Thailand, 312 CataFlex™ filter bags were installed to deal with problematic dioxins. An independent test company documented that the emissions were cleaned to a level far below the most stringent regulations anywhere in the world. More

than 99 per cent of dioxins in the flue gas were destroyed.

Haldor Topsoe's CataFlex™ combine a traditional dust filter bag with an innovative inner bag with catalytic effect. The outer dust filter efficiently traps dust. This improves air quality and ensures the continued functionality of the inner filter that removes hazardous compounds such as dioxins, NO_x (main contributor to smog) and ammonia. CataFlex™ fits existing filter houses, so there is no need for expensive additional equipment.

Haldor Topsoe



Biomass gasification reduces emissions from new CHP plant

Construction has started for a new 12 MW Combined Heat and Power (CHP) plant in Sorø, Denmark. The plant will be based on Dall Energy's biomass gasification technology, ensuring reduced emissions combined with extensive fuel flexibility.

The owner, AffaldPlus, is the local utility company who receives green waste from private gardens and public spaces in the community. The green waste will fuel the new CHP plant, so garden owners may appreciate their garden waste returned as electricity and heat to their homes.

The gasification technology ensures that emissions from the plant will be significantly lower than regulative requirements. Dust emissions will be 50 per cent lower than required, Carbon-monoxide will be 95 per cent lower and NO_x will be 25 per cent lower. In addition, there is no need for flue gas filters or NO_x reducing agents, which minimises operation costs.

When the plant is in operation, it will cover heat demand for about 3,200 citizens and electricity for 2,200 citizens. Heat and power will be sustainable and CO₂ neutral as the plant will be fuelled by local, surplus biomass.

Dall Energy, AffaldPlus



State of Green

State of Green seeks to foster relations with international stakeholders interested in discussing their challenges and brings into play relevant Danish solutions that enable the green transition. As your one-point entry to more than 600 Danish businesses, governmental and research institutions, experts and civil society organisations, State of Green connects you with relevant Danish actors working to drive the global transition to a sustainable, low-carbon, resource-efficient society. State of Green is a not-for-profit, public-private partnership between the Danish Government and Denmark's four leading business associations: the Confederation of Danish Industry, Danish Energy, the Danish Agriculture & Food Council and Wind Denmark. His Royal Highness, Crown Prince Frederik of Denmark, is the patron of State of Green.

Learn more at stateofgreen.com



**Ministry of Environment
of Denmark**

The Ministry of Environment of Denmark

The Ministry of the Environment and Food is responsible for administrative and research tasks in the areas of environmental protection, farming and food production. In Denmark, the administration at state level is managed by the Ministry of Environment and Food. At the regional and local levels, much of the administrative responsibility has been delegated to the municipalities. Some of the core objectives of the Ministry of Environment and Food include supporting sustainable and innovative food production and exports, taking care of nature and the environment, as well as consumer protection and information.

Learn more at en.mfvm.dk



**Ministry of Environment
of Denmark**

Environmental
Protection Agency

Clean Air Vision

The Danish Environmental Protection Agency

The Danish Environmental Protection Agency is part of the Ministry of Environment and Food, and is the national authority on environmental and nature protection in Denmark. The agency is promoting a rich nature, clean water and air, safe chemistry, and green production. The core objective of the Danish Environmental Protection Agency is to implement nature and environmental legislation, balancing the use of resources and protection of human health and nature.

Learn more at eng.mst.dk

The Danish Clean Air Vision

The Danish clean air vision is a vision for Denmark to become world leading in developing and supplying solutions aimed at providing cleaner air. Solutions that will benefit the environment, human health, growth and employment globally. The steering committee for the Danish clean air vision consists of the Ministry of Environment and Food Denmark, the Danish Environment Technology Association, Danish Maritime, the Confederation of Danish Industry (DI), DAPO and Danish Shipping.

Learn more at luftvisionen.dk/english/

Learn more about Danish clean air solutions,
find more case examples from around the world
and connect with Danish expertise at:

www.stateofgreen.com/cleanair

State of Green facilitates relations between Danish and international stakeholders seeking to drive the global transition to a sustainable, low-carbon, resource-efficient society. We are a not-for-profit, public-private partnership founded by:



Confederation of Danish Industry



Danish Agriculture
& Food Council

wind
denmark

