Shore Connection Technology

Environmental Benefits and Best Practices

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Abstract

When it comes to protecting the environment, port communities are on the front lines. The combustion of high-sulfur-content marine fuels in port areas is a major contributor to air pollution and the associated impacts on human health and the environment. Local, national, and international regulations are putting increasing pressure on the maritime industries to control air pollution. This white paper examines shore connection technologies as a way to curb the air pollution generated by maritime shipping activities.

Glossary

Ship emissions	● Particulate Matter (PM); - PM 10, Particulate Matter with aerodynamic diameters of 10 µm - PM 2.5, Particulate Matter with aerodynamic diameters of 2.5 µm ● Nitrogen Oxides, NO_X (NO and NO_2) ● Sulfur Oxide, SO_X (SO_2); ● Carbon Oxide (CO) ● Carbon Dioxide (CO_2) ● Volatile Organic Compounds (VOCs); benzene, toluene, ethylbenzene, and xylene-volatile aromatic compound typically found in petroleum product, such as gasoline and diesel fuel ● Green House Gas (GHG).
AQMD	Air Quality Management District
CARB	California Air Resources Board
ECA	Emissions Control Areas
EEDI	Energy Efficiency Design Index
EPA	Environmental Protection Agency
IAPH	International Association of Ports and Harbors
IMO	International Maritime Organisation
MARPOL	International Convention for the Prevention of Pollution from Ships
PRD	Pearl River Delta
SECA	Sulfur Emissions Control Areas
SEEMP	Ship Energy Efficiency Management Plan
TEU	Twenty Foot Equivalent Unit
WHO	World Health Organization
WPCI	World Ports Climate Initiative

1 Air pollution from maritime shipping

In recent years, public concern about the environmental impacts of maritime shipping has increased. Maritime shipping is responsible for a considerable amount of total global CO_2 emissions and air pollutants. And, if the current trends are not reversed, this situation will only worsen.[1]

In 2009, CO_2 emissions from maritime shipping activities were estimated to account for between 3% and 5% of total global CO_2 emissions.[1] In addition, estimates show that in 2050 maritime shipping will be responsible for 15% of total global CO_2 emissions.

Other air pollutants, such as sulfate, continue to rise and will contribute up to 5.2% to the total tropospheric sulfate burden in 2012.[1]

To a large extent, the health and environmental impacts of air pollutants depend on how near the emission sources are to sensitive receptor sites. On the surface, it would appear that maritime shipping emissions—released far from populated areas or sensitive ecosystems—have less obvious health and environmental impacts than land-based sources of pollution.

And yet, the air pollution generated by maritime shipping activities is carried over hundreds of kilometers, contributing to air quality problems on land. This is particularly true for sulfur and nitrogen compounds.[1]

Given that nearly 70% of ship emissions are released within 400 kilometers of land, ships are potentially major contributors to air pollution in coastal communities.[2] In harbor cities ship emissions are often a leading source of urban pollution, and, in particular, fine particulate matter (PM).

One important factor to consider is that, for economic reasons, many shipping vessels use heavy fuel oil with high sulfur content. As an example, the sulfur content of standard marine fuel is 2,700 times higher than that of conventional diesel for cars.

Heavy fuel oil is responsible for the following air emissions:[1]

- Particulate matter (PM)
  - PM 10, particulate matter with an aerodynamic diameter of 10 µm
  - PM 2.5, particulate matter with an aerodynamic diameter of 2.5 µm
- Nitrogen oxides, NO_X (NO and NO_2)
- Sulfur oxide, SO_X (SO_2)
- Carbon oxide (CO)
- Carbon dioxide (CO_2)
- Volatile organic compounds (VOCs): benzene, toluene, ethyl benzene, and xylene, a volatile aromatic compound typically found in gasoline and diesel fuel.

The amount of air emissions produced by marine engines is directly related to total fuel oil consumption, which depends on different factors: mainly hull shape, loading conditions, and engine operating condition.

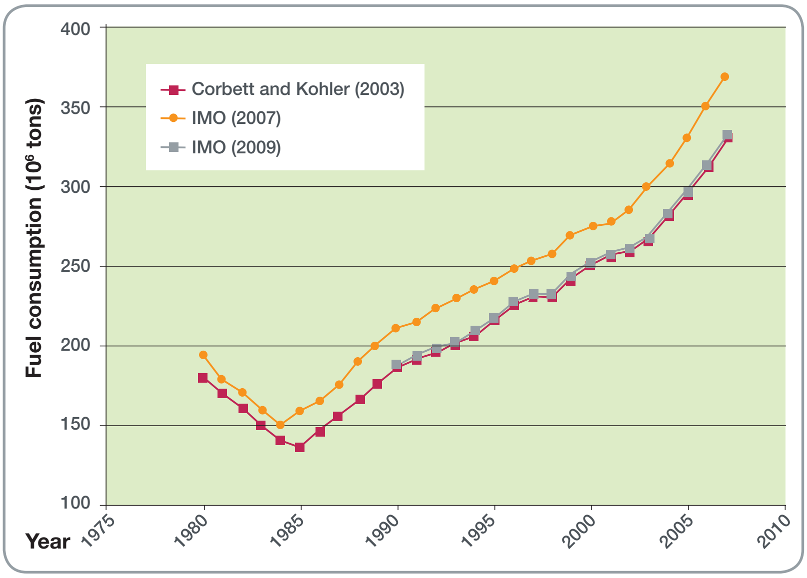
1. “Regulating Air Emissions from Ships.” November 2010
2. “Mortality from ship emissions.” 15 December 2007

Maritime fuel oil consumption has risen steadily since 1985. In fact, it has more than doubled over the last 25 years (IMO 2007, IMO2009, and Corbett and Kholer 2003) and will only continue to increase (Fig. 1).[1]

Auxiliary engines also contribute to total exhaust gas emissions. This is particularly true for cruise ships with their constant demand for power to meet lighting, ventilation, and air conditioning needs both at sea and at port.

Onboard waste incineration is another source of emissions, including dioxins and other heavy metals.[1]

Fig. 1 - **Estimated maritime shipping fuel oil consumption 1975–2010**



It is now well established that maritime shipping contributes significantly to air pollution, particularly in coastal areas.[2]

Annually, oceangoing ships are estimated to emit:
- 1.2–1.6 million tons of PM 10
- 4.7–6.5 million tons of sulfur oxides
- 5–6.9 million tons of nitrogen oxides

Studies have estimated that around 15% of global NO_X and between 5% and 8% of global SO_X emissions are attributable to oceangoing vessels.[2]

1. “Regulating Air Emissions from Ships.” November 2010
2. “Mortality from ship emissions.” 15 December 2007

1.1 Shipping-related air pollution in Europe

While pollutant emissions from land-based sources are gradually decreasing, pollutant emissions from maritime shipping continue to rise.[4]

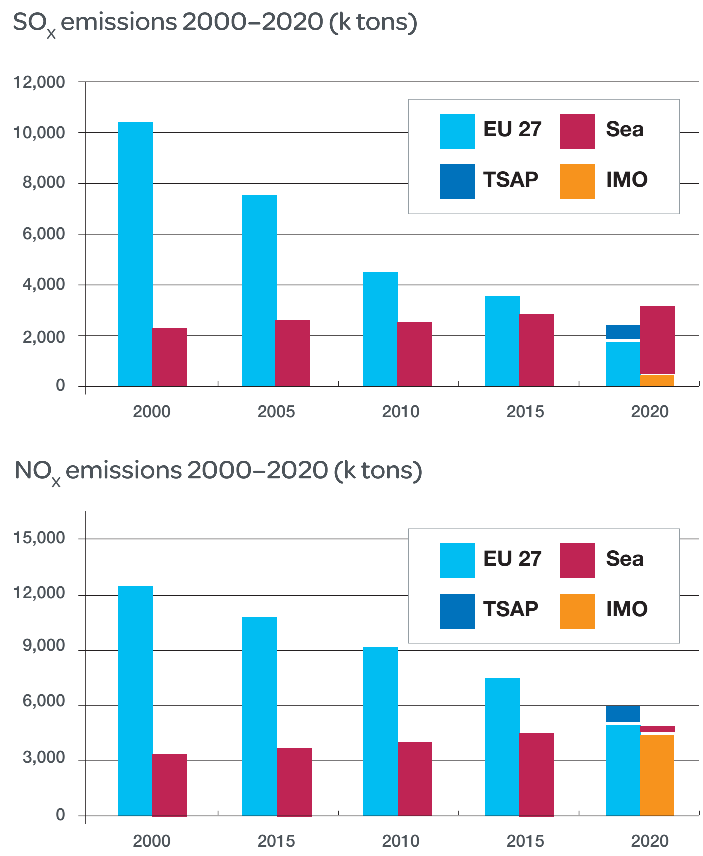
International trade shipping emissions around Europe are expected to reach—or even surpass—total land-based pollution across all 27 EU member states by 2020 (Fig. 2).[4]

The emissions from international trade shipping in the seas surrounding Europe—the Baltic Sea, the North Sea, the northeastern Atlantic, the Mediterranean, and the Black Sea—were estimated at 2.3 million tons of sulfur dioxide (SO_2), 3.3 million tons of nitrogen oxides (NO_x), and 250,000 tons of particulate matter (PM) a year in 2000.[4]

Under the current legislation, it is expected that, by 2020, shipping emissions of SO_2 and NO_x will increase by 40% to 50% over 2000 levels.[4]

These figures, as alarming as they are, include only emissions from international trade shipping. They do not factor in emissions from shipping on EU member states' internal waterways or emissions from ships plying harbor within the same country.[4]

Fig. 2 - SO_x and NO_x emissions in Europe (air pollution from ships)



EU27: Emissions from land-based sources in EU countries (incl. domestic shipping)
Sea: Emissions from international shipping in European seas
TSAP: Target in line with the EU Thematic Strategy on Air Pollution of September 2005
IMO: Expected outcome from implementing the preliminary IMO agreement of April 2008

4. "Air pollution from ships." November 2011

1.2 Shipping-related air pollution in the United States[5]

In the United States, air quality has improved substantially over the last 40 years. Despite population growth, increased motor vehicle traffic, and rising economic activity, total air pollution has fallen by 160 million tons (53%).

However, emissions from shipping are a major exception to these trends. Although emission controls have reduced pollution from new cars and trucks by more than 90%, most oceangoing ships operate without pollution controls at all. New and remanufactured engines on tug boats, ferries, and other vessels have been subject to emission controls since 2008 and 2009, but most existing engines in vessels of these types remain uncontrolled.

The problem is particularly acute in the Los Angeles-Long Beach area—which is both the United States' busiest port and most polluted area.[2] According to the South Coast Air Quality Management District (AQMD):

- Oceangoing vessels are among the largest sources of nitrogen oxides (NO_x) in the area, emitting more NO_x than all power plants and refineries in the South Coast air basin combined. NO_x reacts with volatile organic compounds in the atmosphere to produce ozone and smog.
- 70% of the area's sulfur dioxide (SO_2) emissions come from ships. According to the AQMD, these emissions need to be cut by over 90% if the area is to attain the national air quality standard for particulates by the 2014 deadline.
- Every year, more than 700 premature deaths in the Los Angeles area can be attributed to these emissions, according to the AQMD.

While the Los Angeles-Long Beach area may be the most extreme example, the problem is not limited to Los Angeles or even to California.

According to the United States Environmental Protection Agency (EPA), more than 40 U.S. ports nationwide are located in areas where ozone, fine particulates or both have reached unacceptable levels. In addition, according to the EPA, the problem is not limited to port areas alone. Santa Barbara County, which has no commercial ports, estimates that by 2020, 67% of its NO_x inventory will come from shipping traffic transiting the California coast.

5. "CRS Report for congress. Air pollution from ships: MARPOL Annex VI and other control options." September 2008.

1.3 Shipping-related air pollution in China [6,7]

China's increasing influence on the global economy and its geographical location in the heart of Asia have placed the country at the center of global environmental concerns. And no region of China demonstrates this fact more plainly than the Pearl River Delta (PRD) on the southern coast of China.

The PRD consists of the former colonies of Hong Kong and Macau, the West River Delta, the North River Delta, and the East River Delta in Guangdong Province. The PRD encompasses fourteen counties.

The PRD's massive economic growth and the frenetic activity in its ports have led to considerable air, water, and soil pollution in the region.

The PRD is home to some of the world's busiest container ports[8]:

- Hong Kong, the world's third-largest port with 23.7 million TEU in 2010
- Shenzhen, the world's fourth-largest port with 22.51 million TEU in 2010
- Guangzhou, the world's seventh-largest port with 12.55 million TEU in 2010
- Taiwan, the world's twelfth-largest port with 9.18 million TEU in 2010

Consequently, the PRD's inhabitants are particularly vulnerable to the harmful effects of ship emissions.

An estimated 3.8 million people live near the port of Hong Kong and are directly affected by ship and port-related emissions.

More generally, ship emissions contribute to China's already significant air pollution problem. Figure 3 illustrates the gravity of the situation in Hong Kong.

Fig. 3 - The health costs of air pollution in Hong Kong

200 **Air pollutant concentrations** are today 200% higher than 2006 WHO guidelines.

20 **The annual benefits** of air quality improvement are estimated at $20 billion.

6, 7. "Air pollution in the Pearl River Delta." 2010
"Green harbours: Hong Kong and Shenzhen, reducing marine-and port-related emissions in the Pearl River Delta." June 2008
8. World Shipping council, "Top 50 World Container Ports", http://www.worldshipping.org/about-the-industry/global-trade/top-50-world-container-ports

2 The effects of shipping-related pollution on human health

Historically, ports have generally developed very close to major urban areas. And port operations affect the health of the millions of people living and working in these areas. The negative effects of port activities on local air quality and human health are largely attributable to pollutants like PM 2.5, PM 10, NO_x, SO_x, and acid deposition.[1]

2.1 The effects of particulate matter (PM)

Ambient concentrations of PM have been associated with a wide range of health problems—like asthma and heart attacks—resulting in hospital admissions.[2] Premature mortality is a major PM-related health issue. Increases in PM 2.5 concentrations have been closely associated with higher cardiopulmonary and lung cancer mortalities in exposed populations. Cohen et al. estimated approximately 0.8 million deaths per year worldwide—1.2% of global premature deaths—from outdoor urban PM 2.5 air pollution.[2]

PM emissions from marine shipping contribute to approximately 60,000 deaths per year worldwide, with impacts concentrated in coastal regions on major trade routes.[2] Most of these deaths occur in Europe and Asia, where high shipping-related PM concentrations are present in densely-populated areas.

More detailed estimations using methods like the Geos Chem model—that take into account specific individual emissions and particles—show that in 2002 exposure to shipping-related PM2.5 emissions resulted in 19,000 annual cardiopulmonary and lung cancer mortalities globally.[2] Similar studies performed with the E5/M1 model estimate emissions-related mortalities at 64,000 (Fig. 4).

A forecast for 2012 based on the Geos Chem model indicates 27,000 deaths, an increase of around 40% due to trade-driven growth in shipping emissions (Fig. 4).

As expected, the regions with the highest shipping-related mortality rates are also those where shipping-related PM2.5 concentrations are highest.[2]

Fig. 4 - Annual cardiopulmonary and lung cancer mortality attributable to shipping-related PM 2.5 [2]

	2002 Geos Chem model	2002 E5/M1 model	2012 Forecast Geos Chem model
North America (NA)			
Cardiopulmonary	1,860	4,590	2,770
Lung cancer	210	520	320
NA Total	**2,070**	**5,110**	**3,090**
Europe/Mediterranean (EUM)			
Cardiopulmonary	6,770	24,350	8,990
Lung cancer	670	2,360	880
EUM Total	**7,440**	**26,710**	**9,870**
East Asia (EA)			
Cardiopulmonary	3,490	17,920	5,170
Lung cancer	370	1,950	550
EA Total	**3,860**	**19,870**	**5,720**
South Asia (SA)			
Cardiopulmonary	4,050	9,440	6,090
Lung cancer	230	510	350
SA Total	**4,280**	**9,950**	**6,440**
East South America (ESA)			
Cardiopulmonary	380	690	570
Lung cancer	50	100	80
ESA Total	**430**	**790**	**650**
Worldwide			
Cardiopulmonary	17,340	58,640	24,780
Lung cancer	1,580	5,540	2,240
Worldwide Total	**18,920**	**64,180**	**27,020**

1. “Regulating Air Emissions from Ships.” November 2010
2. “Mortality from ship emissions.” 15 December 2007

2.2 The effects of NO_x

NO_x can penetrate deeply into sensitive lung tissue and damage it, causing premature death in extreme cases. Inhalation of such particles may cause or worsen respiratory diseases such as emphysema and bronchitis. It may also aggravate existing heart disease.

NO_x reacts with volatile organic compounds in the presence of sunlight to form ozone. Ozone can damage lung tissue and impede lung function, mostly in sensitive populations (children, the elderly, and asthmatics). Ozone can be carried by wind currents and cause health problems far from the original sources.

2.3 The effects of SO_2

Current scientific evidence links exposure to SO_2 with an array of adverse respiratory effects including bronchoconstriction and increased asthma symptoms. These effects are particularly noticeable in asthmatics at elevated ventilation rates (such as while exercising or playing). Studies also show a connection between SO_2 exposure and increased emergency room visits and hospital admissions for respiratory illnesses, once again, especially in at-risk populations including children, the elderly, and asthmatics.

SO_2 can react with other compounds in the atmosphere to form small particles. These particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death.

2.4 The effects of CO and CO_2

CO can have significant cardiovascular effects on those who suffer from heart disease. The central nervous system can also be affected. Breathing high levels of CO can result in blurred vision, reduced ability to work or learn, and reduced manual dexterity.[1]

1. “Regulating Air Emissions from Ships.” November 2010

3 The effects of shipping-related pollution on the climate

Carbon dioxide (CO_2) is the most significant contributor to global climate change. And shipping is a major source of global CO_2 emissions at 870 million tons in 2007—a rate that is expected to increase by a factor of between 2.2 and 3.3 by 2050 (IMO 2009).[1]

Sulfur and nitrogen compounds emitted by ships can cause acid deposition detrimental to lakes, rivers, soils, fauna and flora.

Emissions of these compounds at sea can exert an influence on vegetation and land-based objects many thousands of kilometers away.[1]

Another shipping-related emission, black carbon (the darker fraction of PM, which accounts for around 10% of total PM emissions), also contributes to climate change.

Black carbon absorbs sunlight, making it particularly harmful in the Arctic and Antarctic, where it plays a key role in the acceleration of snow and ice melt. This phenomenon—particularly acute in the northern hemisphere, where most shipping activities are carried out—may significantly contribute to the modification of the climate system in the Arctic, and thus that of the entire planet.[1]

1. “Regulating Air Emissions from Ships.” November 2010

4 The international regulatory framework for shipping-related air emissions

To an increasing extent, shipping-related air emissions are the focus of local, national, and international regulations.[2]

4.1 MARPOL Annex VI

The International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978) is currently the main International Maritime Organization (IMO) directive concerning the protection of the marine environment.

The convention establishes the regulatory framework for reducing shipping-related pollution, with specific rules and obligations set forth in the six annexes to the convention.

The annexes cover the various sources of pollution from ships and provide an overarching framework for international objectives. All six annexes have been ratified by the requisite number of nations. Each signatory nation is responsible for enacting domestic laws to implement the convention and effectively pledges to comply with the convention, its annexes, and the related laws of other nations.

In 1997, air pollution was included in Annex VI, setting limits on sulfur oxide (SOx) and nitrogen oxide (NOx) emissions in ship exhaust and prohibiting the deliberate emission of ozone-depleting substances.

Annex VI was ratified by 62 contracting states, which represent 84.3% of worldwide ship traffic. The annex entered into force on May 19, 2005.

In 2008 Annex VI was amended. The revised text, which establishes more stringent emission requirements for ships that operate in designated coastal areas where air quality problems are acute, entered into force on July 1, 2010.

In July 2011, the IMO went further by implementing measures to reduce GHG emissions:

- The Energy Efficiency Design Index (EEDI)
- The Ship Energy Efficiency Management Plan (SEEMP)

will be mandatory by 2013 for ships over 400 tons.

The EEDI applies only to new ships and aims to reduce GHG emissions through ship design improvements. Ships will have to increase their carbon efficiency by 10% by 2013, 20% by 2020, and 30% by 2024.

The SEEMP applies to all ships with the aim of reducing GHG emissions through operational improvements. It establishes a mechanism to improve ships' energy efficiency.
Even if SEEMP mechanism is still under discussion, shore connection is already mentionned in the SEEMP guidelines.

Fig. 5 - SO_x and NO_x emissions caps in MARPOL Annex VI

Year	SO_x limit in fuel (% m/m)		Average NO_x limit in fuel (g/kWh)
	MARPOL Annex VI		MARPOL Annex VI
	High sea and berth	SECA	High sea and berth
2009	4.5%	1.5%	11.8
2010			
2010, July		1.0%	
2011			9.6
2012	3.5%		
2015		0.1%	
2016			2.3
2020	0.5%		

SECA: currently the Baltic Sea, the North Sea, and the English Channel

2. "Mortality from ship emissions." 15 December 2007

4.2 The European Union policy on air and GHG emissions from international shipping

The EU's strategy for reducing and regulating air emissions from ships is based on MARPOL Annex VI. EU directives go further than international regulations with additional rules that aim to reduce sulfur oxide emissions from maritime shipping:

- Directive 2005/33/EC concerning sulfur limits in all fuels used by ships at berth in EU ports
- Recommendation 2006/339/EG for the promotion of shore-side electricity for use by ships at berth in EU ports
- Directive 2003/96/EC concerning the taxation of energy products and electricity
- Subzidise program concerning shore connection projects.

4.2.1 Directive 2005/33/EC

This directive requires EU member states to take enforcement action with respect to vessels flying their flags and to vessels of all flags while in their ports.

According to the directive, it is also appropriate for member states to cooperate closely to take additional enforcement action with respect to other vessels in accordance with international maritime law.

The directive was issued in 2005. It should be adopted by the European Parliament and the European Council in july 2012. It sets the maximum limit of 0.1% sulfur by weight for marine fuels used on inland waterway vessels and ships at berth in EU ports. The directive was initially expected to enter into force on January 1, 2010 (Fig. 6).

Fig. 6 - EU Directive 2005/33/EC

<table>
<tr><th rowspan="3">Year</th><th>SO_x limit in fuel (% m/m)</th></tr>
<tr><th>EU maritime fuel sulfur directive (2005/33/EC)</th></tr>
<tr><th>Berth</th></tr>
<tr><td>2009</td><td>1.5%</td></tr>
<tr><td>2010</td><td rowspan="7">0.1%</td></tr>
<tr><td>2010, July</td></tr>
<tr><td>2011</td></tr>
<tr><td>2012</td></tr>
<tr><td>2015</td></tr>
<tr><td>2016</td></tr>
<tr><td>2020</td></tr>
</table>

4.2.2 Directive 2003/96/EC

Directive 2003/96/EC covers the taxation of energy products and electricity. Under the directive, member states can cut tax rates on electricity provided to vessels at berth in ports. Sweden and Germany have already obtained the necessary authorizations to implement reduced tax rates.

The directive is currently under revision with the goal of including additional articles to exempt from taxation, for a limited time period (in years), electricity produced on shore and directly provided to vessels while at berth in a port as an incentive for the widespread adoption of shore-side electricity.

1. "Regulating Air Emissions from Ships." November 2010
2. "Mortality from ship emissions." 15 December 2007

4.2.3 Recommendation 2006/339/EG

Member States should consider the installation of shore-side electricity for use by ships at berth in ports; particularly in ports where air quality limit values are exceeded or where public concern is expressed about high levels of noise pollution, and especially in berths situated near residential areas.

They should also report to the Commission on actions they intend to take to reduce ship emissions in ports in these areas.

The development of harmonized international standards for shore-side electrical connections is recommended.

4.2.4 Subzidise

To promote new and environmental friendly technlogies, the European Union has set subsidises programs. Private operators implementing a shore connection solution can get subsidize from the European Marco Polo program, in condition that they meet the programs requirements. The subsidize may reach 20 to 50% of the investment.

4.3 Other local regulations in favor of shore-side electricity

4.3.1 California

In 2007, the California Air Resources Board approved the Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port. This regulation aimed at reducing NO_X and particulate matter emissions from both US and foreign-flagged vessels operating in California ports.

The main rules are the following:

- **While at berth in a Californian port, vessels (container, passenger, and reefers) must either stop their engines and use shore-side electricity or use another anti-pollution technology by 2014.**
- **Since 2010: vessels fitted with shore connection capabilities are required to use them while at berth.**
- **By 2015: vessels without shore connection capabilities will not be allowed to berth.**
- **By 2020: at least 80% of berth must be equipped with shore connection capabilities.**

4.3.2 China

Pollution is becoming a critical issue in China. The Chinese Ministry of Transport has included pollution control measures in its 2011–2015 five-year plan, as shown in the figure 7. Shore-side electricity is covered by the plan.

Fig. 7 - Chinese pollution reduction target for 2015 in comparison with 2005

	Index
Total emission from port operation	**Drop 8%**
Emission from vessel operation	**Drop 15%**
Coastal vessel emission	Drop 16%
Inland vessel emission	Drop 14%
Emission of CO_2 from port operation	**Drop 10%**
Emission of CO_2 from vessel operation	**Drop 16%**
Coastal vessel emission	Drop 17%
Inland vessel emission	Drop 15%

The Ministry of Transport: '12th 5Y Execution Program for Water Transport Energy Efficiency and Emission Reduction.

5 The solution to mitigate shipping pollution in port: shore connection

5.1 Shore connection basics

When ships are at berth, they use their auxiliary engines and/or generators to power onboard systems and equipments, generating substantial pollution in port areas. Shore connection technology eliminates ships' need to run their auxiliary engines at berth by providing electricity directly from onshore sources.

Shore connection technology is emerging as the most cost-effective means of reducing pollution from ships at berth. EU recommendation 2006/336/EC highlights shore connection technology as the optimal solution in terms of both cost savings and pollution control. More than just an onshore power supply for ships at berth, shore connection technology also encompasses the equipment and procedures needed to power ships' onboard systems.

This technology provides a number of benefits, including:

- Eliminating ship engine emissions in the port area
- Eliminating noise and vibrations
- Improving working conditions in ports
- Facilitating maintenance and repairs on auxiliary engines while not in operation
- Reducing each pollutant by about 90% and GHG emissions by about 50% depending on the electricity mix.
- Exemption from MARPOL VI requirements
- Generating savings, as onshore electricity may be less costly than engine generator use.

1. US Environmental Protection Agency "Case study and success story" http://www.epa.gov/diesel/ports/casestudies.htm#lbbp-a

5.2 Early experimentation

In addition to local, national, and international regulations, international shipping-industry associations are also addressing pollution control with their own rules and regulations and encouraging ports and harbors to install shore connection capabilities. For example, in April 2008, the International Association of Ports and Harbors (IAPH) asked its environmental committee to work with regional port organizations to help fight climate change. The World Ports Climate Initiative (WPCI) was formally launched in November 2008 to support the IAPH's efforts.

The WPCI, supported by the Clinton Climate Initiative, establishes that ports have a duty to help reduce greenhouse gas emissions—and acknowledges shore connection technology as an effective solution. The port of Gothenburg, which had previously experimented with shore connection, decided to pursue its experimental use of the technology with the aim of demonstrating its environmental benefits.

Under pressure from the California Air Resources Board, the ports of Los Angeles and Long Beach, California have also experimented with shore connection. In 2004, the port of Los Angeles opened the world's first container terminal equipped with shore connection technology. By eliminating the need for container ships to use their auxiliary engines at berth, shore connection technology has reduced NO_x, SO_x and particulate matter (PM) emissions by 95% on average. In the first two years, pollution was reduced by more than 80 tons.[1]

The Port of Long Beach and British Petroleum (BP) have joined forces to install shore-side electrical power supply equipment for two BP tankers. According to the California Air Resources Board, if ships making three or more visits to the port per year used shore connection facilities, emissions would be reduced by 70%—that's about 17 tons of NOx and 4 tons of particulate matter (PM).

This early experimentation paved the way for numerous other ports to adopt shore connection technology, with substantial benefits to the environment.[1]

6 Shore-side electrical connections: international standards

In addition to pollution-control regulations targeting ships, there are also 2 main international standards dedicated to shore connection design and construction.

These 2 standards establish:
- Requirements to ensure the safety of high-voltage shore connections
- Requirements to ensure compatibility between ship and high-voltage shore connection equipment.

The standard aims to:
- facilitate cooperation between the shipping industry and port facilities
- establish appropriate operating procedures
- encourage compliance with the standard so that a maximum number of ships can use high-voltage shore connection equipment at as many ports as possible.

The standard guarantee simple, straightforward connection—eliminating the need for ships to make adaptations to their equipment at different ports. Ships that do not comply with the standard may find it impossible to connect to compliant shore supplies.

The standards cover:
- Quality of the power supply
- Electrical requirements
- Environmental and mechanical requirements
- Safety
- Electrical equipment requirements
- Ship requirements
- Compatibility between shore connection and ship equipment
- Ship-to-shore connection and interface
- Plugs and sockets
- Verification and testing.

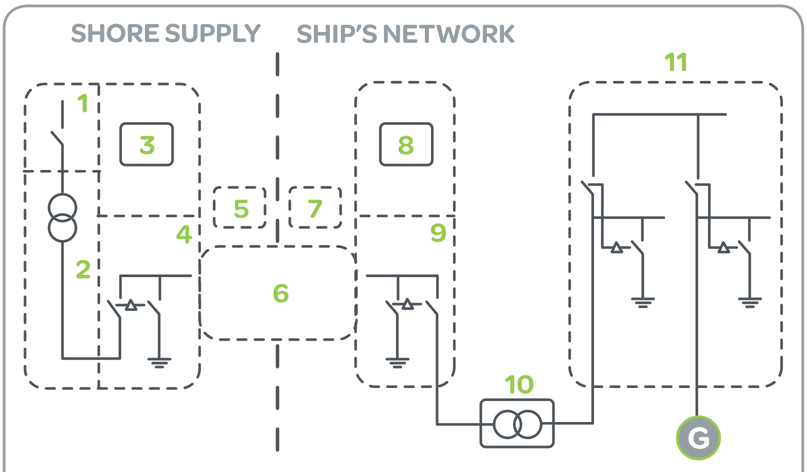
The generic architecture for a HV shore connection system is presented in figure 8. In figure 9, the main requirements of IEC 80005-1 are listed.

IEC/ISO/IEEE shore connection standard

- **Utility connections in port - Part 1: High Voltage Shore Connection (HVSC) System - general requirements: IEC/ISO/IEEE 80005-1**
- **Plugs, socket-outlets and ship couplers for High Voltage Shore Connection Systems (HVSC systems): IEC 62613-1 & 2**

The IEC/ISO/IEEE 80005-1 standard was developed jointly by:
- **IEC technical committee TC18: Electrical Installations of Ships and of Mobile and Fixed Offshore Units**
- **ISO technical committee TC8: Ships and Marine Technology Subcommittee SC 3, Piping and Machinery**
- **IEEE IAS Petroleum and Chemical Industry Committe (PCIC) of the Industry Applications Society**

Fig. 8 - Generic architecture for a HV shore-side electricity connection



1. A shore connection system can be supplied either from national grid or port internal distribution system trough a power frequency conversion or not, depending on the application
2. A shore-side insulation transformer is required to prevent fault current circulation between several ships
3. Shore-side protection relays and interlocking system
4. Shore-side circuit breaker and earth switch
5. 6. 7. Shore-to-ship connection, interface, and control equipment (cable reel, sockets, communication and control wires, earth relays)
8. Ship-side protection relays and interlocking system
9. Ship-to-shore connection switchboard: circuit breaker and earth switch
10. Where applicable (if ship's voltage is different from shore connection voltage) an onboard transformer to adjust the high voltage electricity to the ship's main switchboard voltage; this transformer is preferably located near the main switchboard in the engine room
11. On-board receiving switchboard

Fig. 9 - Contents of the IEC/ISO/IEEE 80005-1 standard

Quality of supply	• Voltage and frequency limits
Electrical requirements	• Voltage system 6.6 kV and/or 11 kV • Range of power • Short circuit withstand capacity • Neutral earthing system
Environmental & mechanical requirements	• Compliance with IEC 60092-101 and 60092-503 • Temperature, humidity, wind, snow, salt, atmosphere • Combination of weather conditions • Protection against moisture and condensation
Safety	• Protection against electrical shocks • Equipotential system • HV plug safety during handling • Interlocking system • Protection against electrical faults • Requirements for hazardous areas • Emergency shutdown • Operating rules
Electrical equipment requirements	• Switchboards • Circuit breakers • Transformers • Inverters • Cooling system
Compatibility between shore connection and ship equipment	• Compatibility assessments to be performed prior to ship connection
Ship-to-shore connection and interface	• Cable system • Types of cables • Monitoring of cable tension • Monitoring of cable length • Cable unbalance monitoring
Plugs and sockets	• Operator safety • Main contacts • Pilot contacts • Earth contacts • Contact connection sequence
Ship requirements	• Shore connection switchboard • Circuit-breaker, disconnector, earth switch • Transformer • Protection against electrical faults • Ship connection procedure • Ship power restoration • Load transfer
Verification and testing	• Visual inspection • Power frequency test for HV switchgear 62271-200 and 60502-2 • Insulation resistance measurement • Functional test of the protection devices • Functional test of the interlocking system • Functional test of the control equipment • Equipotential bond monitoring test • Phase-sequence test • Functional test of the cable management system • Integration tests • Periodic testing and maintenance

7 Shore connection system architectures

Shore connection systems have been used since the 1980s to supply commercial vessels with electricity. Ferries were the first vessels to be equipped with the systems, due to the fact that they always dock in the same position, facilitating connection to a shore-side energy supply. Today, other types of commercial ships – cruise, container, and Ro-Ro – are connecting to the electrical grid in ports around the world.

Historically, shore connection systems used low-voltage shore-to-ship connections. Today, however, ships need more and more power and require high voltage supply when berthed.
Therefore, low-voltage systems have given way to high-voltage ones, which are today considered the most effective way to connect ships to shore-side energy supplies.
The benefits of high-voltage connections are clear: they reduce shore-to-ship cabling needs and curb power losses. A 11 kV high voltage cable can transfer about 25 times more power than a standard 400V cable of the same cross section. High-voltage connections make connecting ships to shore-side power supplies both simple and convenient.
In addition, when docks are located near residential or industrial areas—the case for virtually all ports in Europe—high-voltage power is generally readily available.
When designing an effective shore connection system, it is important to take into account the right dimensioning criteria and choose the best architecture.

The main dimensioning criteria and the typical architectures of the shore connection systems are presented bellow.

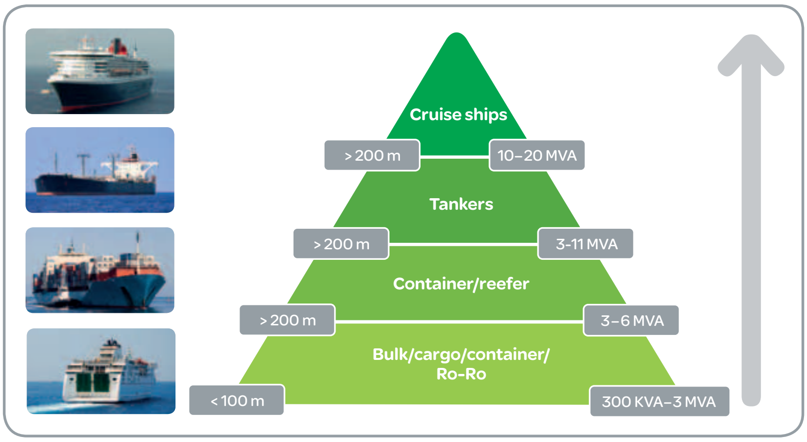
7.1 Dimensioning criteria

When designing a high-voltage shore connection, it is important to consider:

a) Shore-side frequency (e.g. 50 Hz in Europe, 60 Hz in the US) and onboard frequency (50 Hz or 60 Hz), given that 70% of ships are designed for 60 Hz, while only 30% of ports supply 50 Hz power. Shore connection systems must thus be designed for both frequencies.
b) The shore-side high-voltage electricity supply (voltage and distance to nearest supply point)
c) Required power onboard
d) Available space on shore, civil engineering considerations, and docking patterns at port
e) Space and weight restrictions for onboard transformer when required
f) Installation practicalities
g) Environmental conditions
h) Onboard cable installation practicalities and distances
i) Cost of shore-supplied electricity versus that of onboard-generated electricity (including fuel, maintenance, etc.)

One of the main specificity of the shore connection system, is the big difference between ships regarding the necessary power when berthed. Hence, shore connection equipment must be suitable for ships of all types and sizes (Fig. 10).

Fig. 10 - The power supply must be suitable for a variety of vessels at berth



7.2 System architectures

There are two main shore connection system architectures:

A) without frequency conversion (Fig. 11)

● suitable for North America (60 Hz to 60 Hz) and for certain European or Asian waterborne transportation lines (50 Hz to 50 Hz)

● can be low voltage (most often 440 V) or high voltage (6.6 kV and/or 11 kV) connection

● several ships can be supplied at the same time, from the same Shore Connection System by using galvanic insulation transformers.

B) with frequency conversion (Fig. 12)

● generally not applied for North America (as all ocean-going vessels are 60 Hz)

● one or several ships can be connected to the high-voltage shore connection system by using galvanic insulation transformers. The frequency conversion should be dedicated to each shore connection system or centralized at terminal level.

Fig.11 - Typical architecture for a Shore Connection solution without frequency conversion

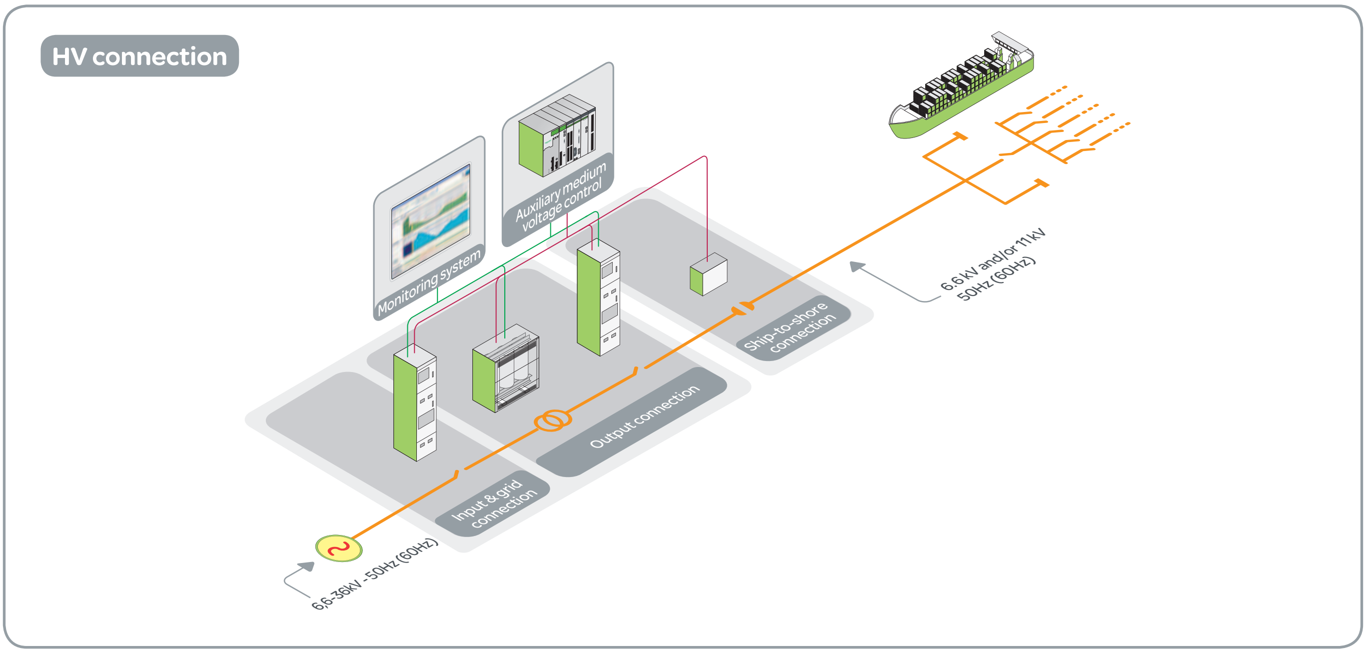
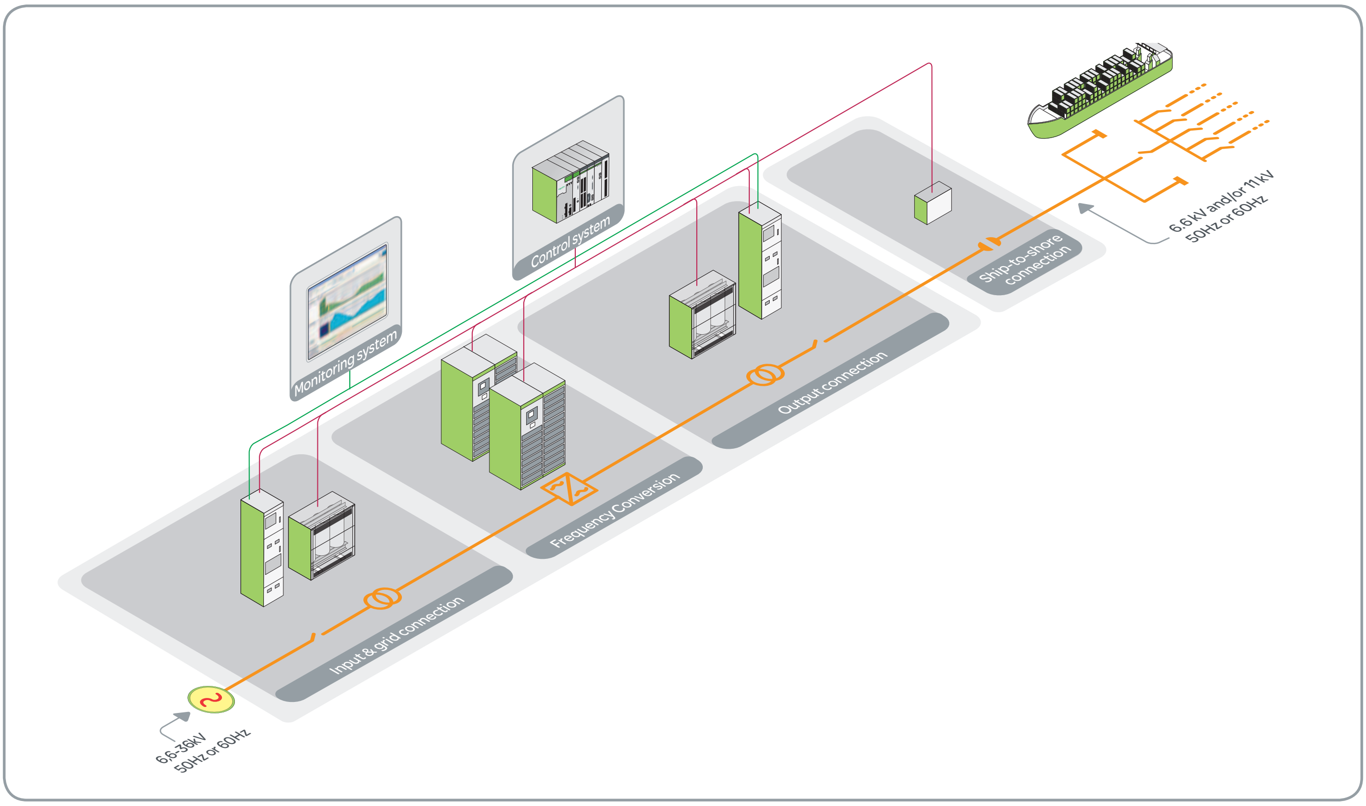


Fig. 12 - Typical shore connection architecture with frequency conversion



A typical shore connection system with frequency conversion includes:

- The frequency conversion build with power frequency converter unit: a single convertor or several in parallel depending on the power required
- The upstream interface, mainly the HV cubicles for the on-shore power supply's connection to either the port's own MV electrical network or to the local grid. One MV/LV transformer is dedicated to each frequency converter unit.
- The downstream interface:
  - The HV breaker with the associated protective relays needed to clear faults
  - The isolators and earthing switches required for safety
  - One LV/MV transformer associated with each converter unit
- The ship connection system incorporating motorized MV cable reels and MV plugs with their handling equipment.

A local control and monitoring system manages all information generated by the on-shore system and supports:

- Local Human Machine Interface (HMI)
- Automation for shore control
- Interlocks required for safety
- Interface with EMCS

An energy management and control system (EMCS) controls and supervises all the shore connection systems of the port. It integrates specialized functions like billing, energy quality monitoring and enhancement, energy management, energy efficiency, environmental impact reports, and more.

7.3 Main features

The shore connection system must bring added value to users regarding investment and operation. To optimize CAPEX and OPEX, the equipments should be:

Standard

All equipments (MV, LV transformers etc.) should be standardized products. The frequency converter could be, for example, based on technology developed for data centres, simple to use and offering high levels of performance and reliability. Moreover maintenance of standardized products is much more easier and cheaper.

Modular

The number of power frequency converter units required depends on the power demand. They must simply be switched on or off in response.

This modular design allows for redundant systems, thereby increasing installation availability and simplifying maintenance operations (since one module can be shut down for work while the others continue to operate).

Optimized for Energy Efficiency

Power frequency converter units should have communication interfaces for their connection to the EMCS. They should deliver data on frequency conversion efficiency, the quality of the electricity converted, and many other useful indicators. EMCS should optimize the number of frequency converters in operation according to the load demand of one or several ships at berth. It should improve at any time the efficiency of the installation as a whole.

Services

To operate the port hassle-free, the implementation of a shore connection system should be accompanied by a range of services such as:

- Site audits with a view to future expansion
- Consulting and engineering to help to prepare the investment brief
- Project analysis and management during the design phase
- Project execution in line with the schedule
- Commissioning of the installation
- Assistance during the start-up phase
- User training
- Performance benchmarking and recommendations.

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