# CLEANER SHIPPING

## Air pollution, climate, technical solutions and regulation


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# CONTENT



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# AIR POLLUTION AND CLIMATE

Between 80% and 90% of global cargo is transported by ships. Shipping is thereby the basis of the still increasing global trade. However, the high transport share leads to around 7 million barrels of oil being combusted in ship engines every day – corresponding to 3-4 times the oil export of Kuwait in 2020 – thereby shipping contributes significantly to global warming.

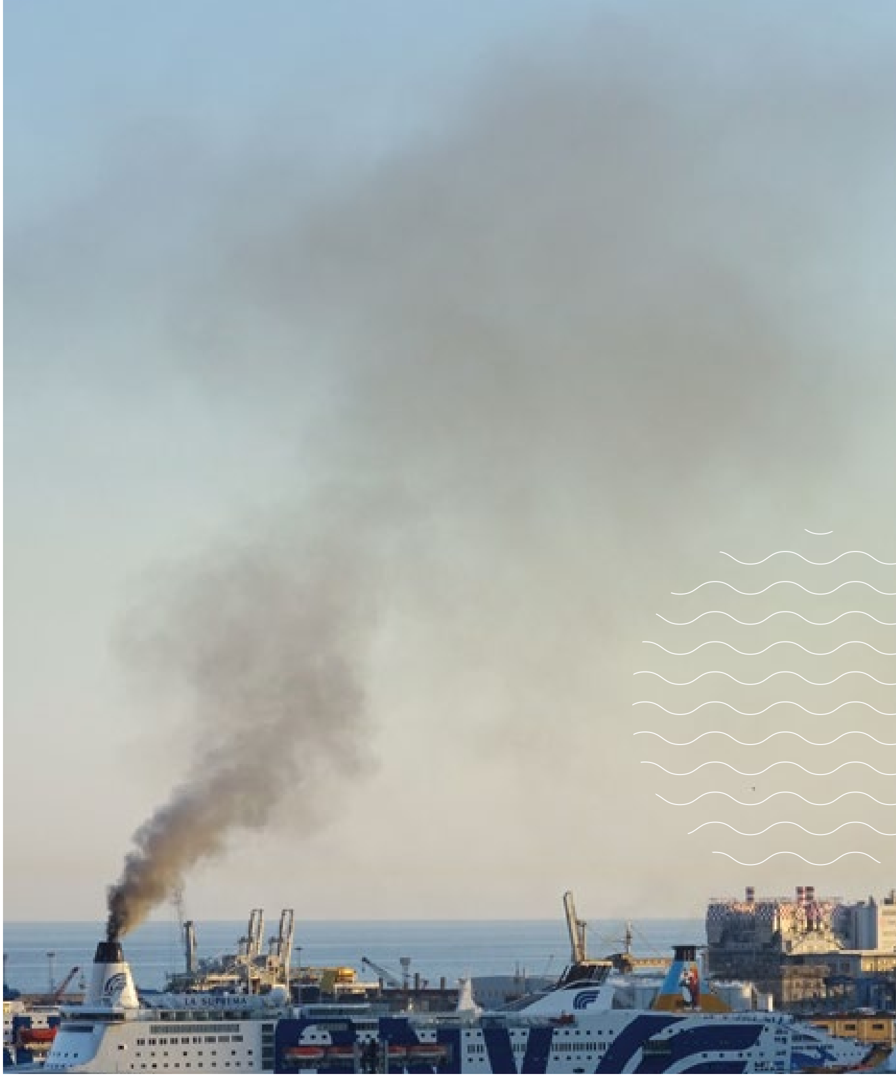
Most ships use very low sulphur fuel oil (VLSFO) that contains around 0.5% sulphur. The phrase "very low" is quite misleading as it contains 500 times more sulphur than standard road diesel in EU (0.001% sulphur). Even in sulphur emission control areas (SECAs) in densely populated regions that has the strictest regulation of shipping, ship fuels contain and emit 100 times more sulphur per litre than road diesel.

Complete combustion in ship engines oxidizes all carbon and sulphur in the fuel into $CO_2$ and sulphur oxides, the latter mainly as sulphur dioxide ($SO_2$). At the same time, free nitrogen ($N_2$) in the air is oxidized to nitrogen oxides ($NO_X$) inside the engine. However, complete combustion does not occur. Hence, the flue gas also contains polycyclic aromatic hydrocarbons, volatile organic compounds, particulate matter, black carbon, etc. Emissions of $SO_2$ increase with the sulphur content in the fuel whereas a high content of aromatics in the fuel seems to increase the black carbon formation.

The most important pollutants in relation to negative health effects are $SO_2$, $NO_X$ and fine particles ($PM_{2.5}$) as these pollutants have a long lifetime and thereby significantly increase air pollution and exposure on land. However, ultrafine particles ($PM_{0.1}$) and black carbon from ships in ports can cause health problems for port workers and significant local air pollution. This is especially the case when cruise ships use their engines for energy generation during long port calls in city centres. $CO_2$ and black carbon (and methane from methane fuelled ships) are the most important climate pollutants.

The main difference between shipping and road transport is that road fuel is much cleaner and that vehicles have efficient flue gas cleaning systems in most of the world. No comparable regulations apply to shipping. However, in the recent years the International Maritime Organization (IMO) has adopted regulation that will reduce emissions.

**Most fuel oils used for ships are waste products from refineries blended with lighter oils to achieve 0.5% sulphur. The fuel oil is extremely viscous and has a high content of sulphur. The fuel oil is heated and combusted under high pressure in ship engines. Today, most fuel oils are combusted without any efficient flue gas cleaning.**



The Danish Centre for Environment and Energy (DCE) at Aarhus University has estimated that air pollution from shipping causes about 50,000 premature deaths in Europe every year. However, the new global sulphur cap from 2020 has reduced the mortality and morbidity related to air pollution from shipping by around 20%, which clearly illustrates that regulation can be an efficient solution. However, air pollution from shipping still causes around 40,000 premature deaths in Europe every year and related health costs above USD 65 billion. On top of this comes damage to the climate, nature, crops, buildings, etc. Emissions of $NO_X$, $PM_{2.5}$, $CO_2$, black carbon and other key pollutants from shipping - and the related adverse effects - are expected to increase with the growth in shipping. Further regulation of pollution from shipping and new zero carbon fuels are urgently needed.

As an example, the seas around Denmark have more than 60,000 ship passages of large commercial ships every year. Large container ships only sail 5-10 meters per litre of fuel. Consequently, huge amounts of fuel are combusted in the seas around Denmark resulting in serious air pollution. DCE estimated in 2019 that air pollution from international shipping annually caused around 650 premature deaths in Denmark and health costs added up to about USD 1.7 billion. The 2020 global sulphur cap did not reduce these adverse effects significantly since Denmark is geographically inside a SECA that already has stricter regulation. If no new actions are taken to further reduce air pollution from shipping, air pollution from shipping in the seas around Denmark will cause almost the same amount of negative health effects in Denmark in 2030 as all domestic pollution sources that are much stricter regulated.

This publication focuses on air pollution with $CO_2$, $SO_2$, $NO_X$ and particles from shipping, technical solutions as well as existing and further regulation and enforcement. The purpose is to inform and inspire decision makers and other stakeholders to implement ambitious regulation to reduce air pollution from shipping to the benefit of the climate, public health and nature. Finally, this publication can be used for teaching.

Shipping causes other serious environmental problems e.g. pollution with invasive species, underwater noise, oil pollution, etc. These are widely described elsewhere and therefore not included.

# ADVERSE EFFECTS

Shipping is not regulated as strictly as most other sectors, when it comes to air pollution. The main reasons are that shipping is an international business and that ships often sail in international seas, thereby only being regulated by international law. The easy reflagging of ships allows to freely choose under which flag ships sail. If one nation regulates shipping through national legislation, its ships will just reflag to nations with less strict environmental legislation.

International regulation of shipping is decided by the IMO. However, as flag states have very different perceptions of environmental challenges and global warming, IMO decisions have traditionally been slow and unambitious when trying to regulate these issues. However, for the last couple of years there has been softening on several accounts and decisions have been taken to further reduce emissions of $CO_2$ and health hazardous air pollution from shipping. At the same time, further $CO_2$ reductions from shipping are discussed intensely, not least due to pressure from the EU. From an environmental perspective, however, the adopted regulation (see page 28) is not ambitious, but should be seen as the best possible compromise between many conflicting interests in the IMO.

Table 1 shows important types of air pollutants from shipping, adverse effects connected to them as well as costs of mortality and morbidity in Europe due to emissions in and outside the Northern European SECA. It should be emphasised that as the value of lost human lives is being significantly revalued these years, the values used in the table are conservative and probably significantly underestimate the true costs.

**Table 1:** Damage and health costs in Europe due to air pollution from shipping (2021 prices)

| | $CO_2$ | $SO_2$ | $NO_X$ | Fine particles |
|---|---|---|---|---|
| Direct adverse health effects | | X | X | X |
| Indirect adverse health effects [1] | | X | X | |
| Global warming | X | | | X [2] |
| Acidification of the oceans | X | | | |
| Acid rain on land | | X | X | |
| Eutrophication | | | X | |
| Adverse health effects outside the SECA (USD/kg) [3] | | 16.5 | 13.5 | 26.5 |
| Adverse health effects outside the SECA (USD/tonne fuel oil) [3), 4] | | 165 | 945 | 185 |
| Adverse health effects in the SECA (USD/kg) [3] | | 18 | 42 | 102.5 |
| Adverse health effects in the SECA (USD/tonne fuel oil) [3), 4] | | 36 | 2,940 | 102.5 |

1) When transformed into adverse health effects secondary fine particles in the atmosphere.
2) Black carbon contributes to global warming and accelerates melting of the icecaps.
3) As the value of lost human lives is being reconsidered and tends to be increased considerably compared to the values in the table, and since many negative health effects caused by air pollution are not yet included, the values stated are conservative.
4) By burning one tonne of VLSFO outside SECA about 10kg of $SO_2$, 70kg of $NO_X$ and 7kg of fine particles are emitted, while burning one tonne of distillate fuel (0.1% S) in SECA emits about 2kg of $SO_2$, 70kg of $NO_X$ and 1kg of fine particles.

Reference: Calculated from data obtained from DCE at Aarhus University with regards to the Northern European SECA.

From table 1 is seen that the average health costs per kilogram of emitted pollutants are higher inside SECA than outside SECA as emissions inside SECA on average are more concentrated in the vicinity of densely populated areas. Total health costs from the three key air pollutants emitted when ships burn one tonne of fuel oil are around USD 1,300 outside the SECA and around USD 3,000 inside the SECA even though distillate fuel used inside the SECA contains five times less sulphur. In comparison, the price of VLSFO was about USD 560 per tonne, while distillate fuel for use in SECAs costs approximately USD 640 per tonne (September 2021). If the costs of negative health effects caused by air pollution was shifted to ship-owners in terms of increased fuel prices, the fuel price would increase more than three times outside SECAs and more than five times inside SECAs. This would immediately make ship-owners switch to distillate fuel on a global level and install efficient flue gas cleaning. At the same time, it would create a significant pressure for energy efficiency and zero emission fuels (shore power, electric ferries, hydrogen, ammonia, etc.). However, as long as society and the public keep paying the costs of the resulting negative health effects nothing will happen. Lack of internalization of externalities thus causes a traditional market failure where shipping pollutes much more than the socio-economic optimal level seen from an economic point of view.

In addition to the health costs displayed in table 1, costs due to climate change from $CO_2$, black carbon, etc. as well as costs due to adverse effects from air pollution on nature, crops and buildings should be added. However, it is difficult to put a precise value on nature damage. Furthermore, it is not possible to make equivalent cost calculations of impacts and damages (externalities) related to $CO_2$ as long-term impacts on society and public health from global warming are highly unpredictable. Hence, in addition to predictable damage to food production, health, biodiversity, etc., more areas are at risk of becoming uninhabitable due to drought, flooding and overheating. Furthermore, costs associated with integration of many millions of climate refugees in Europe and, consequently, an enhanced risk of wars and national isolation/protectionism are impossible to estimate.

Nevertheless, a pricing of $CO_2$ emissions is often seen. Such prices are typically prices of $CO_2$ emission allowances or the cost of reducing one tonne of $CO_2$. This cost is typically USD 50-70 per tonne $CO_2$. However, this is not the costs of damage caused by emitted $CO_2$ but the costs of avoiding $CO_2$ emissions. The attempts of estimating the actual costs of the negative effects of global warming caused by $CO_2$ emissions arrive – with great uncertainty – at much higher quantities. Regardless of the lack of valuation of $CO_2$ impacts, there is an urgent need to reduce both the harmful air pollution and the climate impact of shipping.

Figure 1 shows an estimate of $CO_2$ emissions from large ships in seas around Denmark in 2011 on the basis of ship types. In outline, the relative distribution of $SO_2$, $NO_X$ and particles follows the distribution of $CO_2$ emissions by ship type as all four pollutants are caused by burning fuel oil. Cargo transport is responsible for most emissions.

**Figure 1:** Emissions from shipping in the seas around Denmark in 2011

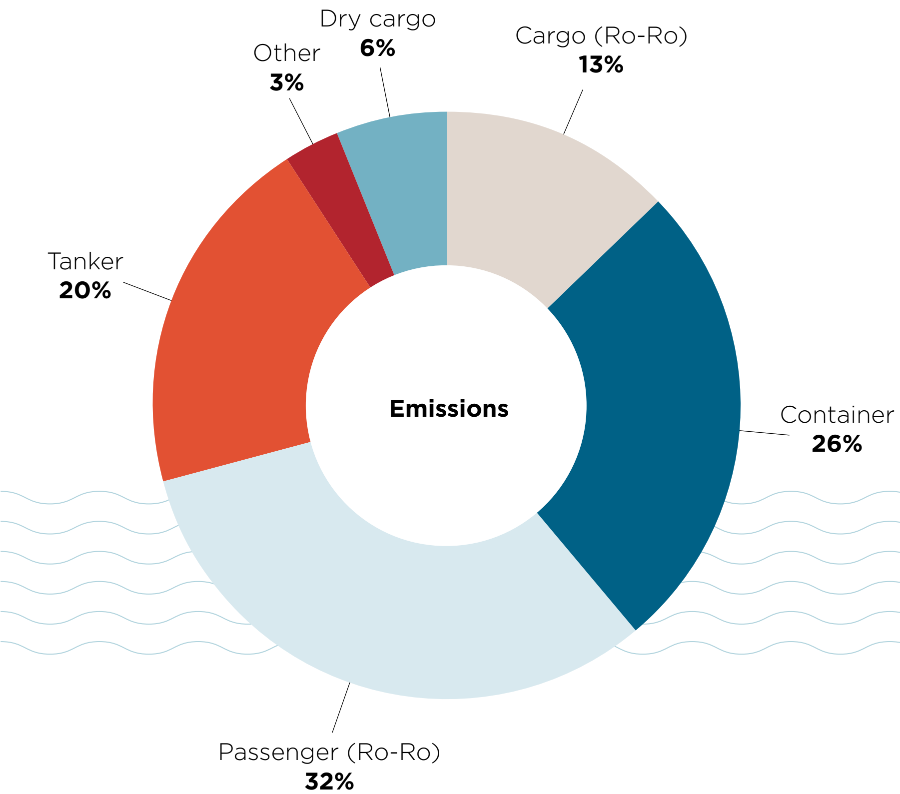


Figure 2 shows emissions from shipping in Danish seas. The main shipping routes are very visible.

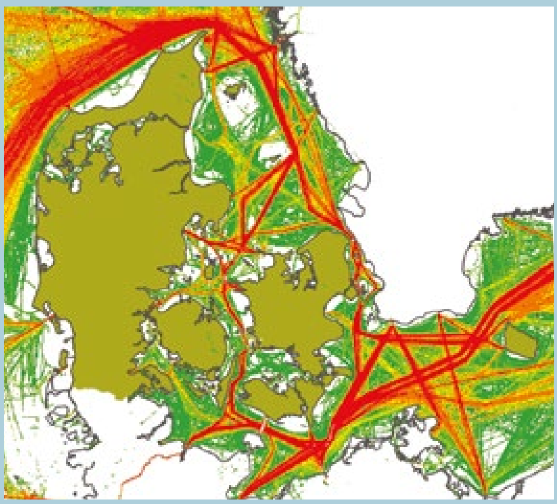


**Figure 2:** Geographic distribution of emissions from shipping in Danish seas

High emissions

Average emissions

No emissions

**Carbon dioxide ($CO_2$)**

Globally, shipping emits around 1,000 million tonnes of $CO_2$ every year, which is almost 3% of the anthropogenic $CO_2$ emissions. About three quarters originate from cargo ships, while one quarter is emitted from passenger ships, large fishing vessels, etc. If shipping was a nation, it would be the sixth largest polluter in the world. The $CO_2$ emission of shipping will grow significantly in parallel to the expected growth in the sector unless further actions are taken. The IMO has several goals and existing regulations to reduce $CO_2$ emissions from shipping (see page 33).

In addition to global warming, the increasing $CO_2$ concentration in the atmosphere contributes to acidification of the oceans as the concentration of carbonic acid increases when $CO_2$ dissolves in the seas. Acidification of oceans together with increasing sea temperature caused by global warming will have fatal consequences for several of the rare and important marine ecosystems e.g. the unique coral reefs.

**Sulphur dioxide ($SO_2$)**

Emissions of $SO_2$ from shipping in seas around Denmark make up around 60% of emissions from domestic sources. If Denmark had not been geographically placed inside a SECA, emissions from shipping would have been 5 times higher i.e. approximately 3 times higher than all domestic sources. The sulphur content in fuel oil is regulated by the IMO both inside and outside SECAs (see page 28).
A substantial part of $SO_2$ in the flue gas is transformed into sulphate in the atmosphere, e.g. by the formation of sulphuric acid creating acid rain that contributes to forest decline, damage on buildings, etc. Furthermore, $SO_2$ is a direct health hazardous gas. However, $SO_2$ from shipping mainly contributes to negative health effects through formation of toxic secondary fine particles through atmospheric reactions between $SO_2$ and other pollutants (e.g. ammonia).

**Nitrogen oxides ($NO_X$)**

In the seas around Denmark, emissions of $NO_X$ from shipping are around double of the emissions coming from domestic sources. Emissions of $NO_X$ are regulated by the IMO (see page 31). $NO_X$ emissions will, however, only decrease significantly in the long run inside $NO_X$ Emission Control Areas (NECAs) as the current regulation is weak.

$NO_X$ emissions consist mainly of nitrogen monoxide (NO) and, to a lesser extent, nitrogen dioxide ($NO_2$). In the atmosphere, $NO_X$ can be transformed into nitric acid creating acid rain that, as sulphate, contributes to forest decline, damage on buildings, etc. Furthermore, $NO_X$ enhances the formation of health damaging smog. In addition, nitrogen dioxide is a harmful gas. However, $NO_X$ from shipping mainly contributes to negative health effects through formation of toxic secondary fine particles through atmospheric reactions between $NO_X$ and other pollutants (e.g. ammonia). Additionally, $NO_X$ deposition in the sea contributes to eutrophication leading to oxygen depletion in some marine areas, and $NO_X$ deposition in nutrient-intolerant ecosystems destroys these unique ecosystems, which are habitats for a wide range of protected flora and fauna species.

**Particles**

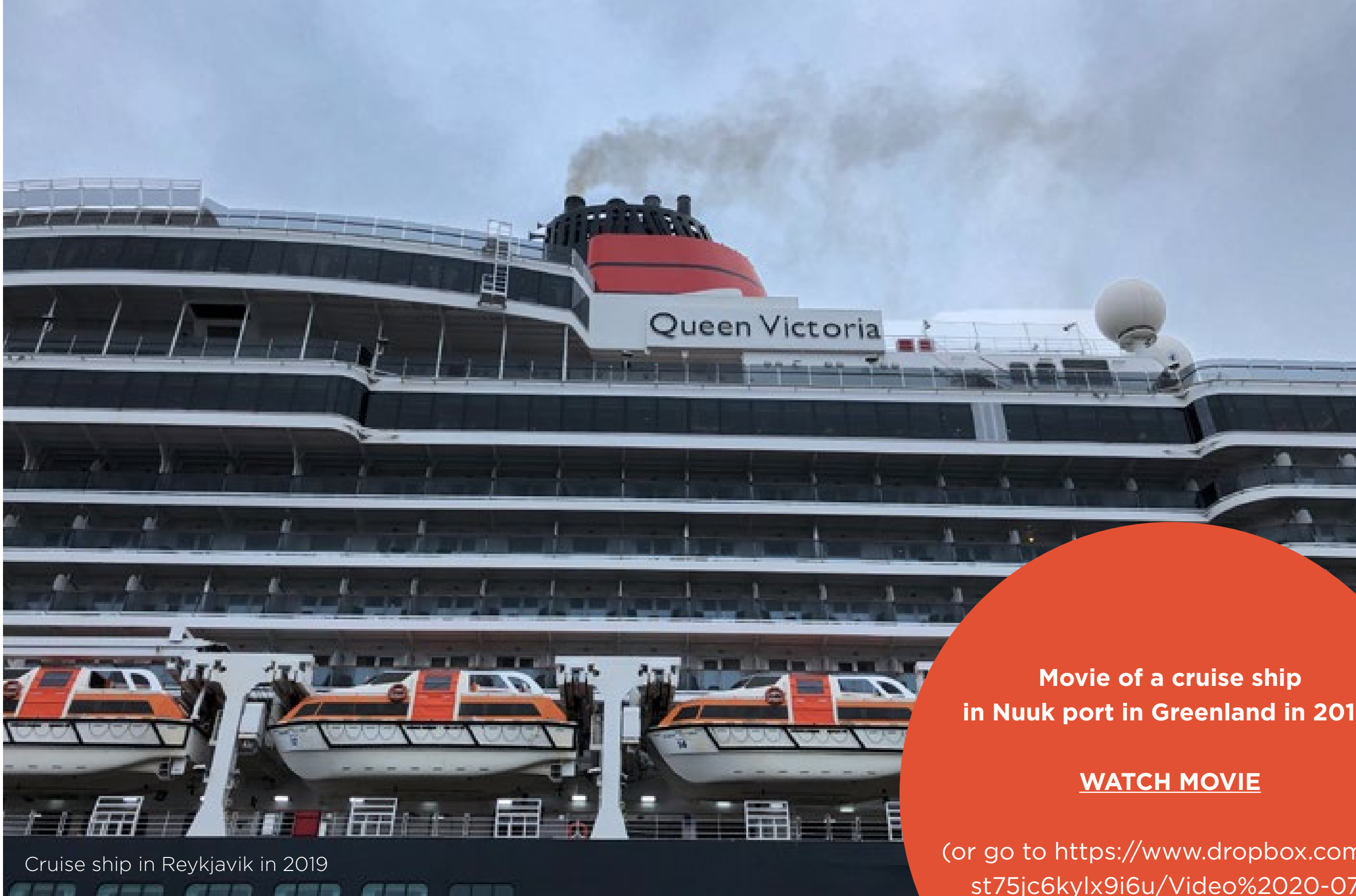
In the seas around Denmark, emissions of fine particles ($PM_{2.5}$) from shipping correspond to approximately 15% of emissions from domestic sources. Emissions are not directly regulated by the IMO.

Particles in air are classified by size and composition. Fine particles ($PM_{2.5}$) are particles with a diameter less than 2.5 micrometers. They are measured as particle mass per volume air, typically as micrograms per cubic meter. They are long lived and therefore cause long-range transboundary air pollution. Ultrafine particles ($PM_{0.1}$) are particles with a diameter less than 0.1 micrometer (100 nanometers). They are measured as number of particles per volume air, typically as number per cubic centimeter. They are short lived and mainly cause local air pollution before they aggregate to fine particles and cause regional air pollution. A part of the particles consists of soot referred to as black carbon (or elementary carbon depending on the measuring method). Black carbon particles are seen as the most toxic particles and are one of the most important reasons for global – and especially Arctic – warming. Neither fine particles, ultrafine particles nor black carbon are regulated by the IMO to date (September 2021).

Both fine and ultrafine particles emitted directly from ship engines as primary particles often contain high levels of toxic soot. In addition, secondary fine particles are formed through chemical reactions in the atmosphere between $SO_2$ and $NO_x$ from shipping and other gasses such as ammonia (see above).

Particles increase the risk of cancer, cardiovascular diseases, blood clots, respiratory diseases, etc. thereby increasing the risk of premature death. As fine particles spread over long distances, they contribute to direct negative health effects when emitted both at sea and in ports. By contrast, ultrafine particles mainly cause direct negative health effects when emitted in port areas and only indirect negative health effects when emitted at sea and aggregated to fine particles.

Black carbon contributes significantly to global warming by heating the atmosphere and when deposited on glaciers in mountain or Arctic areas. The estimated Global Warming Potential of black carbon over a 100-year period (GWP 100) is 900 and over a 20-year period is 3,200. When deposited on ice, black carbon reduces the albedo effect (reflection of sun light) thereby increasing the absorption of heat leading to accelerated melting of ice and thereby reinforcing global warming. Recent studies show that black carbon is the second-most important cause of Arctic warming and melting of Arctic ice after $CO_2$. In the Arctic, climate change happens 2-3 times faster than any other place and the size of the sea ice is currently record low. The closer to the icecap black carbon is emitted, the more black carbon will be deposited on the icecap. In the Arctic, shipping is the most important regional source of black carbon emissions. However, shipping only contributes a limited extent to the deposition of black carbon on the icecap as the main contribution is long-range transboundary pollution coming from wood stoves, diesel traffic, power plants, etc. in Canada, Europe, Russia, etc. Nevertheless, since a high share of black carbon from Arctic shipping deposits on ice, it is cost-effective to reduce black carbon from Arctic shipping. Arctic shipping is increasing and thereby black carbon emissions are increasing leading to further deposition and melting of the icecap, which further increases the possibility for a shortcut through the Arctic, again increasing pollution further. Furthermore, Arctic shipping increases the risk of heavy fuel oil spills and illegal oil discharges in some of the most vulnerable and pristine ecosystems where oil pollution is long-lived and an efficient clean-up is impossible.



Cruise ship in Reykjavik in 2019

**Movie of a cruise ship in Nuuk port in Greenland in 2018:**

**WATCH MOVIE**

(or go to https://www.dropbox.com/s/st75jc6kylx9i6u/Video%2020-07-2018%2021.12.51.mov?dl=0)

**Pollution in port cities**

Ultrafine particles from cruise ships and ferries at berth are a specific problem in relation to occupational health for port workers and for the population in nearby residential and public areas. These ships often use ports close to large cities and emit very high amounts of toxic air pollution. For ferries, it is in particular frequent arrivals and departures (and overnight stays' idle running at berth) that contribute to the pollution, whereas cruise ships, large energy consuming hotels, often have long stays at berth while producing energy for heat and electricity for demanding passenger facilities. The ships burn high amounts of fuel oil containing about 100 times more sulphur than road diesel and air pollution is emitted without air pollution control. Furthermore, cruise tourism is dramatically growing these years, and, at the same time, many ports are progressively expanding with new residential and public areas.

A large cruise ship with 4,000 passengers at berth emits as much $NO_X$ and fine particles per second as 3,500-5,000 cars thereby contributing significantly to local air pollution. Port areas are often in close vicinity to residential areas where families and their children are exposed to these emissions. Emissions are more concentrated in the summer period where residents also ventilate more (open windows) further increasing exposure. As a result, people living in large port cities can be significantly exposed to high concentrations of toxic air pollution.

Table 2 shows emissions of air pollution from the 350 cruise ships that are at berth in Copenhagen every year. The total negative health effects are around USD 13 million per year. On top of being exposed to the pollution, the population also pays these health costs. In addition, costs related to damage caused by climate change, damage on nature, buildings, etc. should be added to the total cost.

**Table 2:**
Air pollution from 350 cruise ships at berth in Copenhagen every year

| | $SO_2$ | $NO_X$ | Fine particles |
|---|---|---|---|
| **Emissions** (kg/year) | 10,765 | 291,000 | 6,400 |
| **Health costs** (USD/kg) | 18 | 42 | 102.5 |
| **Health costs** (million USD) | 0.2 | 12.2 | 0.6 |



**Figure 3:** Measurements of ultrafine particles in Reykjavik cruise port in 2019.

Figure 3, figure 4 and table 3 show results from air quality measurements of ultrafine particles from cruise ships in the port of Reykjavik in 2019. Onshore wind will drive this pollution directly to the city centre.

The figures and the table show that the air pollution with ultrafine particles is about 300 times higher 100m down-wind cruise ships compared to the concentration in the rather clean air up-wind the cruise ships even when wind speed is high causing significant dilution. Under conditions with a less powerful onshore wind, the pollution plume would be much more concentrated and reach the ground several kilometres away in the city centre whereby many people will be exposed to high concentrations of toxic air pollution.

The pollution levels 100m downwind the cruise ships with significant dilution reach around 150,000 particles per cm³. In comparison, ultrafine particles measured directly in the exhaust pipe of a newer diesel car with particulate filter (requirement since 2009) is below 2,000 particles per cm³; along large streets in the centre of Berlin during rush hour the pollution is around 7.5 times less (around 20,000 particles per cm³), and this pollution will not be measurable 100m down-wind the street due to dilution at high wind speeds. Hence, the pollution plume from cruise ships is extremely intense compared to other pollution sources.

**Figure 4:** Ultrafine particles in Reykjavik cruise port in 2019

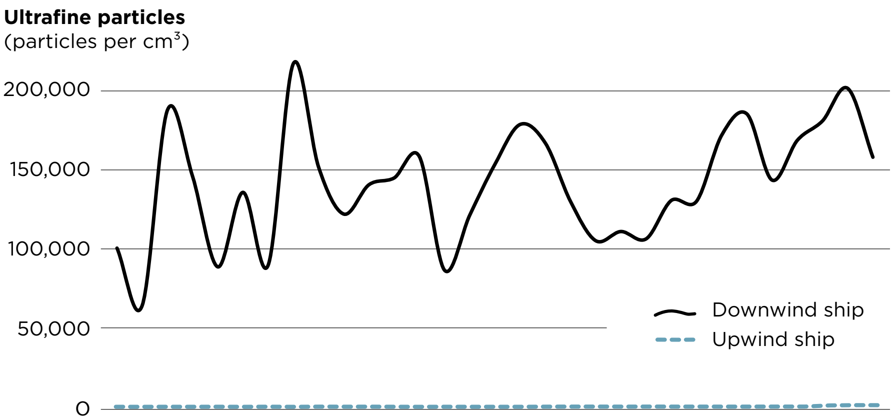



**Table 3:** Ultrafine particles in Reykjavik cruise port in 2019

| | Date | Cruise ships in Reykjavik | Wind (from: speed) | Particle pollution (average particles per cm³) |
|---|---|---|---|---|
| Upwind | 10/8 | *Nieuw Statendam* and *The World* | N: 5-8 m/s | 350 |
| Downwind | | | | 106,700 |
| Upwind | 11/8 | *Nieuw Statendam* and *Boudicca* | N: 7-9 m/s | 450 |
| Downwind | | | | 145,050 |

**Table 4:** Emissions from shipping compared to Danish land-based sources in 2021.

| Emissions in tonnes | $SO_2$ | $NO_x$ | Fine particles |
|---|---|---|---|
| Shipping in the Northern Hemisphere | 300,000 | 3,355,000 | 240,000 |
| Shipping in the North Sea and the Baltic Sea | 29,000 | 955,000 | 13,000 |
| Shipping in the seas around Denmark | 6,000 | 173,000 | 2,500 |
| Danish land-based air pollution sources | 10,000 | 90,000 | 15,000 |

Reference: Calculated from data obtained from DCE at Aarhus University.

**Table 5:** Adverse health effects due to air pollution from shipping in 2021

| | Northern Hemisphere | | North Sea and Baltic Sea | |
|---|---|---|---|---|
| | Denmark | Europe | Denmark | Europe |
| YOLL [1] | 6,825 | 555,000 | 5,300 | 210,000 |
| Days with restricted activity | 580,000 | 45,500,000 | 490,000 | 17,600,000 |

[1] YOLL: Years of lost living (about 10.5 years of lost living is the same as one premature death).
Reference: Calculated from data obtained from DCE at Aarhus University.

**Pollution at sea**
Table 4 shows estimated emissions of $SO_2$, $NO_X$ and fine particles from international shipping in the Northern Hemisphere and shipping in the North Sea and the Baltic Sea compared to emissions from shipping in the seas around Denmark and from all Danish domestic based pollution sources. It should be underlined that there are large uncertainties related to the particle emission in the Northern Hemisphere after introducing the 2020 sulphur cap.

Table 4 shows that the $SO_2$ and particle emissions from shipping in the Northern Hemisphere sum up to 10 and 20 times as high as the ship emissions in the North Sea and the Baltic Sea, respectively, while the $NO_X$ pollution is only about 3.5 times as high. These relative differences are due to lower sulphur content in the fuel used in the SECA covering the North Sea and Baltic Sea, which reduces particle emissions as well but has no significant effect on $NO_X$ emission. Furthermore, it is seen that $NO_X$ pollution from shipping in the seas around Denmark is around double the emission from all domestic pollution sources.

Table 5 shows negative health effects caused by the emissions of $SO_2$, $NO_X$ and fine particles from shipping in the Northern Hemisphere and in the Northern Sea and Baltic Sea for Denmark and Europe. The negative health effect is estimated based on knowledge of where the pollution is emitted (AIS and ship data), dispersion and transformation of the pollution in the atmosphere, the dose-response correlation between air pollution and negative health effects as well as knowledge about the size of population exposed to the pollution. It should be underlined that there are significant uncertainties related to the calculations. Hence, the values should be seen as best estimate.

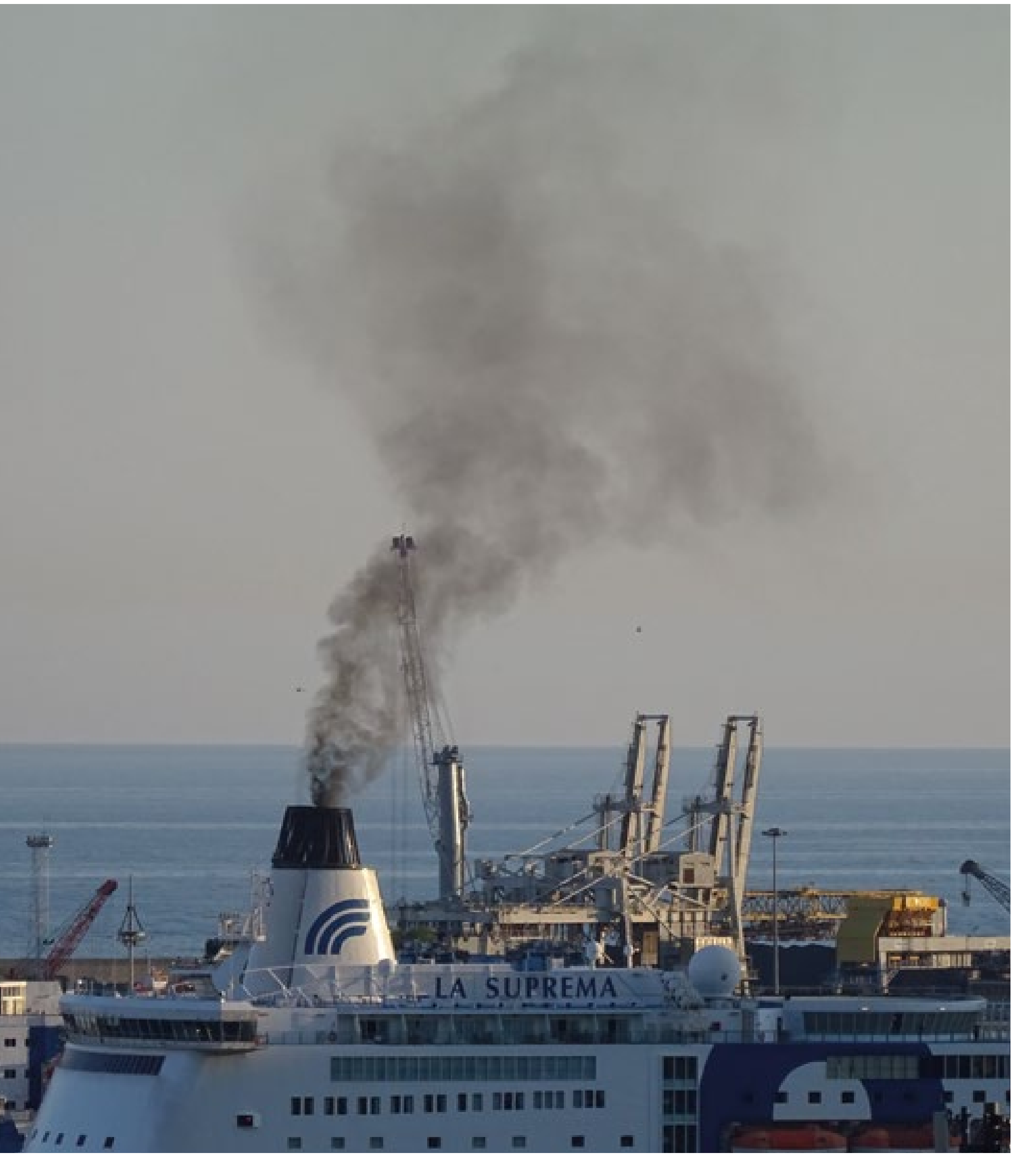
From table 5 it is seen that the pollution from shipping in the Northern Hemisphere causes around 2.5 times as many premature deaths in Europe compared to the pollution in the North Sea and Baltic Sea.
In Denmark, on the contrary, most of the negative health effects are caused by pollution from shipping in the North Sea and Baltic Sea. This illustrates that, despite that SECA covers all seas around Denmark, shipping in these seas continues to cause huge negative health effects due to the weak $NO_X$ regulation and since emissions are concentrated close to land (c.f. figure 2).

**Table 6:** Health costs in Europe due to air pollution from shipping in 2021.

| | Health costs in Europe (billion USD) | | | |
|---|---|---|---|---|
| | $SO_2$ | $NO_x$ | Fine particles | Total |
| Shipping in the Northern Hemisphere | 5 | 45 | 6.5 | **56.5** |
| Shipping in the North Sea and the Baltic Sea | 0.5 | 40 | 1 | **41.5** |

Reference: Calculated from data obtained from DCE at Aarhus University.

Table 6 shows the socio-economic costs due to negative health effects from air pollution from shipping estimated for different key pollutants in Europe. It is seen that negative health effects due to air pollution from shipping in the Northern Hemisphere sums up to a yearly cost around USD 56.5 billion in Europe (around 10% of the total costs related to air pollution in Europe). Likewise, it is seen that $NO_X$ causes the largest total cost – particularly in the North Sea and Baltic Sea, where $NO_X$ accounts for almost all costs related to air pollution from shipping due to SECA limiting the sulphur and particle emissions.




In Denmark, the annual negative health effects due to air pollution from shipping in the Northern Hemisphere amount to around USD 1.7 billion (around 12% of the total costs related to air pollution in Denmark), of which around 80% is caused by shipping in the North Sea and Baltic Sea. In comparison, air pollution from all domestic pollution sources in Denmark sums up to around USD 3.4 billion per year. Air pollution from shipping thereby causes negative health effects and costs in Denmark corresponding to around half of all Danish domestic pollution sources. It should be noted that adverse health effects from ultrafine particles and black carbon is not directly included in these estimates.

**Climate and public health**

If land-based transport per tonne of cargo is compared to shipping, cargo transported by train emits 2-7 times more $CO_2$ while trucks emit 5-15 times more $CO_2$. Hence, in terms of global warming, shipping could be seen as a more favourable mode of transport. However, as shipping emits much more $SO_2$, $NO_X$ and particles than land-based transport modes, shipping causes serious negative health effects and nature damages. From a health perspective, shipping is therefore not an optimal mode of transport. However, shipping has several other advantages compared to land-based transportation such as less noise exposure of the population, fewer traffic accidents and cheap infrastructure. On the other hand, a large share of transportation would not occur at all if not for extremely low shipping prices. Therefore, it does not always make sense to only compare emissions of alternative modes of transport. No transport is, all things being equal, preferable from a climate change and environmental perspective. It is recognized, however, that international shipping can be seen as a precondition for development and a more even distribution of resources.

All new trucks in the modern part of the world use low-sulphur fuel, which contains about 100 times less sulphur than the ship fuel used inside SECAs and 500 times less sulphur than the ship fuel used outside SECAs. Furthermore, modern trucks have efficient $NO_X$ removal and particle filters. Hence, weak regulation and tax-free ship fuels give shipping competitive advantages at the expenses of other transport modes and public health.

The solution is, however, not to stop global trade. Attempting to limit transportation is a possibility, but it seems more reasonable to reduce climate pollutants and toxic air pollution from shipping by converting shipping into a green mode of transport. However, this requires focused efforts technically and, especially, politically. Several technical solutions are developed to minimize climate damage and air pollution from shipping. Most technical solutions have very low marginal reduction costs since astonishingly little has been done to reduce air pollution from shipping. Hence, the relatively high level of air pollution from shipping is mainly a result of lack of political action.

# TECHNICAL SOLUTIONS

Several technical solutions have been developed to reduce emissions of $CO_2$, $SO_2$, $NO_X$ and particles from shipping. As shown below, a combination of solutions can significantly reduce $CO_2$ emissions and minimize $SO_2$, $NO_X$ and particle emissions in the short term. In the long term, new larger ships and cleaner fuels can make shipping the *green* transport of the future.

**There are four types of technical solutions:**

**1. Reduced fuel consumption**

**2. Use of cleaner fuel**

**3. Reduced engine pollution**

**4. Flue gas cleaning**

Reduction costs for implementing technical solutions are often many times lower than the costs of negative health effects caused by air pollution, that is costs of no actions. Thus, many solutions are beneficial from a society point of view as society saves (earns) millions of dollars every time one million is invested in cleaner fuel or flue gas cleaning.

As an example, sulphur regulations inside SECAs have a reduction cost of USD 8.5 per kg of $SO_2$ due to higher fuel prices (summer 2021), while the avoided negative health effect costs are around USD 18 per kg of $SO_2$ pollution avoided, i.e. the profit rate is above 100%. Additionally, a significant particle reduction is automatically achieved. For the 2020 regulation outside SECAs, a reduction cost of USD 2.5 per kilogram of $SO_2$ is seen (fuel prices summer 2021), while the avoided negative health effects are USD 16.5 per kilogram i.e. a profit rate above 500%. For $NO_X$, the reduction cost lies between USD 0.2-2.50 (depending on ship type and flue gas cleaning technology) per kilogram, whereas the avoided negative health effects amount to USD 13.5-42 per kilogram i.e. making $NO_X$ removal an extremely profitable investment.

However, without regulation ship-owners have no incentives to pollute less, as costs due to negative health and climate change effects along with nature damage are paid by society and are thus invisible to ship-owners. Therefore, pollution from shipping must be regulated to harvest the huge benefits of reduced pollution.

There are four types of technical solutions:

1. Reduced fuel consumption
2. Use of cleaner fuel
3. Reduced engine pollution
4. Flue gas cleaning

Some of the solutions can be combined, but reductions do not necessarily sum up. Furthermore, not all solutions can be used on all ships. The largest reductions can be achieved on new ships.

**Reduced fuel consumption**
Fuel consumption can be reduced through several operational actions; including better use of capacity and logistics (route optimisation) combined with maintenance of the hull, propeller(s) and engines along with optimal sailing in respect to the weather and the physical ship characteristics. Furthermore, scheduled arrival may avoid waiting (on idle) for permission to enter ports. Finally, the speed of a ship has a significant influence on fuel consumption. By reducing speed and/or engine power, substantial fuel savings can be achieved. Reduced speed will, however, require more ships (more capacity), if transport capacity must be upheld since the duration of transport between ports increases. Nevertheless, fuel savings of 20-25% net are often achieved with reduced speed (slow steaming). Reduced speed increases flexibility as well, since the speed can be increased when unforeseen delays occur. This increases the probability of scheduled arrival. In the long term, larger ships with improved engines and an energy-efficient design will further reduce fuel consumption, however, not enough to compensate for an increase in fuel consumption due to increased shipping.

In an ideal world, the potentials of operational measures are exploited to an extent equivalent to the economic benefits of the associated fuel savings. If the price of fuel increases, savings increase and the potentials of operational measures will be applied to a greater extent. Hence, in times with high fuel prices, slow steaming has been implemented. However, profitable operational measures are not fully utilised due to various market disturbances.

By minimizing water, wave and wind resistance of the hull through better ship design, new types of coating and air lubrication (release of air bubbles under the hull), further fuel reductions can be achieved. This can be combined with optimization of the engines, such as waste heat recovery (WHR) and optimal design of the propeller/rudder, relative to the specific ship.

**The EU Interreg program for the North Sea Region has funded the WASP-project Wind Assisted Ship Propulsion to identify the potentials of wind technologies for ships.**

Modern wind technologies (rotors, suction wings, sails, kites, etc.) can provide a large part of the power needs for new and existing cargo and passenger ships reducing fuel consumption and the connected emissions significantly. However, it can obviously be challenging to install wind technologies on container ships. But this might be solved by container-based sail solutions.

Fuel savings from wind technologies retrofitted onto existing ships vary from 5-25% depending on ship size, type, speed, route, and weather conditions, etc., as well as type, size and number of wind technologies applied. For new ships where wind technologies are further developed and fully integrated and the ships are designed to use wind propulsion, fuel savings well above 30% are to be expected.


**Ship name:** Ankie
**Type:** General Cargo
**Vessel data:** LOA 90m, 3,638DWT
**Wind system installation:** 2 x 10m(h) suction wings (installed 2020). In 2021: 2 x 16m(h)
**Expected average annual fuel savings:** 5-10%
**Company:** Van Dam Shipping
**Project:** WASP supported by the EU Interreg North Sea Europe programme

**Ship name:** Viking Grace
**Type:** Cruise Ferry
**Vessel Data:** LOA 218m, 57,565 GT
Wind System Installation: 1 x 24m(h) x 4m(w) rotor sail (installed 2018)
**Verified Average Annual Fuel Savings:** 231-315 tonnes of LNG per year


**Ship name:** Copenhagen
**Type:** RoPax Ferry
**Vessel data:** LOA 169.5m; Max. width: 25.40m
Wind system installation: 5m(d) and 30m(h) Flettner rotor (installed 2020).
**Expected average annual fuel savings:** 4-5%
**Company:** Scandlines
**Project:** WASP supported by the EU Interreg North Sea Europe programme

**Existing wind technologies offer free non-polluting energy delivered directly to the ship at sea without investments in fuel infrastructure.
Wind as green propulsion is more efficient than any other green fuel.**

Every time wind technologies save one tonne of marine distillate fuel (0.1% sulphur), societies around the North Sea gain around USD 3,000 due to avoided negative health effects. Therefore, every time larger ships in the area are retrofitted with wind technologies, societies around the North Sea gain USD 500,000-800,000 per year due to avoided negative health effects. On top of gained health benefits, fuel savings achieved by added wind technologies result in less climate change, reduced acidification, etc. The rising number of market-driven installations illustrates that from fuel savings alone some wind technologies become favourable.

Technologies that reduce fuel consumption will:

1. Reduce emissions of air and climate pollutants from the existing and future fleet.
2. Reduce the price gap between fossil fuelled ships and zero emission shipping.
3. Reduce the investments and time needed for decarbonization of shipping.

However, market as well as non-market barriers (lack of information, conservative industry, business structures, externalities, focus on short term profit, etc.) block the rate of implementation of technologies that reduce fuel consumption. Thereby, the related health and climate benefits remain unrealized and the existing market failure is maintained. The barriers can be overcome by flag and technology neutral regulations at IMO, EU, national and/or at regional level.

## Cleaner fuels

By using cleaner fuels, such as the well-known distillate fuel oils (0.1% sulphur) and Liquefied Natural Gas (LNG), air pollution is significantly reduced but the simultaneous climate change challenge of shipping is still not solved. The most significant reductions are achieved by switching to other energy sources, such as electricity (especially for ferries and ships at berth), or new fuels, such as green methanol, ammonia or hydrogen. Ammonia and Methanol are easier to store and take up significantly less fuel tank volume per MJ fuel energy compared to hydrogen. However, just by replacing up to 5% of the cargo space with fuel, 99% of container shipping voyages could be completed by hydrogen fuel cells according to ICCT. Nuclear energy does not emit air pollutants or $CO_2$ but other significant challenges are connected to the use of nuclear energy and it is therefore not further described below.

Benefits of the individual fuels depend on many factors such as ship engine type (2-stroke or 4-stroke). The achieved reductions of pollutants depend on whether only pollutants emitted directly from the ship are considered (tank-to-wake) or the full lifecycle of the fuel (well-to-wake) is considered including upstream emissions. Evidently, there is a crucial difference between what type of energy source is used and how it is produced; e.g. natural gas vs. biogas; whether electricity and electro fuels (methanol, ammonia and hydrogen) are produced from coal or wind power, or from fossil fuels; biofuels produced from crops vs. food waste.

On top of the choice and origin of fuel, auxiliary fuel, lubricant oils and/or support fuels also significantly affect air pollution. Hence, reduction potentials pointed out in this section should only be seen as an estimate and will potentially vary considerably depending on the specific situation. Table 7 shows reductions from the ship stack (tank-to-wake) when using cleaner fuels compared to VLSFO (0.5% sulphur). Reductions are uncertain even when only considering tank-to-wake. The uncertainty increases when considering well-to-wake i.e. it includes production/extraction and transport of fuels. Furthermore, air pollution from VLSFO can vary quite a lot as VLSFO is often a blend of oils and thereby not a specifically defined oil.

**Table 7:** Reductions (in percent) from cleaner fuels compared to VLSFO (tank-to-wake).

| | $CO_2$ | $SO_2$ | $NO_x$ | Fine particles |
|---|---|---|---|---|
| Liquified Natural Gas (LNG) | ? 1) | > 90 2) | 20-90 1) | 40-95 2) |
| Distillate fuel oil (0.1% sulphur) | 5-10 3) | 80 | 0 | > 30 |
| Methanol | 10-25 | > 90 4) | 50-60 | 40-95 4) |
| Ammonia or hydrogen | 100 5) | > 90 4) | No data | 40-95 4) |
| Electricity (battery ferries & ships at berth) | 100 | 100 | 100 | 100 |
| Hydrogen fuel cells | 100 | 100 | 100 | 100 |

1) Depending on engine type (different engines result in different NOx formation and methane slip).
2) Depending on the amount/type of auxiliary fuel/lubrication oil used.
3) Including reduced global warming from black carbon depending very much on time horizon (GWP 20 or GWP 100).
4) Depending on the amount/type of support fuel needed and the amount/type of auxiliary fuel/lubrication oil used.
5) Assumed that no nitrous oxide (powerful greenhouse gas) escapes the stack.

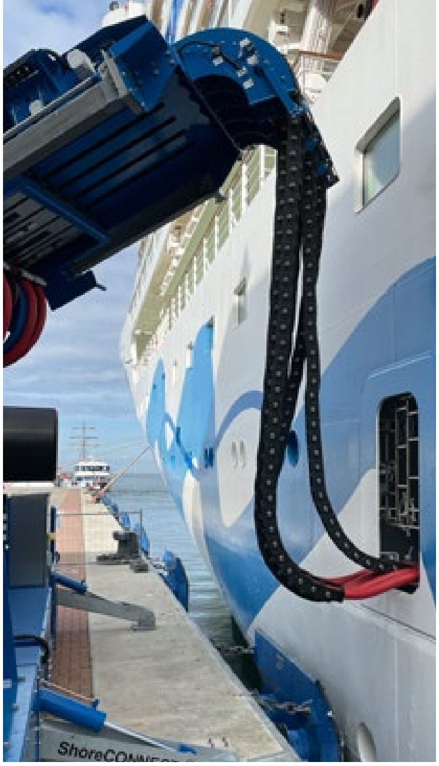
Reference: General literature review

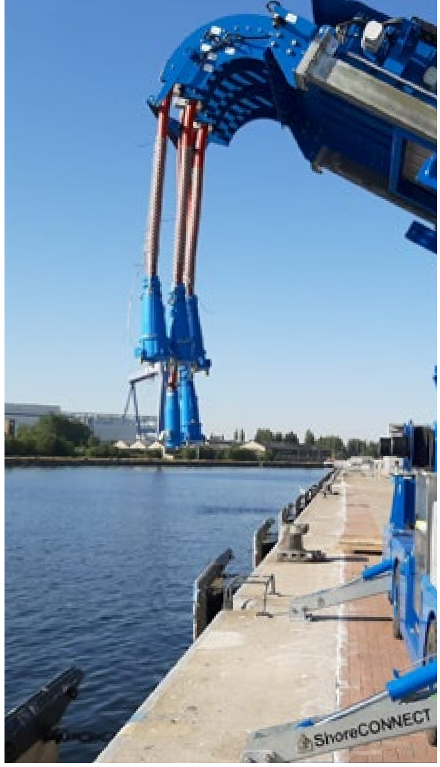


**Ship name:** Ellen
**Type:** Fully Electric Battery Ferry
**Length:** 59m
**Width:** 13m
**Passengers: 150-200**
**Speed:** 13 knobs
**Battery capacity:** 3.8 MWh

Emissions of unburned methane from gas production, transport, storage, and engines (methane slip) impact the climate significantly as methane is a very powerful greenhouse gas. Several new studies conclude that methane as ship fuel in a life-cycle perspective contributes more to global warming than traditional fuel oil due to the methane slip. On the other hand, a methane spill will not cause adverse effects in the marine environment. Distillate fuel oil has similar advantages by reducing the risk of long-term damage from oil spills. This is particularly important in the Arctic where there is no immediate and efficient possibility to clean up after oil spills, not to mention that oil pollution decomposes slowly in darkness and at low temperature. Hence, Arctic oil spills will cause long-term damage to the pristine, unique and sensitive ecosystems in the Arctic area. Finally, distillate fuel oil (and methanol, ammonia and hydrogen) enhances the operation of particle filters for ships, which can almost eliminate particle emissions from shipping.

More and more ferries and smaller ships become fully electric (batteries), and thereby emission free (tank-to-wake), as the battery technology is rapidly developing a high supply of smaller and cheaper batteries. The Danish Ferry Ellen was the first medium sized ferry to use batteries. When the ferry was launched in 2019, it sailed 7 times longer than any other fully electric ferry of similar size. It sails around 40 kilometres on a full charge, however, operators have successfully sailed 80 kilometres (as an experiment) on a single charge. The batteries are super-charged in port during port calls. It is, however, highly unlikely that international shipping will be fully electric within coming decades unless a new, cheap, and energy dense battery technology is developed.






In ports, where air pollution is emitted close to residential areas and thereby causes significant negative health effects, shore power (*cold ironing*) for ships at berth can minimize pollutants; particularly beneficial will be the avoidance of the highly health hazardous ultrafine particles. Especially cruise ships, that are huge floating hotels (often carrying 4,000-6,000 passengers), have very high emissions at berth as they consume high amounts of energy for producing both heat and electricity to maintain the many facilities available for passengers (casinos, swimming pools, restaurants, etc.). At berth close to city centres, energy is supplied by ship engines by burning high quantities of fuel oil without efficient air pollution control. A cruise ship at berth pollutes as much as 3,500-5,000 cars per second. In comparison, a land-based power plant of similar size as a cruise ship engine would have enhanced air pollution control equipment installed to fulfil emission limit values for domestic pollution sources.

In comparison, power plants producing electricity for shore power are usually not located close to residential areas and pollution is emitted from high stacks. In addition, all $CO_2$ emissions from power plants in the EU is included in the Emission Trading System (ETS) and all $NO_X$, $SO_2$ and fine particles emissions from power plants are included in the National Emission Ceiling (NEC) directive. No emissions from international shipping (incl. ships at berth) are included in the ETS or the NEC directive. Some would thereby claim that using shore power for ships will eliminate all pollution since the amount of $CO_2$, $NO_X$, $SO_2$ and fine particles are sealed by ETS and NEC (increased emissions from domestic electricity used by shipping will thereby just cause same emission reductions in other domestic sectors). Finally, the electricity production in Denmark (and in other nations) is rapidly changing to supplying a higher degree of emission-free produced power (sun and wind).

Table 8 shows emission reductions comparing the use of distillate fuel oil with shore power in Danish ports (electricity mix in 2020). It is seen that shore power reduces emissions of $CO_2$ significantly and almost eliminates emissions of air pollutants causing negative health effects compared to emissions from ships using distillate fuels.

**Table 8:** Emissions from cruise ships at berth compared to the Danish electricity mix in 2020.

| g/kWh | $CO_2$ | $SO_2$ | $NO_X$ | Particles |
|---|---|---|---|---|
| Danish electricity mix, 2018 | 140 | 0.04 | 0.16 | 0.02 |
| Cruise ships (dist. fuel in port) | 645 | 0.3 | 13.2 | 0.3 |
| Reduction by shore power | 78% | 87% | 99% | 93% |
| Reduction in the port area | 100% | 100% | 100% | 100% |
| Reduction with ETS/NEC | 100% | 100% | 100% | 100% |

Reference: Declaration for Danish electricity 2020 and emission factors for cruise ships at berth, COWI.

**Table 9:** Economy for a shore power facility in Copenhagen (only serving ships at one cruise terminal).

| **Copenhagen** (one shore power facility) | $SO_2$ | $NO_x$ | **Particles** | **Total** |
|---|---|---|---|---|
| One shore power facility removes (kg/year) | 8,000 | 125,000 | 4,000 | |
| Health benefits from avoided emissions (USD/kg) | 18 | 42 | 102.5 | |
| Total health benefits (million USD per year) | 0.14 | 5.2 | 0.41 | **5.75** |
| Total costs of one shore power facility in Copenhagen (million USD) | | | | **10.65** |

Reference: Emissions for cruise ships at berth and cost of a shore power facility, COWI.

The port itself is typically responsible for the investment in shore power facilities, however, air quality benefits are assigned to the population and society (see table 9). Therefore, ports have no direct incentive to invest in shore power and will most likely only do so if forced to by authorities, pressured by the local population or cruise ship operators, or in the case the port can make a profitable business by selling shore power to ships. However, cruise ships can produce very cheap electricity (as there is no taxation on fuel oils for shipping), which leave them without incentive to buy shore power. But in case cruise ships choose to buy shore power, the extra costs for the passengers (assuming costs will be passed on) are negligible (see box).

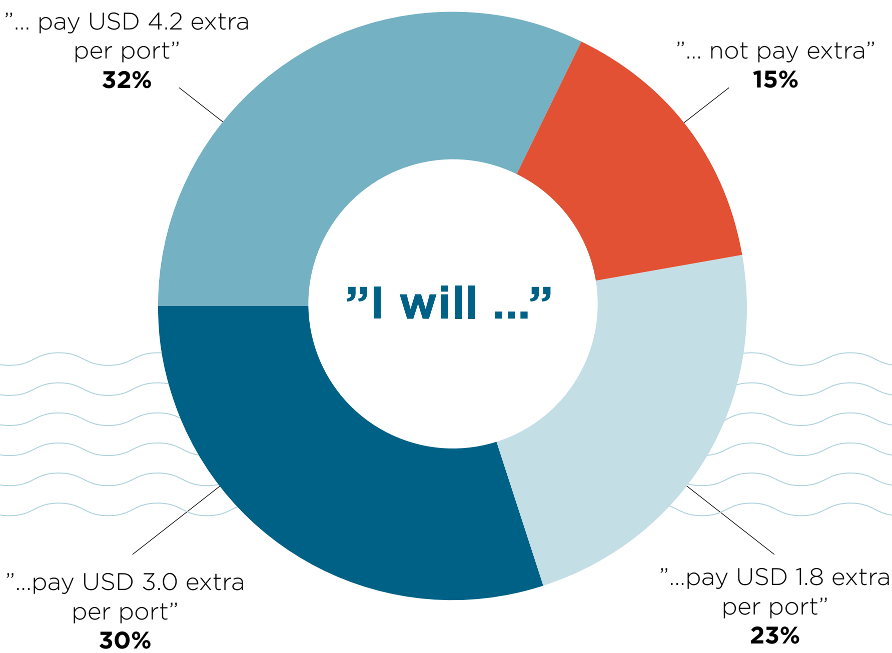
As seen from table 9, a single shore power facility in Copenhagen cruise port would have a payback time of less than two years from a societal point of view due to gained health benefits alone.

**Shore power for cruise ships in Copenhagen**

- A cruise ship at berth consumes around 30 kWh per passenger per port call (10-12 hours).
- The ship can produce its own electricity for around USD 0.21 per kWh (fuel prices fall 2021).
- Positive business case for the port if electricity from shore power is sold for USD 0.27 per kWh.
- Extra costs per passenger per port: 30 kWh * USD 0.06 per kWh = USD 1.8 per port call.
- In comparison, a cup of coffee in Copenhagen cruise port costs around USD 7.
- Prices ***without*** shore power: Baltic cruise vacation in four ports: USD 790 per passenger.
- Prices ***with*** shore power: Baltic cruise vacation in four ports: USD 797.2 per passenger.
- Price increase with shore power: Less than 1%.


From the box at page 21 is seen that if a port invests in a shore power facility (10 years payback time with 10% return on investment per year) it will increase the price of a cruise ship ticket by less than 1%, which is a significantly lower cost for passengers than half a cup of coffee in the cruise port. At the same time, not only residents, but passengers will also avoid exposure to air pollutants and experience a better air quality in the ports and cities they visit.

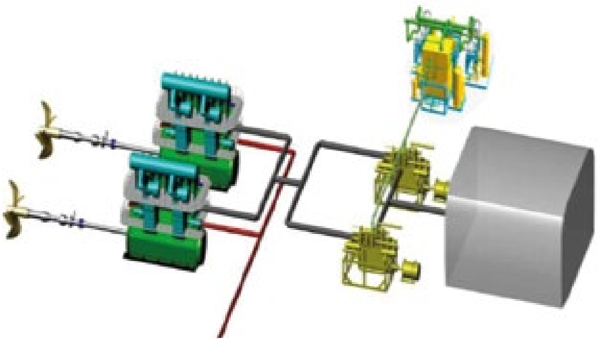
**Figure 5:** Result of cruise passenger survey regarding willingness to pay extra for shore power




Green Transition Denmark conducted an anonymous web-based passenger survey in August and September 2019 in Copenhagen cruise port. Passengers were asked what they think about their ship using shore power instead of fuel oil, and if they are willing to pay extra for shore power. More than 100 passengers from several cruise lines and nationalities answered (see figure 5). The survey was funded by the local district council (Østerbro Lokaludvalg, part of Copenhagen municipality).

The survey clearly illustrates that most cruise passengers think that shore power is a better alternative and are willing to pay far more for shore power than needed (USD 1.8 per port, which makes it a very profitable investment for ports).

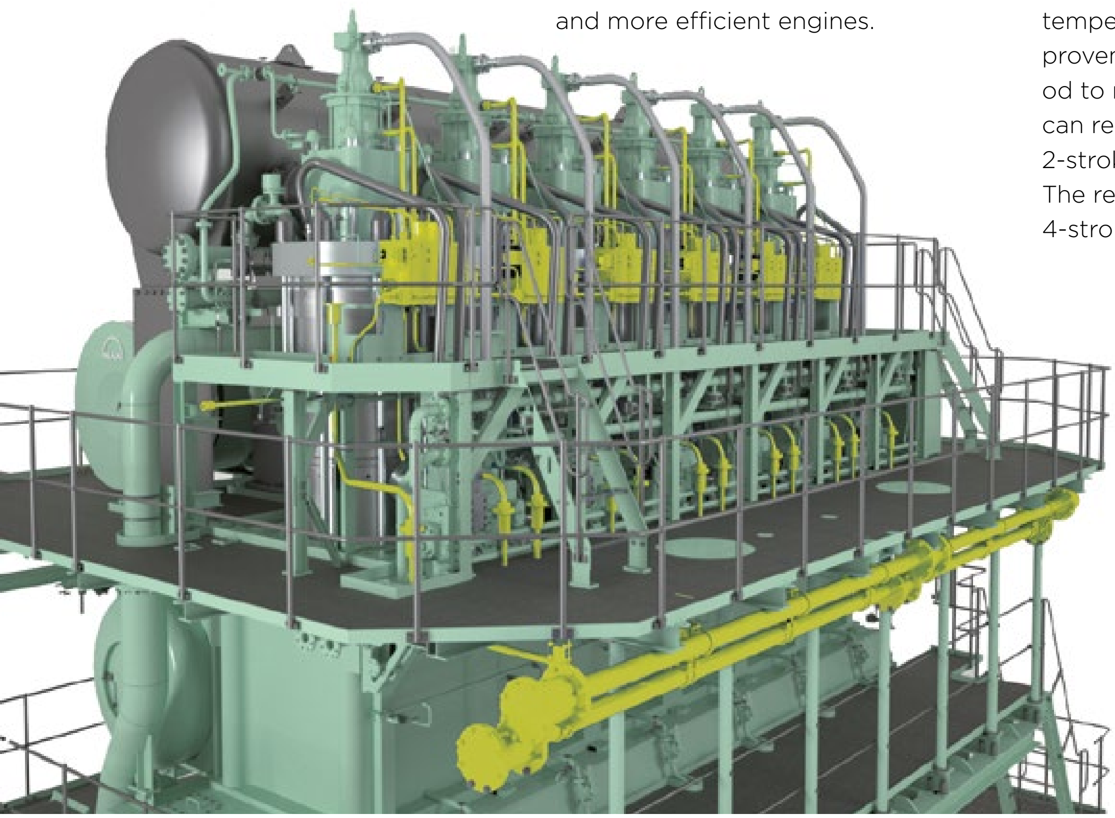
There seems to be international consensus that the source for propulsion for shipping of the future is electricity wherever possible combined with green ammonia and green methanol produced from renewable emission-free electricity sources (wind and solar power). This is the way towards cleaner shipping. However, this will require rapid planning and construction of gigantic wind farms and solar power parks as well as electrolysis plants for producing the ammonia and methanol in the next decades. Furthermore, energy intensive carbon capture for methanol production is required and new $CO_2$ sources in our future society with much less $CO_2$ emissions need to be identified for methanol to become a long-term solution. Huge energy savings in shipping are foreseen since green fuels will probably be three times more expensive than conventional fuels. However, such expensive fuels will incentivise a demand for shore power for ships at berth as that will be much cheaper to use than using their own fuels.



$CO_2$ and $NO_X$ emissions can be significantly reduced by using larger and more efficient engines.

### Better engine technology

For the last 60 years, the consumption of fuel oil per container per nautical mile for larger ships has been reduced by more than 80% through the development of larger engines with increasing efficiency. This reduction will continue to some extent as older and smaller ships are replaced with new and larger ones and as the optimization of engines continues. For example, new waste heat recovery (WHR) systems will reduce the fuel consumption and low-$NO_X$ valves for 2-stroke engines will reduce $NO_X$ formation by 10-20% and also reduce particle emission. Also Exhaust Gas Recirculation (EGR), where part of the flue gas recirculates through the engine thereby reducing the combustion temperature and pressure, has proven to be an effective method to reduce $NO_X$ emissions. EGR can reduce $NO_X$ emissions from 2-stroke engines by more than 80%. The reduction achieved by EGR on 4-stroke engines is 40-50%.



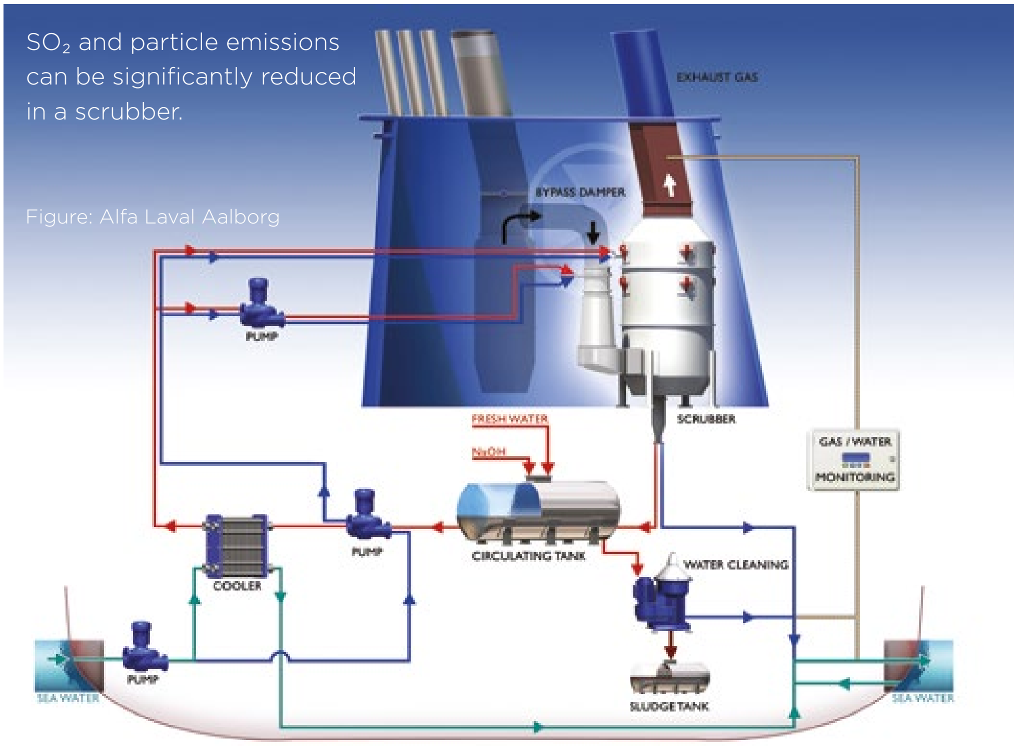
Figures: MAN Energy Solutions

### Flue gas cleaning

Air pollution from shipping can be reduced by implementing the same technologies as used for land-based pollution sources.

<u>$SO_2$ removal</u>

Scrubbers reduce $SO_2$ in the flue gas from ships burning traditional heavy fuel oil (HFO) containing up to 3.5% sulphur. According to Alfa Laval Aalborg, a scrubber removes more than 95% of $SO_2$ and usually 50-60% of the particles in the flue gas. DFDS is seeing the same results from their scrubbers in operation. During testing, some scrubbers have shown removal rates of 70-80% of particles (Venturi scrubber). However, scrubbers show very little ability to remove black carbon from the flue gas. Ships with scrubbers using cheap HFO can thereby fulfil the global sulphur cap (0.5% sulphur) and even the stricter SECA regulation (0.1% sulphur).



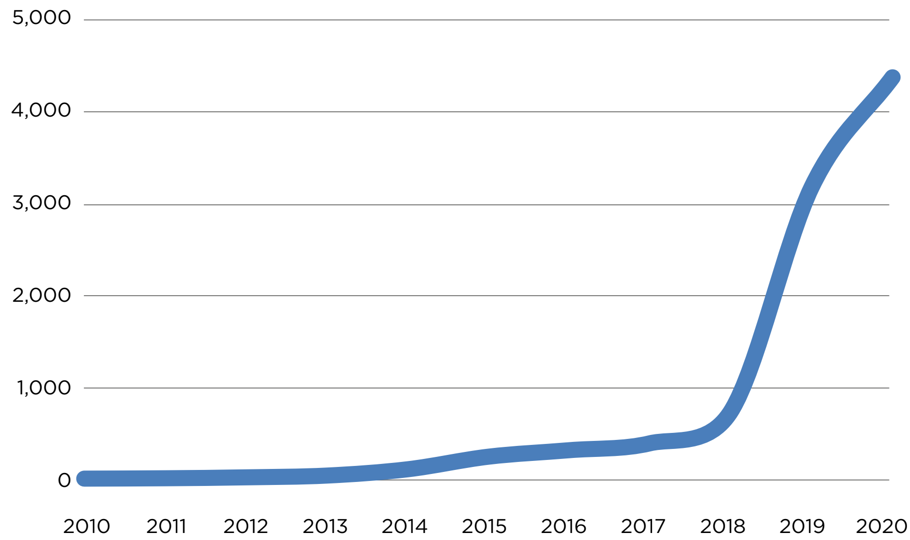

$SO_2$ and particle emissions can be significantly reduced in a scrubber.

Figure: Alfa Laval Aalborg

In a scrubber, the flue gas gets a "shower" removing $SO_2$ from the air to the water as dissolved sulphate. There are three kinds of scrubbers: Open-loop scrubbers, closed-loop scrubbers and hybrid scrubbers. Open loop scrubbers use seawater to shower the flue gas and discharge the scrubber water directly at sea. Closed-loop scrubbers recirculate the scrubber water (keeping pH high by adding sodium hydroxide) and store the highly polluted scrubber water in closed tanks (should be disposed as toxic waste in ports). Hybrid scrubbers can operate both as open-loop and close-loop systems and typically discharge all stored scrubber water when operating as open-loop scrubbers. About 80% of all scrubbers installed are open-loop, 18% are hybrid loop and only 2% are closed-loop.

On the downside, scrubbers increase fuel consumption and the connected emissions by 1-3%. Also, sulphur in the scrubber water dumped at sea cannot be used whereas sulphur removed at the refinery (when refining the cleaner fuel oils) is used as a resource. Furthermore, scrubbers are installed so that ships can continue to use some of the most polluting fuel (HFO) thereby imposing port states worldwide to control the oil in ship fuel tanks to make sure that only ships with scrubbers use HFO. Finally, given that only 2% of all scrubbers installed are closed-loop systems almost all the scrubber water is dumped directly at sea and, in addition to sulphate, scrubber water also contains toxic PAHs and heavy metals causing long-term risks for the marine environment.

**Figure 6:** Number of ships with scrubbers




Scrubber technology was originally developed for power plants to remove $SO_2$ from the flue gas but are now rapidly implemented on ships. The number of ships with scrubbers have grown exponentially (figure 6) towards the 2020 global sulphur cap. In 2011, around 6 ships had scrubbers. 10 years later, more than 4,000 ships had scrubbers i.e. 400 times more ships. At the end of 2020, more than 16% of all containerships (representing 36% of the container capacity), 15% of bulk carriers and 10% of oil carriers have scrubbers installed. The fast-growing number of installations is because scrubbers offer a cheap way to meet the global sulphur cap (and the SECA requirements) since HFO is per tonne around USD 100 cheaper than VLSFO and around USD 200 cheaper than distillate oils (fuel prices, fall 2021).

When discharging such large amounts of scrubber water in areas with dense shipping activity, on top of the long-term risks from PAHs and heavy metals, the low pH will affect the aquatic environment in areas with low buffer capacity (inland waterways) or in seas with dense shipping traffic i.e. if (when) around 35% of the fleet near Rotterdam have open-loop scrubbers, it would make the pH of the local sea surrounding Rotterdam drop to a similar degree as caused by global warming over a 50-year period. This will have adverse effects on the marine environment. Hence, more and more nations ban discharge of scrubber water in ports, inland waters and/or in all their territorial waters.

## $NO_X$ removal

For 4-stroke engines selective catalytic reduction (SCR) is one of the most promising technologies for the removal of $NO_X$. In SCR systems, a precise amount of urea is automatically added to the flue gas. Ammonia ($NH_3$) is released from urea at high temperatures and reacts with $NO_X$ in the flue gas, converting $NO_X$ and ammonia to harmless free nitrogen ($N_2$) and water vapour. SCR systems for ships can remove more than 90% of $NO_X$ in the flue gas at high temperatures (above 300 degrees Celcius). Is the temperature lower, ammonia can be added as a pure gas, thus maintaining high efficiency down to 180 degrees Celcius. Some studies also show particle removal when using SCR systems. Finally, SCR systems can reduce noise significantly. SCR systems have been successfully used on both 2-stroke and 4-stroke engines.

## Particle removal

Particles can be removed from the flue gas by using particulate filters - the same technology as is widely used in diesel cars. Particles are removed by a physical filtration process in a closed particulate filter. Through electrical regeneration (controlled particle combustion inside the filter) particles are transformed to $CO_2$ and water vapour. Low-sulphur content in the fuel oil reduces ash formation and enhances the filtration process. Full scale testing with particulate filters on the old Ærø ferry carried out by Dinex A/S has shown 90% particle removal for both fine and ultrafine particles. Finally, particles can be removed very efficiently in a dry scrubber. CCR Denmark has demonstrated through full scale testing a removal of ultrafine particles of 99.8% in a dry scrubber.

Particles can be efficiently removed by particulate filters.

Pictures: Dinex A/S.

**The $NO_X$-emission** can be minimized by SCR technology.

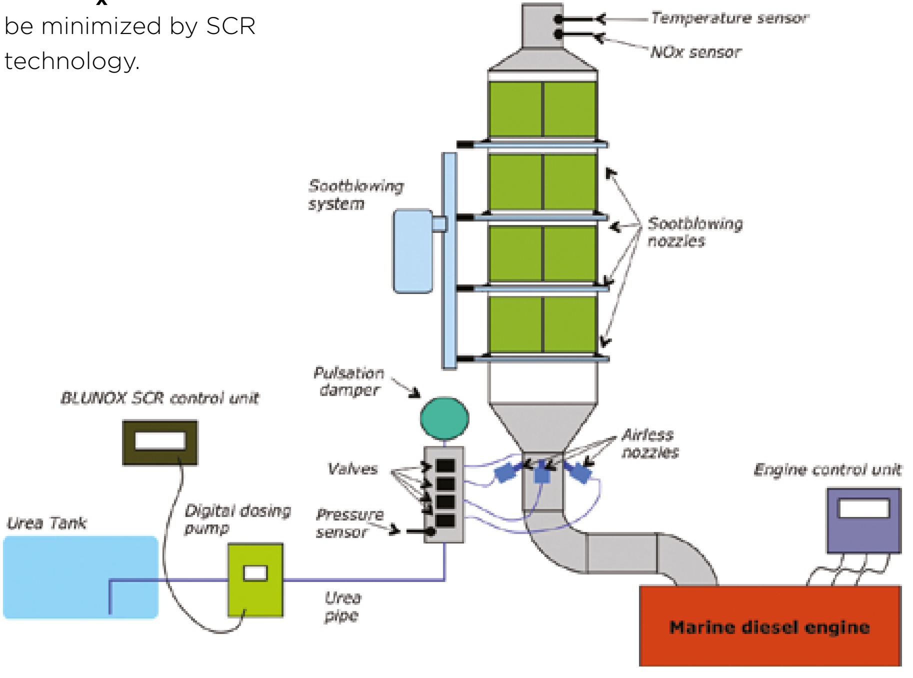



Figure: DANSK TEKNOLOGI

**Combining technical solutions**

Many of the technical solutions can be combined on ships as done on newer trucks and busses to comply with environmental regulation in the developed part of the world where heavy duty vehicles use both desulphurized fuels (max. 0.001% sulphur), EGR combined with SCR and closed particticulate filters. By combining solutions the pollution from shipping can be significantly reduced.

**Technological potentials**

By combining the technological solutions as done on power plants and trucks, health hazardous air pollution with $SO_2$, $NO_X$ and fine particles from shipping can be minimized and society will achieve massive benefits due to less adverse health effects as well as less damage on buildings, nature and the climate. However, to achieve these benefits regulation is needed since ship-owners and ports do not pay the health costs and thereby have no incentive to invest in solutions. Hence, political regulation is needed to internalize the externalities to "make the polluter pay" and thereby exclude the existing marked failure leading to uneconomical under-regulated shipping that cause high air pollution and unfair competition compared to other transport modes and sectors that are subject to much stricter regulation; in particular $NO_X$ emission lacks a regulation focus. Furthermore, political regulation is urgently needed to incentivise production and use of clean electro-fuels for shipping thereby solving the climate challenge and making shipping the green transport of the future.

# REGULATION

As previously mentioned, global environmental regulation for shipping is decided by the IMO.

**Sulphur regulation**
Table 10 shows the IMO regulation of the sulphur content in ship fuels. As an alternative to cleaner fuel oils, ships can choose to remove $SO_2$ from the flue gas using a scrubber.

The seas around Denmark is a SECA. Hence, sulphur emissions have been reduced by around 93% between 2006 and 2015. This reduction is percentagewise somewhat lower than the reduction of the sulphur content (96%) in the fuel as there has been a simultaneous increase in shipping activity. However, a reduction of sulphur emissions of more than 90% shows that SECAs are a success. It also highlights $NO_X$ pollution from ships as the major remaining problem, now accounting for 97. 5% of total adverse health effects from ships in the North Sea and the Baltic Sea.

An estimation of $SO_2$ concentrations in the air in Denmark in 2007 and 2020 is given in figure 7. It clearly shows that shipping has a significant effect on $SO_2$ concentrations in 2007, whereas the pollution is almost invisible in 2020 despite increasing shipping activity between 2007 and 2020.

**Table 10:** Global regulation of the maximum sulphur content in ship fuels (percent)

| | | 2007 | 2010 | 2012 | 2015 | 2020 |
|---|---|---|---|---|---|---|
| Sulphur content | **Non-SECA (World seas)** | 4.5 | - | 3.5 | - | 0.5 |
| | **SECA** | 1.5 | 1 | - | 0.1 | - |

**Figure 7:** $SO_2$ concentrationen (μg/m$^3$) in Denmark in 2007 and 2020

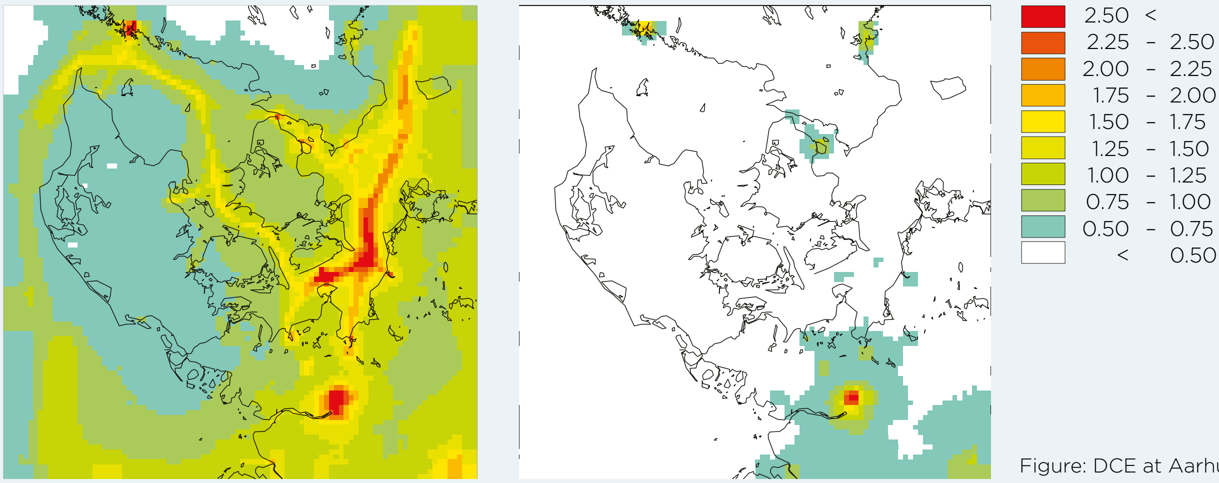



Figure: DCE at Aarhus University.

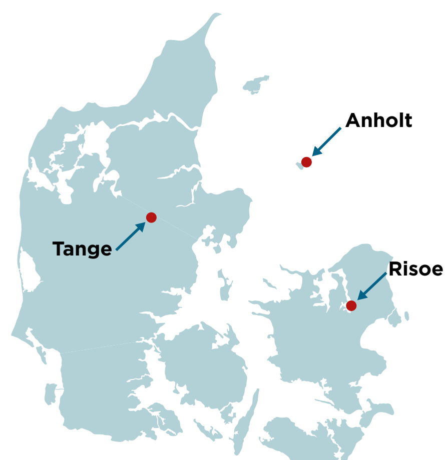
The estimated decline in Sulphur concentrations (figure 7) is supported by Danish measuring stations. Following the tightening of the regulation inside SECAs enforced from January 1st, 2015, measuring stations now detect half the sulphur concentration on land (table 11). Similar reductions are measured in Sweden and at the German island Neuwerk the decline is quite significant (Figure 8). These decreases document that air pollution from shipping is dispersed over land and has a significant influence on air quality and thereby on public health. The measured drop in $SO_2$ concentrations inside SECA further indicates almost full compliance. In addition to the Northern European SECA in the Baltic Sea and the North Sea, SECAs have been established in North America with similar benefits.

According to the Swedish Transport Research Authority, the SECA did not cause a cargo transfer from ship to road. This conclusion is confirmed by a CE Delft study on the impacts of the SECA. On the contrary, a higher growth in ship transport compared to road after enforcing the 2015 SECA limit is observed. With the global 2020 sulphur cap, the price gap between HFO and distillate fuel has been reduced significantly eliminating the chance of a change in transport mode. The Swedish Transport Research Authority further concludes that there has at no time been a shortage in cleaner compliant (0.1% sulphur) distillate ship fuel supply. This conclusion is supported by the CE Delft study on the impacts of SECA.

**Table 11:** $SO_2$ concentrations before and after the 0.1% sulphur limit in the SECA was enforced January 1st 2015.

| SECA: Effects of 2015 SECA limit | Anholt | Risoe | Tange |
|---|---|---|---|
| Mean 2011-14: Before 2015 limit | 0.33 | 0.34 | 0.22 |
| Mean 2015-16: After 2015 limit | 0.13 | 0.17 | 0.10 |
| Reduction (μg sulphur per m$^3$) | 0.20 | 0.17 | 0.12 |
| **Reduction (%)** | **60%** | **50%** | **55%** |

Reference: DCE at Aarhus University.

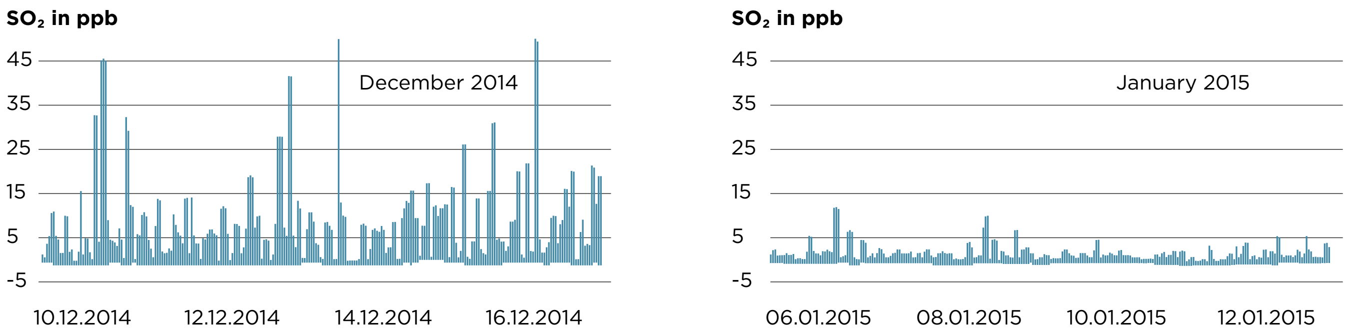


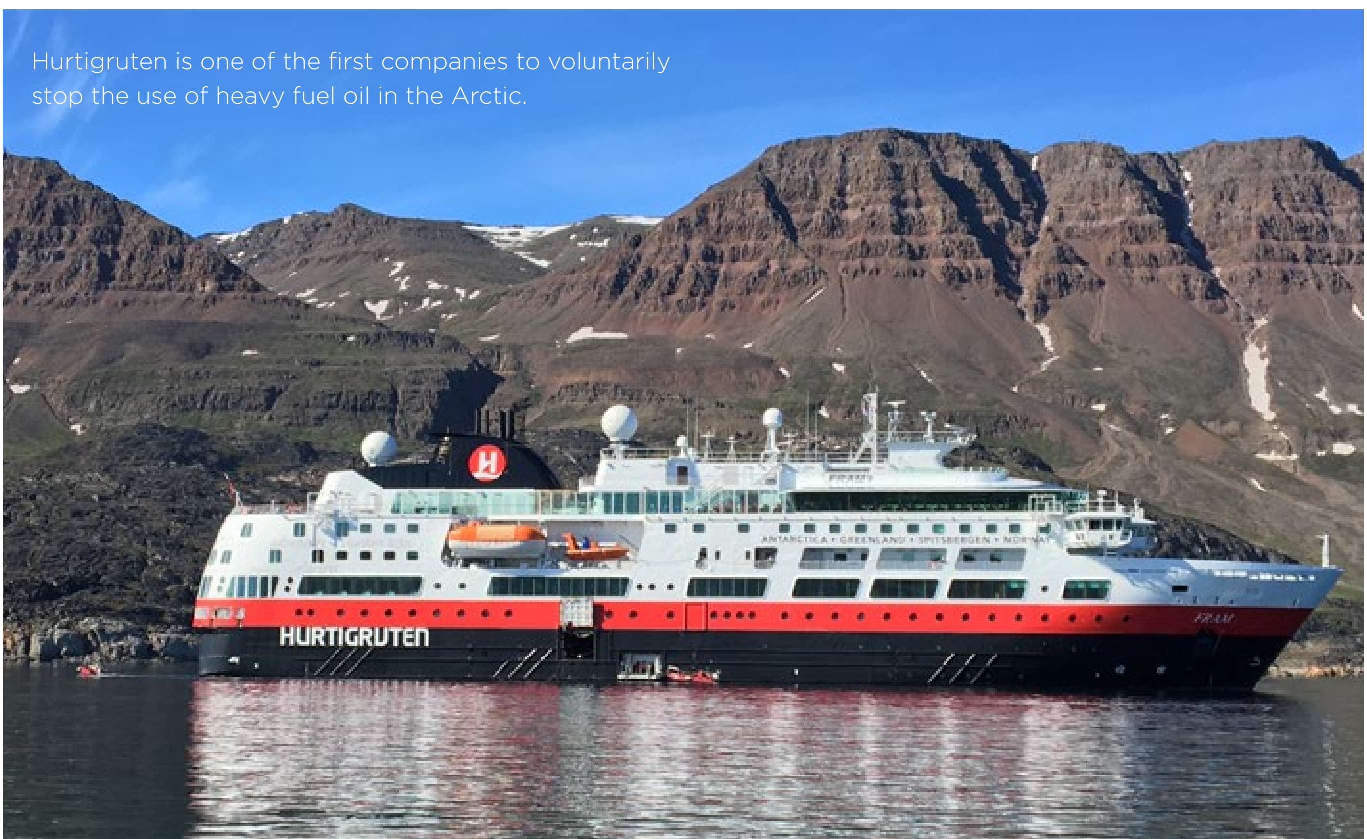
Increased costs for cleaner fuels and/or exhaust gas cleaning do not cause notable increases in consumer prices in ECA. The annual additional administrative burden for maritime public authorities in SECA is not significant (has been estimated to 260,000 euro in total for the Baltic Sea Region). The annual additional administrative burden for ship-owners is about 2,000 euro per year per ship but these costs will – just as the extra fuel costs and exhaust cleaning costs – be transferred to slightly higher shipping prices and in the end have an insignificant influence on consumer prices.

In addition to $SO_2$ reductions in SECA, the switch to low sulphur fuel (distillate with max. 0.1% sulphur) reduced soot (black carbon) emissions from shipping in SECA by around 30% providing health and climate benefits. However, this reduction is now undermined by an increasing number of ships with installed scrubbers that unfortunately do not reduce black carbon emissions significantly (cf. page 24).

On top of SECA regulation, a maximum sulphur content of 0.1% in ship fuels (or equivalent flue gas cleaning in scrubbers) has been required at berth in the EU since 2010. Furthermore, the IMO has banned the use of heavy fuel oils (HFO and most VLSFO blends) in the Antarctic since 2011 and in the Arctic from 2029, which will reduce the emission of sulphur and black carbon as well as long-term effects of oil spills and illegal discharges in these extremely sensitive areas.

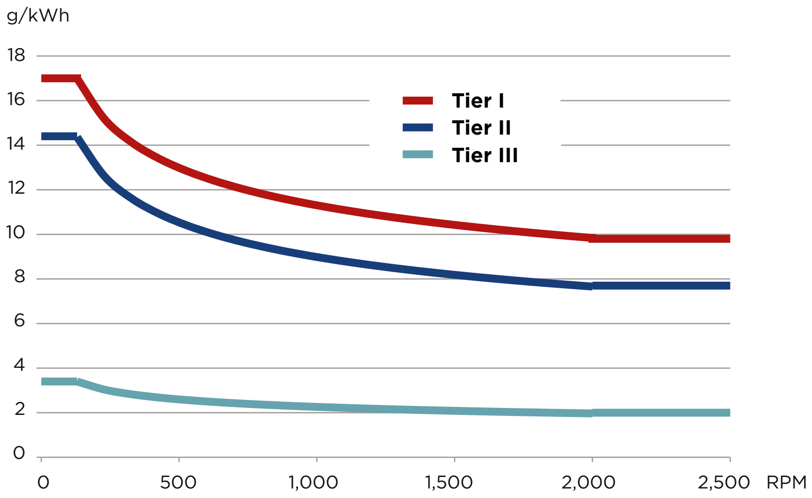
**Figure 8:** The measured drop in sulphur concentrations from January 1st, 2015, in the German island Neuwerk.



Hurtigruten is one of the first companies to voluntarily stop the use of heavy fuel oil in the Arctic.

**Figure 9:** Regulation of $NO_X$ from shipping




**Tier I:** Ship engines (above 130 kW) installed on a ship built after 1st January 2000

**Tier II:** Ship engines (above 130 kW) installed on a ship built after 1st January 2011

**Tier III:** Ship engines (above 130 kW) installed on a ship built after the year the specific NECA came into force.

Reference: International Maritime Organization

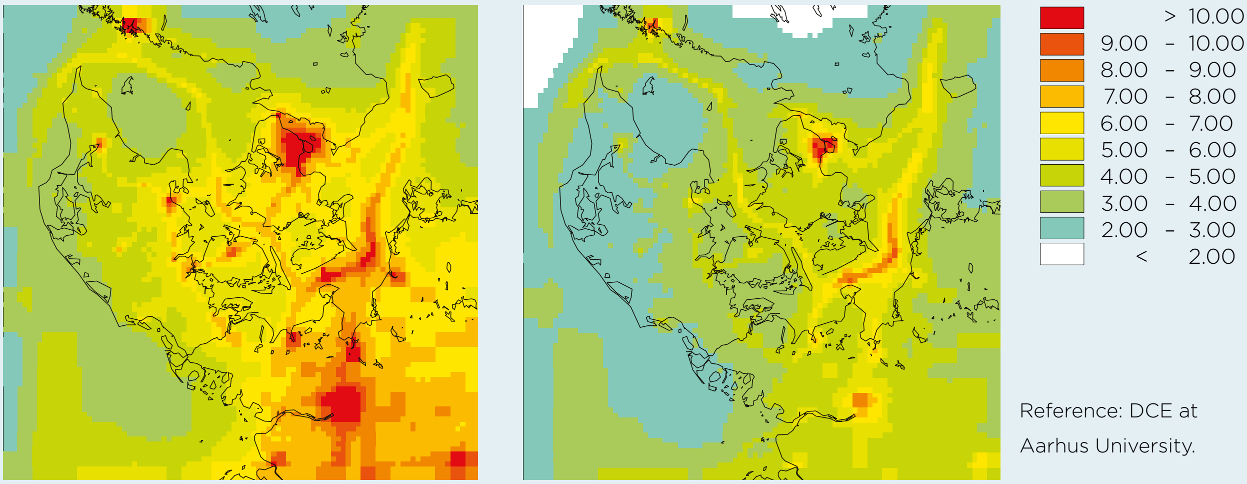
**$NO_X$ regulation**

Figure 9 shows the global regulation of $NO_X$ emissions from ships, which includes Tier I, II and III. The age of the ship and the engine's power determine how much $NO_X$ the ship is allowed to emit. In line with SECAs, NECAs have been introduced requiring $NO_X$ reductions of 80% (Tier III) but only for ships built after the specific NECA is implemented. For 2-stroke engines this can be fulfilled by installing SCR and EGR. For 4-stroke engines it can be fulfilled by installing SCR or using LNG.

Although $NO_X$ is the cause of almost all adverse health effects (cf. table 6 page 12) both on a global level and inside ECAs, strict $NO_X$ regulation (Tier III) only apply to new ships (built after the specific NECA came into force) and only inside the NECA. The NECA in the North Sea and the Baltic Sea came into force on January 1st 2021, and only ships built after this date must apply to the Tier III in these seas. However, as soon as a new ship leaves the NECA, it must only meet global regulation (Tier II) and can turn off air pollution control technologies. Finally, ship engines built between 1990 and 2000 must be upgraded to Tier I but only if technology is available. Despite the fact that SCR could be retrofitted on most ships.

It should be noted that it is the age of the ship and the engine's power that determines how much the ship is allowed to pollute with $NO_X$. Old ships and smaller ships can thus pollute more than new and large ships. This gives an incentive to maintain old small ships, which in general pollute much more than new large ships.

**Figure 10:** $NO_2$ concentrations (µg/m$^3$) in Denmark in 2007 and 2020




Reference: DCE at Aarhus University.

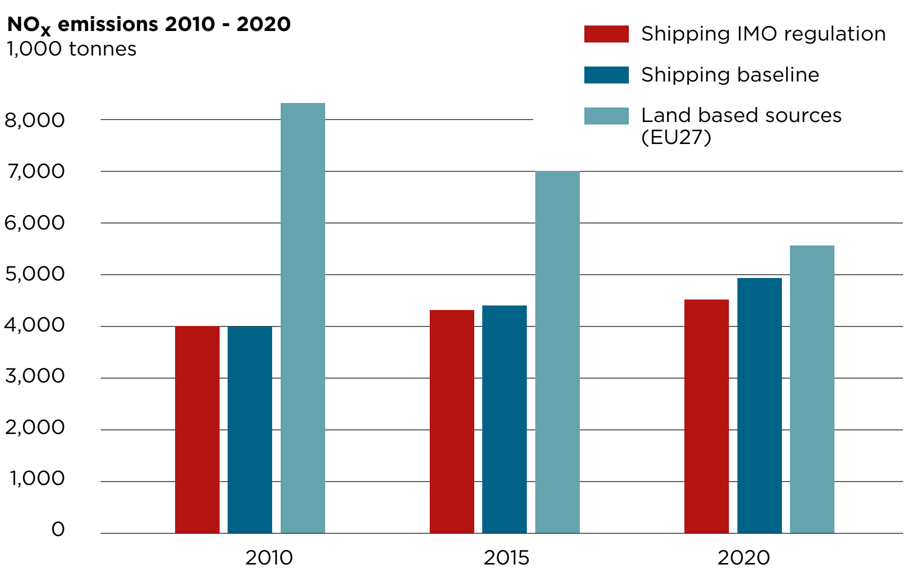
Estimations of $NO_2$ concentrations (indicator for $NO_X$ pollution) in Denmark in 2007 and 2020 are shown in figure 10. During this period, a small increase in $NO_X$ emissions in the seas around Denmark were observed due to increased shipping activity. Yet, the concentration of $NO_2$ decreased significantly due to a substantial decrease from land-based emission sources because of further restrictions by EU regulation. Nevertheless, the $NO_X$ regulation of shipping had a positive effect as $NO_X$ emissions would have increased by 10-15% from 2007 to 2020 without any regulation. By 2040, the North Sea and the Baltic Sea NECA is expected to reduce $NO_X$ emissions by about 66% compared to baseline in 2020 without a NECA.

Figure 11 shows the $NO_X$ emission from shipping on the Northern Hemisphere with the existing IMO regulation. For comparison, the baseline (without $NO_X$ regulation) and the land-based emissions in the EU are shown. EU regulation has reduced $NO_X$ emissions from all land-based emission sources with 33% from 2010 to 2020. The regulation of $NO_X$ from shipping shows to be insignificant and fail to prevent the absolute emission of $NO_X$ from increasing due to increasing shipping.

**Particle regulation**

IMO has no direct regulation of particle pollution neither in the climate-sensitive Arctic areas nor in metropolitan ports. However, particle pollution is significantly reduced in general because of $SO_2$ regulation and will specifically be reduced in the Arctic regions because of the heavy fuel oil bans.

**Figure 11:** $NO_X$ emission from shipping in the Northern Hemisphere with and without (baseline) IMO regulation.



**$CO_2$ regulation**

In 2018, the IMO adapted the initial strategy on reduction of greenhouse gases (GHGs) from shipping. The overall goal is to reduce total GHG emissions from international shipping by at least 50% by 2050 compared to 2008, and to pursue efforts towards phasing out GHGs aligned with the Paris Agreement i.e. limiting global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels. Furthermore, IMO set a goal for reducing carbon intensity ($CO_2$ emissions per transport work), as an average for international shipping, by at least 40% by 2030, pursuing efforts leading to a 70% reduction by 2050, compared to 2008.

In 2020, the IMO published the fourth GHG study showing that GHG emissions (including carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$), expressed in $CO_2$-equivalents) of shipping (international, domestic and fishing) have increased by 9.6% from 2012 to 2018 (977 million tonnes in 2012 to 1,076 million tonnes in 2018). In 2012, 962 million tonnes were $CO_2$ emissions, while in 2018 this amount has grown by 9.3% to 1,056 million tonnes of $CO_2$ emissions. The share of $CO_2$ ship emissions in global anthropogenic emissions have increased from 2.76% in 2012 to 2.89% in 2018. The carbon intensity of shipping has however improved by about 11% in this period, but the growth in activity has been larger than efficiency gains. Furthermore, the study indicates that emissions could increase by up to 50% by 2050, relative to 2018, despite further efficiency gains, as transport demand is expected to grow. Far the majority of $CO_2$ emissions are related to international shipping.

To be aligned with the 1.5 °C goal of the Paris Agreement shipping should reach net zero no later than 2040 and to be aligned with the 2 °C goal shipping should reach net zero no later than 2050 (Figure 12).

The IMO regulates $CO_2$ emissions from new ships through the Energy Efficiency Design Index (EEDI), which is mandatory for all new ships built after January 1st, 2013 (table 12). Furthermore, IMO decided to require ships to calculate their Energy Efficiency Existing Ship Index (EEXI) following technical means to improve their energy efficiency and to establish their annual operational Carbon Intensity Indicator (CII) and rating.

**Table 12:** EEDI regulations (reductions in percent) for selected ship types built in different years.

| | **Size** (Dwt) | **Phase 2:** Jan. 1st 2020 March 31st 2022 | **Phase 2:** Jan. 1st 2020 Dec. 31st 2024 | **Phase 3:** April 1st 2022 and onwards | **Phase 3:** Jan. 1st 2025 and onwards |
|---|---|---|---|---|---|
| **Bulk carrier** | ≥ 20,000 | | 20 | | 30 |
| | 10-20,000 | | 0-20 [1] | | 0-30 [1] |
| **Gas tanker** | ≥ 15,000 | 20 | | 30 | |
| | 10-15,000 | | 20 | | 30 |
| | 2-10,000 | | 0-20 [1] | | 0-30 [1] |
| **Tanker** | ≥ 20,000 | | 20 | | 30 |
| | 4-20,000 | | 0-20 [1] | | 0-30 [1] |
| **Container ship** | ≥ 200,000 | 20 | | 50 | |
| | 120-200,000 | 20 | | 45 | |
| | 80-120,000 | 20 | | 40 | |
| | 40-80,000 | 20 | | 35 | |
| | 15-40,000 | 20 | | 30 | |
| | 10-15,000 | 0-20 [1] | | 0-30 [1] | |

1) The reduction factor is linear in the interval (highest for large ships and lowest for small).

Reference: International Maritime Organization

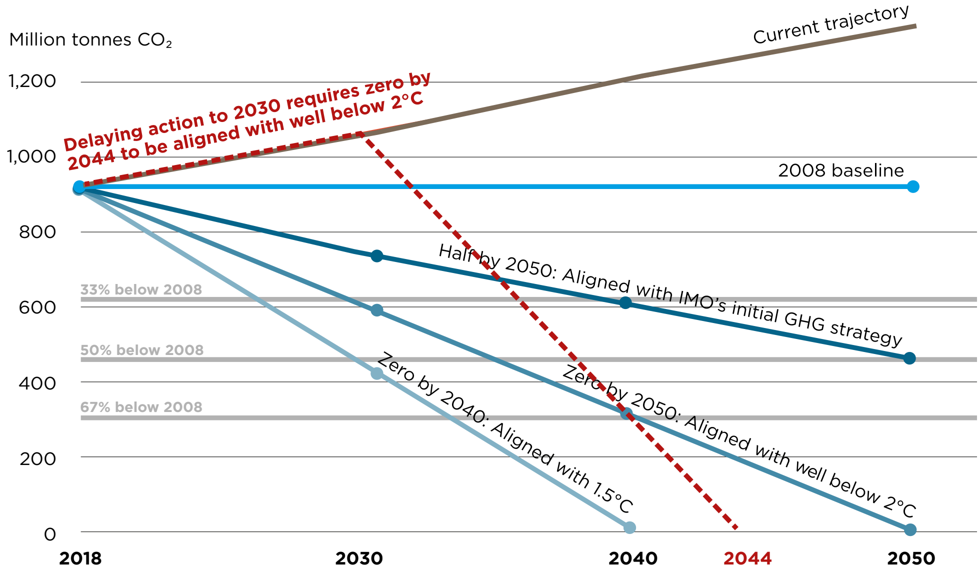



**Figure 12:** Actions needed to align shipping with the climate goals of the Paris Agreement.

Reference: International Council on Clean Transportation

EEDI promotes more energy efficient ships by requiring increased energy efficiency for different ship types and sizes compared to a specified reference level. It is measured in grams of $CO_2$ per transport work (capacity mile) and calculated from several parameters: ship type and design, fuel, engine type and size, propellers, etc. By further tightening regulation, energy efficiency will continue to increase on new ships. Regulations only focus on the performance of ships and not on the technologies used to fulfil them. This allows ship designers and ship builders to freely choose the most efficient solutions and it motivates to develop even better technologies. More than 85% of total $CO_2$ emissions from shipping originate from ship types covered by EEDI.

Carbon intensity (EEXI and CII certification) links GHG emissions to the amount of cargo carried over distance travelled. Ships are rated according to their energy efficiency (A, B, C, D, E - where A is the best), not to be confused with the labelling suggested on page 44 in this publication. Administrations, port authorities and other stakeholders are encouraged to provide economic incentives for ships rated as A or B to ensure that ship-owners strive for the highest energy efficiency rating for their ships, and also to send out a strong signal to the market and financial sector. A ship rated D or E for three consecutive years is required to submit a corrective action plan to show how the required index (C or above) will be achieved. EEXI and CII certification will come into effect from January 1st, 2023. This means that the first annual reporting will be completed in 2023, with the first rating given in 2024. A review clause requires the IMO to review the effectiveness of the implementation of the CII and EEXI requirements, by 1st January 2026 at the latest, and, if necessary, develop and adopt further amendments.

The key challenges, however, are lack of sanctions for ships not fulfilling ratings better than D for three consecutive years, ships not submitting a full corrective action plan, or that ships fulfil a C rating every third year e.g. by slow steaming and thereby avoid fulfilling regulations 2 out of 3 years.

The performance level will be recorded in the ship's Ship Energy Efficiency Management Plan (SEEMP). The SEEMP is an operational tool earlier adapted by the IMO to reduce the fuel consumption of ships and thereby $CO_2$ emissions. SEEMP can be used for both new and existing ships and is based on best practice in relation to energy efficient operation. This can be combined with the Energy Efficiency Operational Indicator (EEOI), which is a monitoring tool that allows monitoring fuel efficiency during various operational changes. The IMO has developed teaching modules in SEEMP for ship-owners.

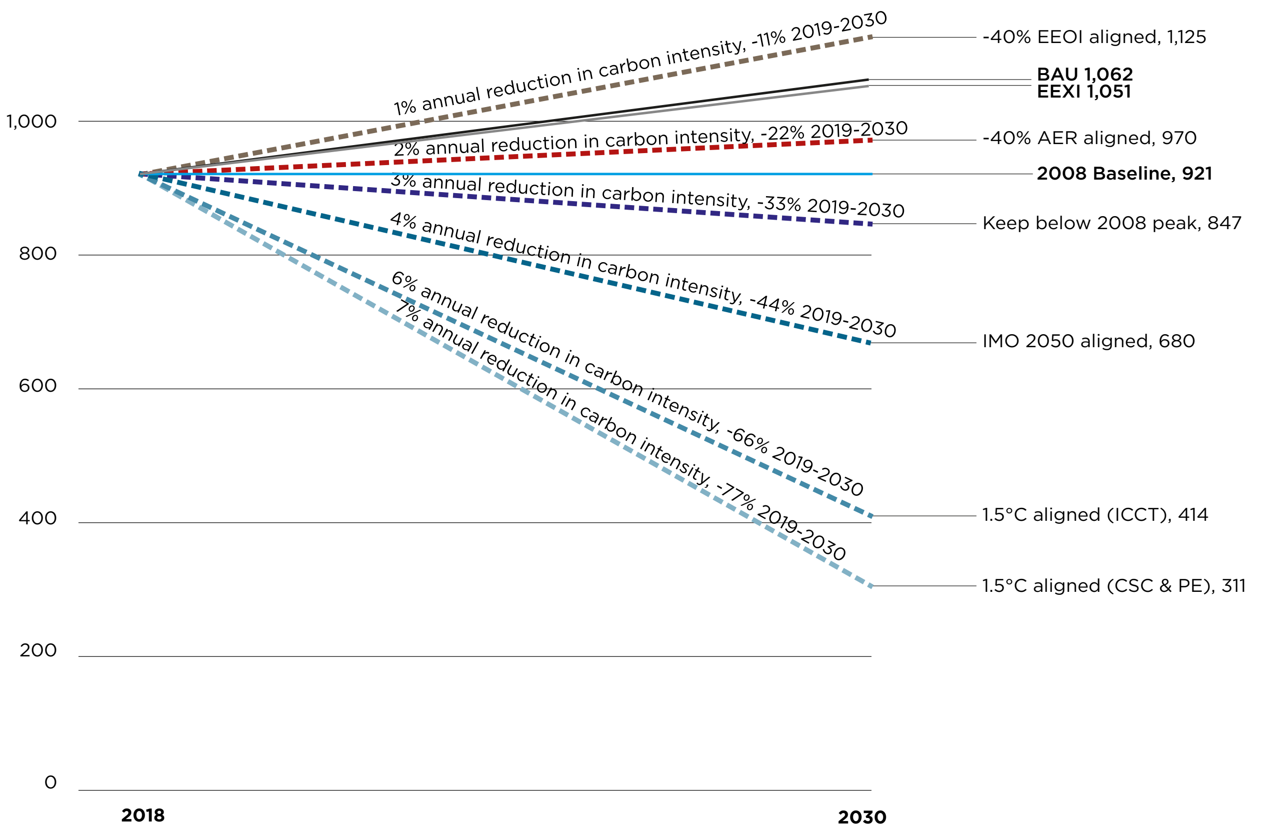
By 2050, it is expected that the existing IMO regulation will cut more than 1,000 million tonnes (more than 40%) of $CO_2$ emissions from shipping, compared to a baseline without $CO_2$ reductions. However, with the expected increase in shipping this is far from sufficient to be aligned with the Paris Agreement (Figure 12). In addition to $CO_2$ reductions, fuel savings will help close the price gap to zero emission ship fuels and, all things being equal, reduce air pollution of $SO_2$, $NO_X$ and particles (compared to baseline emissions).

Figure 12 shows that, $CO_2$ emissions from shipping are expected to increase despite the agreed regulation. Delaying actions to cut GHG emissions from shipping will require significant reductions later on to be able to align GHG emissions of shipping with the Paris Agreement. Hence, it is very important to reduce absolute GHG emissions between 2018 and 2030 for emissions to reach a level well below the 2008 baseline.

Figure 13 illustrates the business as usual (BAU) GHG emission of shipping compared to the reductions by EEXI (about 1% reduction compared to BAU) and different annual reductions in carbon intensity (assuming full compliance and no exemptions). The figure shows that annual reductions in carbon intensity above 5% are needed to be aligned with the Paris Agreement. Unfortunately, to date (October 2021) there are no indications that suggest such ambitious annual reductions will take place.

Although IMOs regulation is a major step in the right direction - especially for sulphur - shipping is still subject to much weaker regulation than land-based transport; fuel oil used in SECAs contains 100 times more sulphur than road diesel; new ships in NECAs (Tier III) emit around 5 times more $NO_X$ per kWh engine power compared to new trucks; and ships emit 50-100 times as many particles as trucks. Hence, even the strictest IMO regulation in SECAs/NECAs does not transform shipping into the green transport of the future. As a result, negative health effects and nature damage caused by air pollution from shipping will continue to be a major economic burden for society, mainly due to a weak $NO_X$ regulation. Considering the climate, there is an urgent need for action as the existing regulation does not reduce $CO_2$ emissions from shipping in alignment with the Paris Agreement.

**Figure 13:** GHG emissions from shipping with different annual reductions in carbon intensity.




Reference: International Council on Clean Transportation

# ENFORCEMENT

International regulation of shipping is needed to gain major economic, health and climate benefits from reduced pollution. Regulation is, however, not sufficient in an international industry, where circumvention and corruption is widespread. To avoid systematic violations of the regulation, enforcing the regulation will be just as important as the regulation itself to achieve the full environmental benefits. The economic incentive to circumvent the regulation is considerable while enforcement is modest; control and fines are symbolic compared to the economic savings from circumvention. Thus, there is a risk that shipowners violating the regulation will outmatch compliant shipowners fulfilling the regulation and thereby profit on causing more pollution than allowed. Finally, systematic violations must be avoided to allow compliance costs (e.g. extra fuel costs) to be transferred from shipowners to cargo owners and further on to end consumers who get the benefits of less mortality and morbidity.
Efficient enforcement prevents violations by making it more expensive to circumvent the regulation than to comply with the regulation. This requires the right balance between control and sanctioning for circumvention. If the risk of being caught violating the regulation is low, the economic sanctions must, of course, be high to prevent non-compliance. However, the IMO regulation only focuses on environmental regulation. IMO entrusts the enforcement to the flag states, which have a very different priority of regulation.

The enforcement of the sulphur regulation in SECAs and on a global level from 2020 has been the object of intense discussions. In SECAs, savings of around USD 80,000 per ship (English Channel to Gdansk and back) can be attained by using VLSFO instead of the required more expensive distillate fuel oil. Hence, ships violating the regulation can make higher profit and offer lower prices than compliant shipowners. $NO_X$ regulations in NECA (Tier III) will face similar challenges.

**The world's largest shipping companies have now joined forces in Trident Alliance only to achieve enforcement of the sulphur regulation**

Green Transition Denmark has organised several large conferences in Copenhagen and Brussels on enforcement in close cooperation with Danish Shipping and other key stakeholders.

**Northern European SECA**

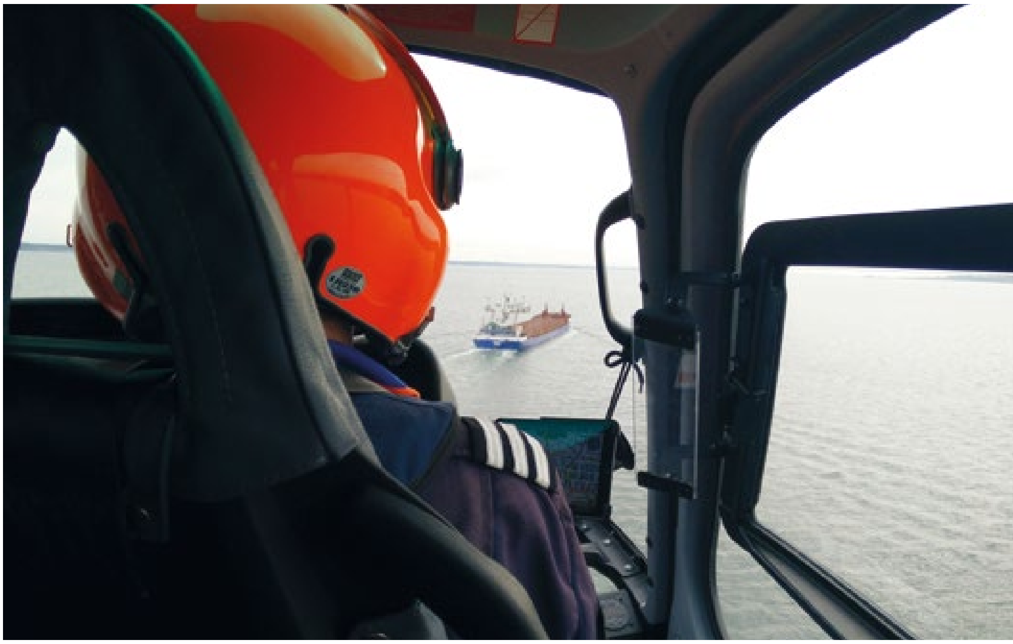
To meet the challenges associated with enforcement, the EU has passed a directive establishing a procedure for port state control in the EU. Member States perform the port state control and must inspect 10% of all port calls to control logbooks, fuel oil receipts, etc. In addition, fuel samples for sulphur analysis must be carried out in 4% of all port calls. However, fines for violations are based on national decision (non-EU competence). Nonetheless, according to the EU directive fines must be high enough to prevent systematic violations. Hence, if the risk of getting caught in the SECA is 4-10% while the saving is USD 80,000, the fines should be USD 0.8-2 million just to break even. Higher fines are needed to make violations unattractive. However, fines are typically 25-50 times lower (USD 0.03-0.06 million). Thus, from an economic viewpoint, the benefits of non-compliance are 25-50 times greater than being in compliance, if inspections are only performed randomly. However, focused inspections through international cooperation can reduce the benefits of non-compliance.

To support port state control, Denmark has installed sulphur measuring equipment under the large bridges, and authorities conduct controls at sea using helicopters measuring sulphur directly in the ships' flue gas. Based on the ratio of $CO_2$ and $SO_2$ in the flue gas, the sulphur content of the fuel oil can be calculated. If these measurements indicate non-compliance, authorities are immediately contacted at the ship's next port. There, a sulphur sample of the fuel oil is taken, which can be used as evidence in court. Finally, the authorities have taken initiative to create a public register that displays shipping companies (name and shame) who are caught circumventing the regulation.

Since the regulations inside SECAs were tightened in 2015, Danish authorities have reported about 20 cases of violations to the police. During the same period, there have been approximately 300,000 ship passages in the seas around Denmark. According to model calculations, the measured sulphur reduction indicates that more than 95% of the ships inside the SECA fulfil the sulphur regulation.

The 9,865 inspections that were carried out in the EU's SECA until spring 2017 showed that 92.5% of the ships complied with the regulations. Of the 7.5% that did not meet the regulations, several of the violations were of administrative character (insufficient logging, missing fuel receipts, etc.), and not non-compliant fuel.

The small, Danish entrepreneurial company *Explicit* is specialised in monitoring sulphur emissions from ships through measurements from helicopters and drones.



**Global 2020 sulphur cap**

The IMO has prohibited ships without certified scrubbers to carry heavy fuel oil with a sulphur content above 0.5% in their fuel tanks after the global sulphur cap entered into force in 2020. This is an important element for enforcement of the 2020 regulation. Efficient enforcement of the 2020 regulation will reduce the benefit of non-compliance in SECAs as well, since the price difference between VLSFO (0.5% sulphur) and distillate fuel oils (0.1% sulphur) is half of the difference between traditional HFO and distillate fuel oils, which implies less profit from non-compliance in SECAs.

**$NO_X$ inside NECAs**

The $NO_X$ regulation (Tier III) must be checked by performing standard tests at artificial test facilities and through log files from the systems while operating. This gives a potential for systematic violations, resulting in actual $NO_X$ reductions being significantly below the predicted 80%. For diesel cars, it is well-known that emissions of $NO_X$ were 3-5 times higher in real-life situations compared to the type-approval emissions. In addition, the SCR system of trucks can easily be chip tuned to make the engine system think that the SCR is working although it is off and $NO_X$ emissions are thereby not reduced. Shipping will probably face similar challenges.

**Effective enforcement**

An obvious possibility to achieve effective control is to install sealed online $SO_2$ and $CO_2$ sensors in the ships' stack (similar systems are mandatory for ships with installed scrubbers) and make the results available through the AIS system (Automatic Identification System). This ensures constant monitoring of sulphur emissions from the ship, which reveals any non-compliance both inside and outside SECA. Legally, it is not realistic that the IMO will decide this. However, if key regional units (EU, US, Canada, etc.) decide that only ships with such equipment installed will gain port access, it will matter significantly; likewise, an increasing support for such a regulation from other important shipping regions, e.g. China, can ultimately make the regulation practically global. As an alternative, port state control can be intensified and combined with several national measures such as helicopters and drones with measuring equipment. However, this is expensive and can only be done regionally in coastal areas. Finally, discussions on monitoring through *big-data*, where model estimations based on fuel receipts, ship data and sail routes can tell whether a ship at all times has been able to use compliant fuel, are ongoing.

The $NO_X$ regulation (Tier III) inside NECAs is more difficult to enforce as it necessitates constant monitoring of the EGR and SCR equipment to ensure that these fulfil the desired $NO_X$ reductions, which are defined per kWh engine power (cf. figure 9 above). However, it is also possible to continuously measure $NO_X$ emissions from the stack, and these measurements can be combined with ship engine data and the $CO_2$ content in the flue gas. Thereby, an estimation of the $NO_X$ emissions per kWh can be made, which can be made available through the AIS system. In this way, the ship can be monitored to see if the $NO_X$ regulation (Tier III) is complied with during operation at sea. In the same way control at sea by helicopters can be performed simultaneously with the sulphur control.

In addition, sanctioning may be harmonised within the EU using detention sanctions, where ships violating the regulations are detained for e.g. 15 days in EU ports. On top of extra expenses for port fees, etc., the ship insurance does not cover delay costs when the cargo is delayed due to violations of international sulphur and $NO_X$ regulations.

Finally, shipping companies violating the regulation in Denmark are displayed publicly. They should be displayed in large, international registers as well. Hopefully, insurance companies will deny insuring these shipowners, large companies will avoid using them for transportation, large banks will not authorise loans for them, pension funds will not invest in such shipping companies, ports will deny access for their ships, etc.

# FURTHER REGULATION

As mentioned above, shipping (and air pollution from shipping) is traditionally regulated by the IMO, governing the regulation globally. This solves several challenges such as reflagging of ships to flag states with less strict environmental legislation as well as legal challenges connected to regulation of pollution in international seas. The challenge is, however, that the decision-making process within the IMO is slow and that the decisions are not always environmentally ambitious, since the many stakeholders within the IMO have very different opinions when it comes to environment and climate. From a socio-economic point of view, and to fulfil the Paris agreement for shipping, there is a need for further environmental regulation within the IMO. In addition, market-based regulation of shipping is an overlooked possibility. Finally, regional regulation (or threats of it), e.g. from the EU, often stimulates more ambitious decisions in the IMO. Below, three options for further regulation are discussed, holding the potential to transform shipping into the *green* transport of the future.

1) Further IMO regulation
2) Marked-based regulation
3) Regional regulation

**Further IMO Regulation**

The existing IMO regulation reduces sulphur emissions by 80-90%. In the short term, no further regulation of $SO_2$ emissions from shipping (except for the implementation of more SECAs) should be expected. Instead, enforcement inside and outside SECAs must be prioritised to get the full benefits of the regulation. In the long-term perspective, however, it will be necessary to further reduce sulphur emissions from shipping. This may happen by using alternative fuels and/or by switching to road diesel, since road diesel will become cheaper gradually with the phase-out of diesel cars, which will result in an excess supply of road diesel.

In relation to $NO_X$, the Tier III regulations inside NECAs should be implemented globally; initially for new ships and shortly thereafter for existing ships (it can be done by retrofitting SCR systems). $NO_X$ continues to be the greatest health cost caused by shipping, both inside and outside NECAs. Much stricter global $NO_X$ regulation will ensure optimal regulation from a socio-economic point of view. Until then, as many NECAs as possible should be established.

Negotiations at the IMO are often slow

**Work on the Arctic HFO ban at the IMO is performed by the Clean Arctic Alliance.**

Regulation of particle emissions from shipping should make particulate filters (or similar technologies) mandatory if ships operate in sensitive areas. This is especially relevant in Arctic regions, where soot particles (black carbon) from shipping to a very high extent are deposited on the ice, contributing to ice melting and thereby to global warming; especially since a significant increase in shipping activity through the Arctic is foreseen because the sea ice gradually melts, and a shortcut opens through the Arctic. Furthermore, ports with residential areas polluted with ultrafine soot particles from shipping have a need for particle regulation, either by imposing shore power or filters.

In the Arctic, an obvious first step is a ban on the use of heavy fuel oils from 2024 (instead of 2029 as decided), which will reduce emissions of black carbon around 30%. A similar heavy fuel oil ban has existed in the Antarctic since 2011. Such a ban will also enhance the use of particulate filters and reduce the consequences of oil spills in the sensitive Arctic ecosystems, where a clean-up is almost impossible and oil pollution decomposes very slowly. An impact study of an Arctic heavy fuel oil ban commissioned by Denmark clearly underlines that the ban will not cause notable price increases for consumers in Greenland and will have a positive impact on society due to saved health costs.

$CO_2$ emissions from shipping are expected to significantly increase by 2050 due to increased shipping and will not be able to fulfil the agreed IMO goal or be aligned with the Paris Agreement. Earlier scientific studies have shown that the IMO requirements for $CO_2$ emissions are significantly lacking behind the state-of-the-art technology. For instance, a CE Delft study documented that a substantial fraction of the ships that started operating back in 2014/15 could easily comply with the 2020 EEDI regulation and the most efficient ships from 2014/15 could even comply with the 2025 EEDI regulation. An obvious option is to further tighten the existing EEDI regulation for 2025 (cf. table 12 page 33) and to introduce EEDI regulation for 2030 and onwards that are ambitious. That is, EEDI must reflect best available technology (BAT) and the expected technological progress to achieve the desired $CO_2$ reductions. Hence, to tighten the EEDI regulation for most ship types by 50% by 2024/25 seems more fitting. As rapid technological development is expected, the 2030 regulation could be set at 75% if technology/design is documented available by 2028. Especially because ships built in 2030 will be at sea after 2050. Furthermore, future electro-fuels are expected to be three times as expensive as VLSFO i.e. energy efficient ships will be needed to keep fuel costs down.

In the short term, the most efficient way to achieve $CO_2$ reductions is to reduce speed. The NGO *Seas At Risk* (part of the *Clean Shipping Coalition* in the IMO) has over the last 10 years continuously pointed out the environmental and climate potentials of slower speed. Introducing a global speed/power limit for ships, which is easy to control as ship speed can be measured by the AIS, is a straightforward solution. Sanctions must be introduced in parallel to ensure that ships comply with the speed limit. This would be a very efficient method to ensure a swift $CO_2$ reduction from the existing fleet, thereby buying time until more long-term actions take effect. The speed limit should be differentiated so that $CO_2$ neutral ships can sail at preferred speed, while energy efficient ships can sail at a higher speed than inefficient ships, which must sail at lowest speed. This will help accelerate the development of cleaner shipping.

**At a high-level kick-off event for delegations during COP22 in Marrakech in 2016, organized by Green Transition Denmark and Danish Shipping with support from the Danish Maritime Foundation and Climate Works Foundation, it was suggested that the share of $CO_2$ emissions from shipping should not exceed the current level. Thus, the fraction of 2.8% of global $CO_2$ emissions that shipping is currently emitting must not increase. Hence, $CO_2$ emissions from shipping must as a minimum be reduced at the same rate as global $CO_2$ emissions.**

**Carbon levy**

A levy is the most cost-efficient way to stimulate green transition next to transferable quotas. The basic idea is to put a price on emissions (here calculated simply as $CO_2$ tank-to-wake) and thereby incentivize reduced emissions. The polluter decides if it is best to reduce emissions or pay - and the polluter decides how to reduce emissions.

Levies work if they are significant enough to motivate changes e.g. energy savings and/or switch to zero carbon fuels. Furthermore, levies need to prospectively be transparent to stimulate investments in green transition of shipping, such as production of zero carbon fuels, development of new engines, etc. Levies should be adjusted over time in parallel with fuel price development. Finally, levy revenues can reduce green transition costs by reimbursing the revenue as financial subsidies for zero carbon fuels.

Business case without a levy

Green ammonia/methanol fuel will probably cost around USD 1,500 per tonne fuel oil energy equivalent (FO-eq). The current price of VLSFO is around USD 500 per tonne and HFO is around USD 400 per tonne (March 2021). The price gap between green ammonia/methanol, and VLSFO and HFO, respectively, will be:

- USD 1,000 for VLSFO per tonne FO-eq
- USD 1,100 for HFO per tonne FO-eq.

There is therefore no financial driver for green shipping fuels due to the price gap.

A carbon levy closes the price gap

By introducing a basic levy of USD 100 per tonne $CO_2$ (tank-to-wake, GWP 100) to VLSFO/HFO in 2025, which will correspond to a price increase of around USD 300 per tonne VLSFO/HFO, and subsequently increase the levy by USD 30 per tonne $CO_2$ per year reaching USD 250 in 2030 and USD 400 in 2035 corresponding to a price increase of USD 750 and USD 1,200 per tonne VLSFO/HFO in 2030 and 2035, respectively, the price gap will be closed since VLSFO/HFO prices will exceed that of green ammonia/methanol fuel. A similar

**Table 13:** Levy, reimbursement and resulting fuel prices towards 2040 driven by a carbon levy.

| Year | VLSFO ($/t) market price | HFO ($/t) market price | Levy in $ per tonne $CO_2$ (tank-to-wake, GWP 100) | Levy in $ per tonne VLSFO/HFO (tank-to-wake, GWP 100) | VLSFO ($/t) price with levy | HFO ($/t) price with levy* | Green $NH_3$/methanol ($/t FO-eq) market price | Green $NH_3$/methanol ($/t FO-eq) reimbursement | Green $NH_3$/methanol ($/t FO-eq) net price |
|---|---|---|---|---|---|---|---|---|---|
| 2025 | 500 | 400 | 100 | 300 | 800 | 700 | 1500 | 825 | 675 |
| 2026 | 400 | 300 | 130 | 390 | 790 | 690 | 1500 | 825 | 675 |
| 2027 | 300 | 200 | 160 | 480 | 780 | 680 | 1500 | 825 | 675 |
| 2028 | 200 | 100 | 190 | 570 | 770 | 670 | 1500 | 825 | 675 |
| 2029 | 100 | 100 | 220 | 660 | 760 | 760 | 1500 | 825 | 675 |
| 2030 | 100 | 100 | 250 | 750 | 850 | 850 | 1500 | 825 | 675 |
| 2031 | 100 | 100 | 280 | 840 | 940 | 940 | 1500 | 725 | 775 |
| 2032 | 100 | 100 | 310 | 930 | 1030 | 1030 | 1500 | 625 | 875 |
| 2033 | 100 | 100 | 340 | 1020 | 1120 | 1120 | 1500 | 525 | 975 |
| 2034 | 100 | 100 | 370 | 1110 | 1210 | 1210 | 1500 | 425 | 1075 |
| 2035 | 100 | 100 | 400 | 1200 | 1300 | 1300 | 1500 | 325 | 1175 |
| 2036 | 100 | 100 | 430 | 1290 | 1390 | 1390 | 1500 | 225 | 1275 |
| 2037 | 100 | 100 | 460 | 1380 | 1480 | 1480 | 1500 | 125 | 1375 |
| 2038 | 100 | 100 | 490 | 1470 | 1570 | 1570 | 1500 | 0 | 1500 |
| 2039 | 100 | 100 | 520 | 1560 | 1660 | 1660 | 1500 | 0 | 1500 |
| 2040 | 100 | 100 | 550 | 1650 | 1750 | 1750 | 1500 | 0 | 1500 |

FO-eq: Fuel oil energy equivalent. *On top of this comes scrubber costs.

levy should be introduced on natural gas, distillate fuels, etc. The revenue should be reimbursed as support for green ammonia/methanol and poor developing countries (table 13). This could result in decarbonisation of shipping towards 2040 (table 14 and figure 14), which aligns with the Paris-agreement. Furthermore, huge fuel savings are gained since many savings have reduction costs far below these fuel prices. Price increases for the end consumer will be negligible (less than 0.5%).

Business case with a levy in 2030
Assuming green ammonia/methanol will cost USD 1,500 per tonne FO-eq and that the price of VLSFO and HFO will drop to USD 100 per tonne due to reduced demand. Levy cost for VLSFO/HFO: USD 750 per ton FO-eq. Reimbursement: USD 825 per tonne FO-eq cf. table 14.

Zero carbon fuels will thereby be financially attractive since the price of VLSFO/HFO incl. levy will be USD 850 (100 + 750) per tonne and the reimbursement reduces the price of green ammonia/methanol to USD 675 (1,500 - 825) per tonne FO-eq. Hence, this will give a financial driver for green shipping.

The levy and reimbursement should, of course, be adjusted in relation to the actual development in the price of VLSFO/HFO and green ammonia/methanol as well as other key factors.

Thereby, the decarbonisation curve for shipping could look different from figure 14, which is only based on a quick back-of-the-envelope calculation to illustrate the key principle.

**Figure 14:** Possible course for full decarbonisation in 2038 driven by a carbon levy per 100 tonne FO-eq.

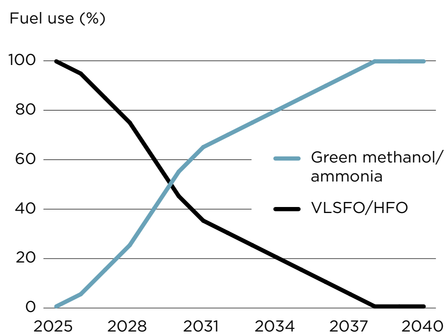



**Table 14:** Possible course for full decarbonisation in 2038 driven by a carbon levy per 100 tonne FO-eq.

| Year | Use of VLSFO/HFO (t) | $CO_2$-levy revenue ($) | Use of green $NH_3$/methanol (t FO-eq) | Total reimbursement ($) | Administrative costs, 5 % of revenue ($) | Compensation to poor countries, 2.5% of revenue ($) | Reimbursement account balance, accumulated ($) |
|---|---|---|---|---|---|---|---|
| 2025 | 100 | 30000 | 0 | 0 | 1500 | 750 | 27750 |
| 2026 | 95 | 37050 | 5 | 4125 | 1853 | 926 | 57896 |
| 2027 | 85 | 40800 | 15 | 12375 | 2040 | 1020 | 83261 |
| 2028 | 75 | 42750 | 25 | 20625 | 2138 | 1069 | 102180 |
| 2029 | 60 | 39600 | 40 | 33000 | 1980 | 990 | 105810 |
| 2030 | 45 | 33750 | 55 | 45375 | 1688 | 844 | 91654 |
| 2031 | 35 | 29400 | 65 | 47125 | 1470 | 735 | 71724 |
| 2032 | 30 | 27900 | 70 | 43750 | 1395 | 698 | 53781 |
| 2033 | 25 | 25500 | 75 | 39375 | 1275 | 638 | 37994 |
| 2034 | 20 | 22200 | 80 | 34000 | 1110 | 555 | 24529 |
| 2035 | 15 | 18000 | 85 | 27625 | 900 | 450 | 13554 |
| 2036 | 10 | 12900 | 90 | 20250 | 645 | 323 | 5236 |
| 2037 | 5 | 6900 | 95 | 11875 | 345 | 173 | 0* |
| 2038 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| 2039 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| 2040 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |

FO-eq: Fuel oil energy equivalent. *Rounded to USD 0 (calculated as minus USD 256 ≈ 0)

## Market-based regulation

The first step towards market-based regulation is to create market transparency, i.e. information on pollution from different ships. This creates a market signal allowing cargo owners, banks and professional investors to select the least polluting ships. The market signal must be understandable and the ranking method must be based on transparent conditions.

Environmental labelling of ships from A to E, as it is known from other sectors, is an effective market signal. The labelling should be based on reductions relative to a well-defined baseline (such as it is done with the EEDI), e.g. based on reductions compared to pollution from a standard ship on the same route in 2013-14. The baseline and reductions must be documented by an independent and recognised audit. The IMO may select organisations that issue labels based on the audit. Table 15 lists proposals for reductions (compared to baseline) needed for different labels.

The minimum regulation that must be fulfilled to obtain label E is a basic reduction compared to the baseline. However, this reduction is achieved through the existing sulphur regulation combined with minor operational changes and simple technical solutions. To attain a D label, more than just minor changes must be made. Good, new container ships with EGR, using *slow steaming*, and good newer ships with simple SCR plus other operational measures, will automatically achieve a D label.

Better labelling requires both new ships with energy efficient design and/or the installation of a wide range of operational and technical solutions combined with new types of fuels. Electric and green electro-fuel powered ships fuelling in the EU can be classified with an A label, since $CO_2$ emissions from power generation are regulated by a fixed number of emission allowances (emissions of $SO_2$, $NO_X$ and particles from the power plants are sealed by emission allowances as well). In principle, a ship then becomes pollution neutral when using electricity (or electro-fuels) produced in the EU, as the number of $CO_2$ ($SO_2$, $NO_X$ and particles) emission allowances are fixed.


**Table 15:** Reductions (tank-to-wake) for labelling in percent compared to the baseline.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| **$CO_2$** | 95 | 75 | 50 | 40 | 30 |
| **$SO_2$** | 95 | 95 | 90 | 80 | 80 |
| **$NO_x$** | 95 | 80 | 80 | 50 | 20 |
| **Fine particles** | 95 | 80 | 50 | 30 | 30 |

**The Norwegian government pension fund, which invests more than USD 995 billion, has banned investments in four shipping companies after discovering that they left their ships for scrapping under questionable environmental conditions in Bangladesh and Pakistan. If large pension funds, such as this one, decide only to invest in shipping companies with labelled ships from 2025, the labelling would have a swift offset.**


The labelling should be voluntary just like the FSC label and Fairtrade. Through the labelling, large global cargo owners, banks and professional investors can integrate pollution from shipping in their environmental policies (CSR goals). For instance, a cargo owner can choose to use at least 40% C labelled, 30% D labelled and 30% E labelled ships from 2025; similarly, banks and professional investors (e.g. pension funds) could decide to only lend money to and invest in shipping companies that, by 2025, have as a minimum label E ships. Investment rules could then be tightened year after year.

The labelling enables companies' green accounting to include a quantitative overview of shipping activities categorised by labelling. This makes the pollution from shipping visible, thus enabling public procurement officers and large, responsible companies to dictate environmental regulations for their suppliers' shipping transport. Environmental NGOs can also push companies to request more and more ambitious labels for their shipping transport. Ultimately, consumers can through the media be made aware of the environmental shipping label used by companies, thereby visualising the pollution from shipping to the end user. Hence, the consumer can push companies even further towards more ambitious environmental labels for their ship transport.

As a result, some shipowners will see an economic potential in having labelled ships, as it becomes a condition for transporting certain cargo, getting certain loans approved and attracting certain investors. If more and more companies set environmental requirements for ship labels, more and more shipping companies will get labels for their ships. With an increasing demand for still more ambitious labels, shipowners will request still better ships that will emit still less pollution.

The largest technical challenge in the proposed labelling system is that, e.g., container ships often transport cargo for many different clients, which may demand different environmental labels. A need for flexibility may therefore be needed during a transition period. If 10% of the clients require label C, 20% require label D, 40% require label E and 30% have no requirements, the whole cargo can of course be transported by a ship with label C. Alternatively, the cargo could be transported so that the total pollution from the complete transport corresponds to 10% of the route being sailed with a label C ship, 20% of the route with a label D ship and 40% of the route with a label E ship. This will of course increase requirements for documentation and control during a transition period.

## Regional regulation

Regional environmental regulation in important shipping regions has several times accelerated IMO decisions. As an example, the EU's decision to introduce a sulphur regulation of maximum 0.5% by 2020 (in EU seas outside the SECA) contributed to ensuring a global sulphur regulation of 0.5% by 2020 decided by the IMO. The EU has recently decided to integrate shipping in EUs $CO_2$ regulation because of lack of actions from IMOs side. This happens by introducing a carbon levy on half of the $CO_2$ emission from international shipping to/from EU ports i.e. EU takes responsibility for half of the emission. This regulation is not enough (with the planned $CO_2$ levy reflecting the carbon price in the ETS) to stimulate a transition to clean fuels (like green ammonia) that is expected to be three times more expensive than fuel oils, as described above. However, it is an important step in the right direction. The EU-based umbrella organization *Transport & Environment* has been one of the main drivers behind this regulation.

Regional regulation introduces a progressive pressure on the development of the climate strategy in the IMO. It is stimulating a faster and more ambitious result than what would have been achieved without the EU regulation. Hence, regional regulation can both raise the bar and increase the probability of success in the IMO. Finally, the EU has decided on the so-called MRV (Monitoring, Reporting, Verification), which from 2018 requires that all ships calling at EU ports must report their $CO_2$ emissions. By expanding the MRV to include $NO_X$, $SO_2$ and fine particles, it can serve as a basis for a labelling system (cf. market-based regulation above).

In addition to the above labelling of ships (cf. page 44), regional areas (EU and US) could introduce port fees according to labels of ships: the better label, the lower port fees. By doing so, ships without a label would be charged very high port fees in the EU and/or the US, E labelled ships would be charged high fees, etc. This would ensure a direct economic incentive for ships to acquire a label and implement technical solutions and operational measures to attain the best possible label. Further, a decision dictating that all cruise ships and ferries in major EU ports must use shore power (or efficient flue gas cleaning) by 2025 could be made. Regional regulation will require all ports within a larger area, e.g. the EU or the US, to coordinate. This could be done by making central decisions within the EU and/or the US on, e.g., harmonised minimum port fees for each ship label. Furthermore, port access for the most polluting ships or ships using heavy fuel oils in the Arctic should be denied.

More complete ECAs (combined SECAs and NECAs) in densely populated areas with major shipping routes need to be established to protect people and society from health hazardous air pollution. As an example, the Mediterranean, which is shared between EU states, African states, Turkey, etc., is a very densely populated area with major shipping routes and should be protected by a complete ECA as soon as possible. This ECA has been discussed for many years in REMPEC that, now (summer 2021), seems to be ready to submit a SECA proposal for the IMO, followed by a NECA proposal. However, since $NO_X$ by far constitutes the health costs from shipping in the Mediterranean Sea it is urgent to also introduce a NECA in the region.
Alternate to a complete ECA covering the whole Mediterranean Sea, the EU could introduce an ECA in all EU territorial seas and/or introduce a high and harmonized EU port fee for ships entering EU ports without fulfilling the SECA and NECA regulation in all the Mediterranean Sea.

**Project LIFE4MEDECA is funded under the EU LIFE programme to support designating a complete Mediterranean Sea ECA.**

**Promotion movie for a complete ECA in the Mediterranean Sea:**

**WATCH MOVIE**

(or go to https://m.youtube.com/watch?v=N0mfpIX-0aQ)

**Consequences of regulations**

As shipping is $CO_2$ effective compared to other modes of transport, it is important that regulation does not encourage shifting cargo from ships to trucks. The regulation corresponding to the most ambitious labels (A and B, cf. table 15 page 44) will increase the price of ship transport, while no greater costs are connected to meeting the regulations for label C, D and E. Ship transport is, however, quite inexpensive compared to other modes of transport, thus, a significant shift is not foreseen even if regulation in the long term results in label A and B ships.

The actual transport costs for cargo transported by ship typically represent very little of the final product price. Hence, small price increases is not foreseen to influence the demand, even when using the most ambitious environmental regulation or when all ships use green ammonia. If, for instance, the transport costs are doubled for shipping wine from New Zealand to the EU, the price of the wine at the supermarket will increase with about 1%, which corresponds to roughly USD 0.08 per bottle. Such a price increase will not affect demand. For electronics coming from Asia, the relative price increase is much smaller. By implementing ambitious environmental and climate regulation for shipping, only for low-cost products, such as wood pellets, coal, ore, etc., the price will visibly increase. However, trains and trucks will only to a very limited extent be competitive transport modes for bulky products.

Increased costs for cleaner fuels and/or exhaust gas cleaning do not increase consumer prices in the ECA. The transport costs for a pair of shoes shipped from Asia to Europe without an ECA are about 15 euro cents. Half of these costs are related to fuel, i.e. 7.5 euro cents. When introducing the intended complete ECA, costs will increase around 15% for about 10% of the distance from Asia, i.e. the price increase of shoes in a shop in the Mediterranean will be about 7.5 euro cent · 0.15 · 0.10 = 0.1 euro cent. If the shoes cost 40 euro before the ECA then the price increase will be 0.0025% due to the complete ECA.

By ensuring international regulation or harmonized regulation in larger regional entities, e.g. for ports in the EU/US, notable distortion of competition is avoided. Ship-owners can thus pass on additional costs of cleaner shipping to cargo owners who will further pass on costs through the value chain to the end-user. Nevertheless, the price increase will be so small and insignificant that the consumer will hardly notice the difference. In return, consumers gain longer and healthier lives, and damage on buildings, crops and the climate is reduced.

Further regulation using levies, market-based regulation through labelling, and regional regulation complements other regulations and allows faster pollution reductions, which are needed to gain the health benefits and decarbonize shipping in accordance with the Paris-agreement.


# COMMERCIAL POTENTIALS

Denmark has a unique position when it comes to shipping and technical solutions for reduction of air pollution from shipping. Denmark is the home of the world's largest container company, the world's largest developer and supplier of ship engines as well as the world's leading clean-tech companies in the field of flue gas cleaning technologies. Furthermore, Denmark has developed one of the leading research and consultancy communities in terms of mapping and reducing pollution from shipping. Globally, Denmark is recognised as a leader in both shipping and clean-tech.

Several Danish key stakeholders within shipping have joined forces in *Green ship of the future*, an innovation network that aims at developing emission free shipping. The efforts towards cleaner shipping are also strongly rooted within the authorities and the industry associations *Danish Shipping* and *Danish Maritime*, acting at the forefront of international negotiations on cleaner shipping.

In Denmark, several power2x projects are now starting to convert clean wind energy to hydrogen and ammonia for cleaner shipping fuels. In parallel, MAN Energy Solutions are constructing and optimizing the first generation of ammonia engines for shipping."

Danish ships are in general larger and newer than the average world fleet. Thus, pollution from Danish ships is on average less than the world fleet per transported tonne of cargo. These unique circumstances, together with the many Danish environmental competencies, make further environmental regulation of shipping possible. Further regulation will at the same time promote a swifter scrapping of the oldest and most polluting ships, which will be replaced by new ships, many of which will be equipped with a Danish engine and environmental technology. Thereby, further environmental regulation will only improve the competitiveness of the Danish maritime sector and both uphold and secure the status of the country as a leading green maritime nation. The same will be the case for all other flag states being frontrunners on maritime environmental matters.

# RECOMMENDATIONS

To transform shipping into *the green transport of the future*, it is necessary to reduce pollution further in both the short and the long term. This will require a tightening of existing regulation and a focused effort on international, regional and national levels.

**The International Maritime Organization should:**

> Expand Tier III regulation of $NO_X$ to all new ships from 2025 and all ships from 2030.
> Put a carbon levy of USD 100 per tonne $CO_2$ in 2025 and increase the levy by USD 30 per year.
> Introduce a $CO_2$-depending speed/power limit leading to lower speed/power from 2024.
> Raise EEDI requirements to 50% by 2025 and to 75% by 2030, if technically possible by 2028.
> Reduce $CO_2$ from shipping aligned with the 1.5°C goal of the Paris Agreement.
> Decide that $CO_2$ emissions from ships must not exceed 3% of global emissions at any time.
> Initiate an ambitious and standardized labelling of ships based on $CO_2$, $SO_2$, $NO_X$ and particles.
> Decide on a global MRV for ships' emissions of $CO_2$, $SO_2$, $NO_X$ and fine particles from 2025.
> Ban discharge of scrubber water in all seas from 2025 and ban scrubbers from 2030.
> Ban heavy fuel oils and require flue gas cleaning for black carbon in the Arctic from 2024.
> Decide that new ships by 2030 shall fulfil the same emission standards as trucks in EU in 2020.

**Regional entities (EU, USA, Asia, etc.) should:**

> Ensure efficient enforcement (control and sanctioning) of global and regional regulations.
> Introduce full ECAs in all territorial seas and, if possible, in all surrounding international seas.
> Exclude the most polluting ships and ships using heavy fuel oil from ports from 2025.
> Ban any discharge of scrubber water from ships in all territorial seas from 2025.
> Exclude ships with scrubbers from entering all ports from 2028.
> Devise a labelling system and introduce high port fees for ships with poor environmental labels.
> Recommend international companies to set CSR goals in relation to environmental labels.
> Demand that cruise ships and ferries at berth in all large ports use shore power by 2025.
> Introduce an MRV system for $SO_2$, $NO_X$, fine particles and black carbon for ships by 2025.
> Stop all support of fossil fuels or fossil fuel infrastructure (including LNG).

**National authorities should:**

> Push for stricter environmental regulation both at the IMO and regionally (see above).
> Ensure efficient enforcement of regulations and share national experience globally.
> Promote cleaner shipping in green public procurement.
> Stop all support of fossil fuels or fossil fuel infrastructure (including LNG).
> Ban discharge of scrubber water from ships in all territorial seas from 2025.

# MORE INFORMATION

**Websites**
Green Transition Denmark: www.rgo.dk/frontpage-english/air-pollution/
Clean Arctic Alliance: www.hfofreearctic.org
Seas At Risk: www.seas-at-risk.org/
ICCT: www.theicct.org/marine
Danish Shipping: www.danishshipping.dk/en
Green Ship of the Future: www.greenship.org
International Windship Association: www.wind-ship.org
EU Interreg program project WASP: www.northsearegion.eu/wasp/
EU LIFE project LIFE4MEDECA: www.uniondelosoceanos.com/life4medeca-en
Transport & Environment: https://www.transportenvironment.org/challenges/ships/
IMO: www.imo.org/en/OurWork/Environment/Pages/AirPollution-Default.aspx

**Key publications**
IMO's carbon intensity target could be the difference between rising or falling shipping emissions this decade:
https://theicct.org/blog/staff/updated-imo-carbon-intensity-target-may2021

Zero-emission shipping and the Paris Agreement:
https://theicct.org/blog/staff/marine-shipping-imo-ghg-targets-global-sept21

Accounting for well-to-wake carbon dioxide equivalent emissions in maritime transportation climate policies:
https://theicct.org/publications/well-to-wake-co2-mar2021

Cost-benefit analysis of $NO_X$ control for ships in the Baltic Sea and the North Sea:
www.ivl.se/download/18.3016a17415acdd0b1f4961/1493194706323/C228.pdf

Nordic Action for a Transformation to Low-carbon Shipping:
http://norden.diva-portal.org/smash/get/diva2:1111495/FULLTEXT01.pdf

By joining
Green Transition Denmark,
you can support our efforts to
reduce air pollution and climate
pollutants from shipping.
Read more on: www.rgo.dk
or write to info@rgo.dk

GREEN TRANSITION
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# GLOSSARY

**AIS:** Automatic Identification System
**CII:** Carbon Intensity Indicator
**Dwt:** Deadweight Tonnage
**ECA:** Emission Control Area
**EEDI:** Energy Efficiency Design Index
**EEOI:** Energy Efficiency Operational Indicator
**EEXI:** Energy Efficiency Existing Ship Index
**EGR:** Exhaust Gas Recirculation
**ETS:** Emission Trading System (of the EU)
**FO-eq:** Fuel oil energy equivalent
**GHG:** Green House Gas
**GWP:** Global warming potential
**HFO:** Heavy Fuel Oil
**LNG:** Liquefied Natural Gas
**MRV:** Monitoring, Reporting and Verification
**NECA:** $NO_X$ Emission Control Area
**$NO_X$:** Nitrogen oxides
**$PM_{0.1}$:** Ultrafine particles
**$PM_{2.5}$:** Fine particles
**REMPEC:** Regional Marine Pollution Emergency Response Centre (for the Mediterranean Sea)
**SCR:** Selective Catalytic Reduction
**SECA:** Sulphur Emission Control Area
**SEEMP:** Ship Energy Efficiency Management Plan
**$SO_2$:** Sulphur dioxide
**VLSFO:** Very Low Sulphur Fuel Oil
**WHR:** Waste Heat Recovery

# CLEANER SHIPPING


Most global cargo (80-90%) is transported by ship. Shipping is thereby a key platform for increasing global trade. However, the high transport share and the weak environmental regulation of shipping result in a significant contribution to global warming and air pollution with negative health effects caused by sulphur dioxide ($SO_2$), nitrogen oxides ($NO_X$) and particle emissions.

Most air pollutants from shipping are long-range transboundary and significantly contribute to mortality, morbidity, and nature damage on land. Every year, air pollution from shipping causes approximately 40,000 premature deaths in Europe and cost more than USD 55 billion due to negative health effects. On top of this comes global warming and damage on nature, crops, buildings, etc.

More than 60,000 ship passages (large commercial ships) pass through the seas around Denmark every year. As large container ships only sail 5-10 meters per litre of fuel, vast amounts of fuel oil are thus combusted in Danish seas near densely populated coastal areas resulting in associated high air pollution.

The solution is to reduce air pollution and $CO_2$ emissions from shipping and transform shipping into the green transport of the future. This requires both further environmental regulation of shipping and an efficient enforcement, which will ensure a level playing field for the industry allowing shipping companies to pass on abatement costs.

This booklet focuses on pollution with $CO_2$, $SO_2$, $NO_X$ and particles from shipping, technical solutions, the existing regulation and enforcement as well as potential benefits achieved through further environmental regulation of shipping. The purpose of the booklet is to inspire decision-makers and stakeholders to work focused on further environmental regulation of shipping to the benefit of public health, society, the climate, and nature.

GREEN TRANSITION DENMARK

EUROPEAN UNION