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The optimization and promotion policy for a shore-to-ship power supply system in the port of Tianjin

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Contents

Summary

This report presents a comparative analysis of shore-to-ship power supply systems in Tianjin Port and other selected leading ports worldwide. Ports were interviewed that act as leaders in the development and application of shore-to-ship power: Hamburg, Vancouver, Gothenburg and Trelleborg. These interviews were complemented by a literature review, which enabled the port of Los Angeles to be included in the analysis. The experience of the Port of Vancouver shows that it is possible to develop a voluntary shore-to-ship power system with sufficient incentives for almost all cruise ships to use the system for all their port calls. The example of the Port of Los Angeles is particularly important, because it demonstrates the conditions under which general commercial shipping will convert to shore-to-ship power.

There is now considerable global experience in operating shore-to-ship power systems. While earlier systems delivered power at low voltages, modern systems deliver electricity at 6.6 kV, 50 Hz and 60 Hz. Systems are now installed that comply with the IEC/ISO/IEEE 80005-1 standard for High Voltage Shore Connection (HVSC) systems, usually 6.6 kV rated at 7.5 MVA. This requires power supply systems with transformers, frequency converters and power management systems onshore and transformers on-board. These systems entail considerable investments by the port and shipowners.

Tianjin Port is implementing the Chinese government's policy for developing shore-to-ship power. At the end of 2018, Tianjin had seven containers, seven bulker, two Ro-Ro and three general berths fitted for 6.6 kV/60 Hz, 6.6 kV/50 Hz shore-to-ship power with plans to fit further container berths and two cruise berths. However, the use of shore-to-ship power in the port is still limited. Management and operation of the shore-to-ship systems require further development, and the legal and contractual structure requires clarification.

This report makes recommendations for measures to address these barriers. A combined set of measures featuring regulation and support for shipowners, ship operators and Tianjin Port is required to ensure the extensive use of shore-to-ship power.

The most important measures are:

- A regulation requiring all ships calling at Tianjin Port to use shore-to-ship power.
- Allocating financial resources to Tianjin Port to meet the considerable costs of rapidly expanding the shore-to-ship systems to cover most berths in the port and the additional management, contract and operating personnel needed to operate a much larger number of shore-to-ship installations.
- A cooperation between Tianjin Port and shipping lines to promote investment in on-board equipment and to agree on the standards and procedures for operation and maintenance, in particular for connection/synchronisation and disconnection of shore power.
- Subsidies for ship operators to help cover the cost of shore power for ship operators should be made available.
- Operating safety, in particular connection and disconnection, can be improved by developing systems with a high degree of automation.
- Developing management systems and training port staff in the operation and maintenance of the shore-side equipment will also improve safety and ensure effective operation and maintenance as the number of installations increases.

Glossary

AMP	Alternative Maritime Power
BC	Hydro British Columbia Hydro and Power Authority
BMVI	German Federal Ministry for Transport and Infrastructure
BP	British Petroleum
CAC	Criteria air contaminant CARB Californian Air Resources Board
CO_2	Carbon dioxide
CTT	Closed Transition Transfer
DWT	Deadweight Tonnes
ECAs	Emission Control Areas ESI Environmental Ship Index EU European Union
GHGs	Greenhouse gas emissions
GRT	Gross Registered Tons
HPA	Hamburg Port Authority
HFO	Heavy fuel oil HVSC High-Voltage Shore Connection
Hz	Hertz
IMO	International Maritime Organisation IEEE Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission ISO International Organization for Standardization
kA/s	Kiloampere seconds
kV	Kilovolts
kVA	Kilovolt Amperes
kW	Kilowatts
kWh	Kilowatt hours
LADWP	Los Angeles Department of Water and Power
LNG	Liquid natural gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MVA	Megavolt Amperes
MW	Megawatts
MWh	Megawatt hours
NECA	Nitrogen emission control areas
NNEI	No Net Emission Increase programme
NO_x	Nitrogen oxides
OGV	Ocean-Going Vessels PLC Programmable logic controllers
PM	Particulate matter
POSCO	Pohang Iron & Steel Company
Ro-Ro	Roll-on Roll-off ship
Ro-Pax	Roll-on Roll-off ferry for passengers and freight
SECA	Sulphur emission control areas
SO_2	Sulphur dioxide
SO_x	Sulphur oxides
TIWTE	Tianjin Research Institute for Water Transport Engineering
TEU	20 foot container units
TS 86	BC Hydro Tariff Supplement 86
UIC	International Union of Railways
V	Volts

1. Introduction

1.1. Background and objectives

Maritime trade is a vital factor in economic development, because it accounts for over 80 % of global trade by volume (UNCTAD 2017; Ssali 2018). Ships currently use large amounts of diesel and heavy fuel oil (HFO) in diesel motors to provide on-board power with high levels of emissions. The International Maritime Organization's (IMO) 3rd Green-house Gas Study estimates that shipping contributes around 2.2 % of global greenhouse gas emissions (GHGs) (IMO 2014). While GHG emissions are important on the global level, ships also emit NO_x, SO_x and CO_2 as well as particulate matter (smoke or soot: PM) due to the partial combustion of fuel (Homsombat et al. 2013). These emissions affect local air quality and emissions from ships' auxiliary engines in port can be a major source of pollution in port cities and coastal waters (Chen et al. 2018). These issues have led to the adoption of polices to control emissions from ships (Köhler et al. 2018). The IMO has revised the MARPOL Annex VI to define sulphur emission control areas for SO_x (SECAs), while emission control areas for NO_x (NECAs) and PM have been defined in the USA and Canada, the North Sea, the Baltic and the Caribbean (Figure 1). China has also developed emission control standards for ships for the Pearl Delta, Yangtze Delta and the Golf of Bohai. From 2019, a target has been set of 0.1 % sulphur content for ship fuels. These regional regulations have been reinforced by a global regulation of 0.5 % sulphur content for ship fuels, agreed by the IMO for ships over 100 Gross Registered Tons (GRT). This global regulation will enter into force on 1st January 2020.

These policies mean the maritime industry must consider how to reduce emissions from the combustion of fossil fuels. While equipment has been developed to remove emissions (SO_2 scrubbers and catalytic conversion for NO_x), alternative fuels that do not produce SO_x, NO_x or PMs are also available. Köhler et al. discuss the use of liquefied natural gas (LNG) as a ship fuel and summarise other alternative fuels such as methanol or ammonia. However, ships in port have another option: to take electrical power from the shore (also called shore-to-ship power (SSP) or alternative maritime power (AMP) or "cold ironing" after the traditional practice of shutting down ships' boilers in port so that the boilers cooled down (Köhler et al. 2018). This option has two advantages in terms of emissions. It completely removes local air emissions from ships and can reduce global air and GHG emissions if the grid electricity includes renewable power sources. This is the reason China is developing shore-to-ship power supply systems and Tianjin Port is promoting these developments.

Zis reviews the status of shore-to-ship power (Zis 2019). California requires ports to pro-vide shore power and the European Union requires all ports to have a shore-to-ship power installation by 2025. The environmental benefits of shore-to-ship power were assessed for the port of Kaohsiung by Tseng and Pilcher, who found that shore-to-ship power has financial and emissions benefits but that the investment costs are a barrier to its installation (Tseng and Pilcher 2015). A further problem is that both the port and the ships have to invest, leading to a coordination problem. Ports need to be confident that sufficient numbers of ships will use the installation to justify its expense, but shipowners will only invest in the required onboard systems if they are confident that shore-to-ship power will be available in their ports of call. Innes and Monios calculated a payback period of seven years for the port investment without subsidies in a simulation study of the medium-sized port of Aberdeen, UK (Innes and Monios 2018).

Area	Emissions	Date of adoption
Baltic	SO_x	19th May 2006 (binding from 1st January 2015)
	NO_x	Ships comissioned from 1st January 2021
North Sea	SO_x	22nd Nov. 2007 (binding from 1st January 2015)
	NO_x	Ships comissioned from 1st January 2021
North America	SO_x and PM	1st August 2012
	NO_x	Ships comissioned from 1st January 2016
US-Carribean (Puerto Rico and Virgin islands)	SO_x and PM	1st January 2014
	NO_x	Ships comissioned from 1st January 2016

Figure 1: Emission control areas (ECAs) (Köhler et al. 2018).

1.2. Structure of the report

This report presents a comparative analysis of shore-to-ship power supply systems in Tianjin Port and other selected leading ports worldwide. It considers technical requirements, operational data (number of ships of different types and berths, power used) and the considerations facing ports, shipowners and operators when adopting shore-to-ship power supplies. The report assesses the policies and regulations required for the successful development of shore-to-ship power. Section 2 reviews the development of shore-to-ship power systems. Section 3 presents a brief overview of the general features of current shore-to-ship power systems. Section 4 describes current practices in selected ports worldwide based on questionnaire data and a literature review. It uses the results to distil the current international „best practice“ in shore-to-ship systems. Section 5 reviews the current position in China and in Tianjin Port in particular, identifying aspects of shore-to-ship systems and management that require improvement. Section 6 provides recommendations for Tianjin Port and Section 7 concludes.

2. Review of the development of shore-to-ship power supply systems

2.1. Initial demonstrations

ENVIRON reviewed early demonstrations of shore-to-ship power (ENVIRON 2004).

US Navy, Royal Navy

Military ships have a long history of using shore-to-ship power (Paul and Haddadian 2005). They spend long periods of time in port, increasing the benefits of shore-to-ship power (ENVIRON 2004). However, as military vessels often operate to different standards than commercial shipping, this experience is not necessarily applicable to commercial ships in ports.

POSCO Dry Bulk Vessels: Pittsburg, California

Pittsburg port has enacted local air permits for ships to comply with the California Environmental Quality Act. This regulation requires the use of shore-to-ship supply for electricity and steam. To comply with these requirements, the Pohang Iron & Steel Company (POSCO) chartered four bulk carriers fitted for shore-to-ship power for trade between South Korea and Pittsburg, San Francisco Bay area (ENVIRON 2004). The first vessel used shore-to-ship power at Pittsburg in 1991. An onshore step-down transformer con-verted the power supply from the local distribution network utility to 440 V. This low voltage was the one used in the ship's electricity distribution system, so that a step-up transformer and an on-board step-down transformer were not required. The connection was rated at 800 amps (approximately 0.5 MW). The connecting cable was handled manually. Communications and tests of the system were controlled manually before the ship's auxiliary motors could be switched off and were not part of the connection cable. The time required for the connection process was 20 minutes, and the ships were at berth for 48 hours (on average).

Ro-Ro ferries: Gothenburg, Sweden

Gothenburg installed a low-voltage shore supply for three Ro-Pax vessels in 1989. In 2000, it was the first port to install a high-voltage shore connection in cooperation with the pulp and paper company Stora Enso, who wished to develop a green logistics concept for their paper and forest products trade using Ro-Ro freight ships. Electricity from the utility distribution network was stepped down to 6.6 kV 50 Hz. The system was used by six Ro-Ro ships from two shipping companies. These ships also used shore-to-ship power at Zeebrugge. In 2003, the shore system was adapted to supply 10kV 50Hz to ships, so that the substation for the step-down transformer was no longer required. Stena Lines passenger ferries have also used 10 kV 50 Hz shore power since 2006 (IAPH 2019). Ships fitted with on-board transformers then convert this high-voltage shore power to 400 V for their electricity distribution system (see IAPH 2019).

Long Beach/British Petroleum pilot

In 2009, BP and the Port of Long Beach initiated the first shore-to-ship power project for tankers on the Alaska-California trade route. These tankers had electric cargo pumps and were frequent callers to the port. A 6.6 kV high-voltage system rated at 8 MW was installed. The total investment cost was $ 23.7 million (TankerOperator 2009).

Princess Cruise Vessels: Juneau, Alaska and Seattle

In order to comply with local air quality standards for clear visibility, Princess Cruises in-vested $ 5.5 million in a shore supply facility for five cruise ships (ENVIRON 2004). The installation came into service in 2001. The shore power is supplied directly by the regional power company, Alaska Electric Light & Power, from renewable sources. On-board installation costs were around $ 500,000 for each vessel. Princess Cruises estimated that shore power costs $ 4,000-$ 5,000/day, compared to $ 3,500 for the auxiliary diesel engines. Cruise ships have also used high-voltage shore power at Seattle from 2006.

Los Angeles

The port of Los Angeles commissioned a dedicated power barge positioned close to a container berth to first provide shore-to-ship power in 2004. The barge had a transformer and switchgear to convert electricity at 34.5 kV from the local grid to 6.6 kV at 60 Hz and then to 440 V and performed the step-down function and shore switchboard functions. The barge housed a high-voltage cable management system to connect the barge to the local grid and a low-voltage cable management system to connect the barge to the ship receiving shore power.

In 2005, the port commissioned a high-voltage 6.6 kV shore connection. The system was suitable for vessels with an on-board transformer and switchgear to convert the 6.6 kV shore power to the ship's low-voltage system. This simplified the shore-to-ship connection equipment needed and reduced the transmission losses from the supply utility to the ship. NYK ATLAS was the first vessel to use the HVSC (Wärtsilä 2019).

Current facilities in international ports

Figure 2 summarises the current installations. The identified fields of application are:

- Cruise ships
- Dry bulk/tankers
- Container ships
- Ro-Ro/Ro-Pax/ferries
- Service vessels (e.g. tugs)
- Inland waterways vessels

Europe	Asia	North America	Oceania
Belgium Antwerp (container, barges) Zeebrugge (Ro-Ro)	**Azerbajian** Baku (container)	**Canada** Halifax (cruise) Montreal (cruise) Vancouver (container, cruise) Prince Rupert (cruise)	**New Zealand** Auckland (cruise)
Finland Helsinki (Ro-Ro) Kemi (Ro-Ro) (container) Kotka (Ro-Ro) Oulu (Ro-Ro)	**China (main facilities)** Tianjin (container) Nanjing (container) Dalian (Ro-Ro) Haikou (Ro-Ro) Lianyungang (passenger) Ningbo-Zhoushan (passenger/OGV)	**USA** Los Angeles (OGV) Long Beach (OGV) Oakland (container) San Francisco (OGV) San Diego (refeer ships) Seattle (cruise) Juneau (cruise) Pittsburg (bulk)	
France Le Havre (ferries) Marseille (ferries)	**India** V.O.Chidambaranar (bulk)		
Germany Lübeck (Ro-Ro) Hamburg Altona (cruise) Kiel (Ro-Pax)	**Japan** Tokyo (OGV)		
Netherlands Amsterdam (river boats) Rotterdam (Ro-Pax, barges)	**S. Korea** Busan (OGV) Incheon (OGV) Ulsan (OGV) Yeosu Gqangyang (OGV)		
Norway Oslo (Ro-Pax, cruise) Bergen (supply vessels)	**Taiwan** Taipei (OGV)		
Sweden Gothenburg (Ro-Ro) Helsingborg (ferry) Pitea (Ro-Ro) Stockholm (Ro-Pax) Trelleborg (Ro-Pax) Karlskrona (Ro-Pax) Ysatd (Ro-Pax)			
UK Milford Haven (tugs)			

Figure 2: Current shore-to-ship installations.
Adapted from (Zis 2019; Ningbo-Zhoushan Port 2015; TrainMosII 2015).

Some ports supply shore-to-ship power to several types of ocean-going vessels. All Californian ports provide shore-to-ship power as required by the Californian Air Resources Board regulation of 2007: “Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port“ (also referred to as the “At-Berth“ Regulation). This requires ships to turn off auxiliary diesels and use shore-to-ship power (see Section 4 for a discussion of the regulation). China has also implemented an extensive development programme of shore-to-ship power. Other installations have been developed in Canada and Alaska, mainly for cruise ships and for Ro-Ro/Ro-Pax ferries. European Union legislation (Directive 2014/94/EU, in force from 31st December 2025) is driving the development of shore-to-ship power in Northern European and Baltic ports.

Port and service vessels, such as tugs or dredgers, represent one field of application that has been largely neglected so far, even though they spend relatively long periods in ports and therefore have considerable potential to reduce emissions.

3. Technical requirements for shore-to-ship power supply systems

The requirements for the provision of shore-to-ship power are summarised in Sciberras et al. (Sciberras et al. 2015). Ships usually have a low-voltage distribution network (ranging from 440 V to 220 V or 110 V) at either 50 Hz or 60 Hz, although some newer ships can accept a 6.6 kV supply, which is converted on-board. The first systems were installed in the ship distribution network, but these involved considerable transmission and conversion losses. Shore-to-ship power from a grid utility is usually medium voltage (often in the range 15 kV to 11 kV) at 50 Hz. Therefore, the supply from the utility must be stepped down and, if necessary, the frequency is converted onshore and supplied to the ship at 6.6 kV (see Figure 3). This requires the ship to have on-board equipment to step down the voltage. The phase of the shore supply has to be synchronised with the on-board system. Once the ship's system has been synchronised, the ship's auxiliary motors can be switched out and powered down. Synchronisation and connection can be performed manually, but the latest systems often provide automatic checks and synchronisation, e.g. Kiel Norwegenkai (Kiel 2018). A further problem is the effect the ships' load may have on other consumers in the local distribution network (Sciberras et al. 2015). Ships represent a very large load in comparison to other domestic consumers. The power electronics used may generate frequency harmonics with associated power losses and voltage distortions. These quality concerns may require filter equipment to be installed at the onshore switchboard.

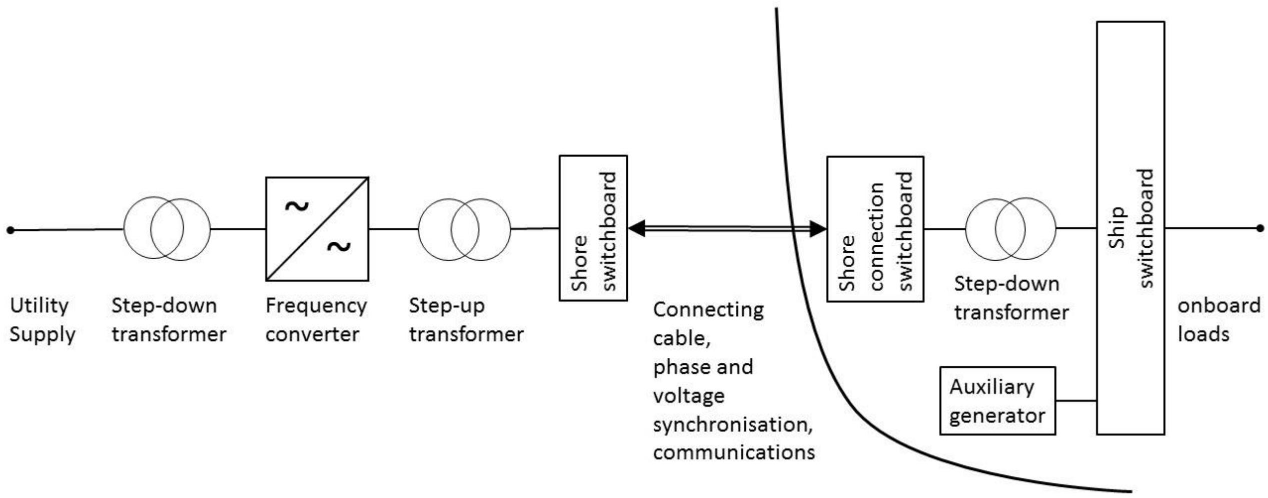

Figure 3: High voltage shore-to-ship configuration (Sciberras et al. 2015).

4. Assessment of best practice ports

Figure 4: Overview of best practise ports worldwide

4.1. Data and sources used

The study uses a combination of methods. First, the literature on shore-to-ship power supply is reviewed. This review identifies ports active in the development of shore-to-ship power systems. Then a number of these ports were contacted and asked to provide information about their shore-to-ship systems. The information was requested using a questionnaire developed by Fraunhofer ISI and Fraunhofer CML. Of the ports contacted, questionnaires were received from Hamburg, Vancouver, Gothenburg and Trelleborg. The port of Los Angeles did not respond to the questionnaire. Tianjin Port supplied a report describing the current application of shore-to-ship power supply systems in China. The questionnaire was structured as shown in Figure 5 and the questionnaire is shown in the Appendix 8.

4.2. Analysis of shore-to-ship power in selected global ports

Of all the ports with shore-to-ship power facilities, the following were selected for the comparative analysis because they have played a leading role in the development of shore-to-ship power. Questionnaires to complement the desk research were received from the ports of Hamburg, Vancouver, Gothenburg and Trelleborg. Los Angeles did not respond to the questionnaire so the analysis for this port is based on a literature review. The analysis for each port is structured as follows:

- Berths and systems
- Organisation and institutions for shore-to-ship power supply
- Costs and incentives
- Operational experience
- Assessment of port

General questions	• How long has the system been in operation? • Why was the system developed? • What are the expected benefits for the port?
Cost of shore-to-ship electricity compared to fuel for ships' auxiliary engines in the local markets	• Charging scheme and price per kWh • Price per kWh constant or dependent on the time of day / season or other variable? Is it included in a port fees package? • Subsidies • Influence of peaks loads from ships on the electricity price
Energy consumptions	• Energy consumption per vessel type (demand side)
Supply side, Power supply	• Number, type and capacity in kWh of installations per berth • Any customised solutions (e.g. electrical power supply via small-scale LNG turbines?) • Energy mix of on-shore power supply
Regulatory framework	• Port fees • Additional incentives • Is the use of shore power mandatory for some vessels/berths? • Is there a bonus and malus system in place?
Operational issues	• Who is responsible for shore-side system management and operation? Who is responsible for inspection and safety? • Power management systems for matching (frequency and voltage etc.) the shore power supply with ships' power systems • Customized berthing system to serve as many vessels as possible? What are the arrangements for flexible high capacity cables on the berth to allow for different positions of the connections on different ships? • Percentage share of severe failure in supplying vessels

Figure 5: Structure of the questionnaire

4.2.1 Hamburg Port Authority (HPA)

The first alternative power supply facility at HPA was the Hummel LNG power barge, which started operating in 2015. A pilot project for shore-to-ship supply was commissioned in 2016 at the Altona cruise terminal, and commercial operation began in 2018. The cruise terminal at the Hamburg HafenCity has also been provided with infrastructure for the LNG power barge (HPA 2019a). There is also a portable LNG power pack with a rating of 1.5 MW arranged as two UIC containers, which has been trialled on a container ship (MAREX 2018).

The shore supply facility for the Altona cruise terminal consists of a single power supply point. The equipment comprises a transformer station with four transformers, a frequency converter, cables and a cable channel for the shore side and a mobile shore-to-ship connector. The utility supplies electricity at 10 kV/50 Hz. Supply to the ship can be 11 kV/60 Hz, 6.6 kV/60 Hz, 10 kV/50 Hz or 6 kV/50 Hz. The system has a rating of 12 MVA, with 100 % renewable electricity supplied by the electricity utility. A second shore-to-ship supply system is under construction.

"The Hummel LNG hybrid power barge" built by Becker Marine Systems has a rating of 7.5 MVA and can supply electricity at 11 kV/60 Hz and 10 kV/50 Hz. It is berthed adjacent to the cruise terminal and is connected to receiving ships by cables over the quayside.

Both the power barge and the utility power supply system automatically synchronise the shore supply and the ship system once the two are connected. The ship's auxiliary engines can then be switched off. AIDA Cruises, HPA and the energy supplier Hamburg Energie have a contract to supply power from 100 % renewables to cruise ships using the Altona terminal. Any other users would also have to enter into a contract with the port and the electricity utility. Contracts for power supply from the LNG power barge are made with the barge operator, Hybrid Port Energy. The price for electricity is part of the contract between AIDA Cruises and Hamburg Energie, the electricity supplier. There is no provision for smoothing peak loads due to the demand from a cruise ship. HPA considers that the price of power will no longer be a significant factor when more ships use the shore-to-ship power system. This implies that the price for electricity from Hamburg Energie will fall with a higher utilisation of the shore-to-ship system.

The investment in shore terminals and the LNG power barge has been supported by regional and national innovation programmes (EU Commission 2014). The harbour dues also include several financial incentives for emission reduction technologies (HPA 2018a, 2018b). Harbour dues offer a range of environmental discounts for different ship types. The electricity price reduction can be up to € 3000 per port call for cruise ships using the shore supply.

Specific discounts are described in HPA (HPA 2018a). There is a special reduced rate for using shore-to-ship power or the LNG power barge. Charges for the berth are reduced by 80 % if shore supply with 100 % renewable electricity is used or if power is taken from a LNG power barge (HPA 2018a). There is also a range of environmental discounts for ships registered in the international Environmental Ship Index (ESI). There is a 2 % reduction in harbour dues for vessels that have been awarded the "Blue Angel" ecolabel by the German Federal Ministry of the Environment, Nature Conservation, Building and Nuclear Safety and the German Federal Environment Agency. There is also a 3 % reduction in harbour dues for oil, product and chemical tankers, LNG carriers and, following the launch of the certification program later this year, LPG carriers that have a "Green Award".

During the first season of its operation, the LNG barge supplied 11 port calls and increased this to 16 in 2016. The LNG barge supplied all the shore-to-ship power for the AIDAsol for a whole season's operations. In 2018, the cruise ship AIDAsol made 22 port visits and used shore-to-ship power for the duration (HPA 2019b). Contracts with other cruise ships are under negotiation. AIDAsol is currently the only ship using the shore-to-ship system, and represents 10 % of cruise ship port visits. There have been no interruptions to the power supply to the AIDAsol. HPA incur extra costs for operating the shore-to-ship system. These include costs for personnel to operate the system (partly working in shifts to ensure a continuous power supply) and inspection/maintenance of the shore equipment.

Assessment

The use of shore-to-ship power in Hamburg involves increased costs for the ships for the on-board power supply equipment and higher energy costs than running auxiliary motors. The provision and maintenance of the shore-side equipment involves extra equipment and operating costs for the port. However, HPA has identified the cruise market as a potential growth area that is a leader in alternative fuel provision. In the case of HPA, AIDA Cruises have been willing to invest in LNG motors on their cruise ships and to make some provision for shore-to-ship power systems. The HPA subsidy has provided sufficient financial incentive for AIDAsol to use shore-to-ship power for all its port visits to Hamburg. AIDA Cruises may decide to equip further ships for shore-to-ship power, but this has yet to be demonstrated. Other cruise lines competing in similar markets in northern Europe may decide that they need to compete on environmental quality as well, including the use of shore power in port. However, AIDAsol is currently the only ship using shore-to-ship power, so it is possible that further measures will be required for more cruise ships to adopt shore-to-ship power. Furthermore, cruise ships only account for a small proportion of the ships calling at Hamburg, where the highest level of activity is for container ships.

4.2.2 Port of Vancouver

The overall objective of investing in shore-to-ship systems in the Port of Vancouver was to improve local air quality by reducing greenhouse gas (GHG) and criteria air contaminant (CAC) emissions. The energy utility uses renewable hydroelectricity. This results in lower GHG, NOx, and SOx emissions and shore-to-ship power also reduces the noise of running the ship's auxiliary engines. These emission reductions contribute towards meeting British Columbia's and Canada's GHG reduction targets.

The expected benefits for the port are that shore-to-ship power will help to achieve the Port of Vancouver's vision to 'be the most sustainable port in the world'. 97 % of the electrical capacity comes from hydroelectric generation, so that shore-to-ship power significantly reduces greenhouse gas emissions and improves the air quality for terminal employees, the surrounding community, and the natural environment.

The Port of Vancouver offers shore-to-ship power at three terminals:

1. Cruise ship terminal located at Canada Place, Vancouver Downtown - in operation since 2009.
2. Centerm container terminal located at Burrard Inlet, Vancouver – commissioned in October 2018.
3. Deltaport container terminal located at Roberts bank, Delta – the system is installed and ready for a suitable vessel (as of January 2019).

The cruise ship terminal has two shore-to-ship power connections rated at 10 MW and 12 MW. The shore power infrastructure at the container terminals is designed for 7.5 MVA as per IEC/ISO/IEEE 80005-1 High Voltage Shore Connection (HVSC) systems.

A Closed Transition Transfer (CTT) system is used to connect ship and shore, which al-lows temporary paralleling of the vessel's diesel generators and the onshore power utility (in this case BC Hydro – the British Columbia Hydro and Power Authority). The CTT system automatically synchronizes and transfers the load between the shore power supply and the vessel power supply once connected.

There are several different safety features implemented throughout the shore-to-ship power system at Port of Vancouver terminals.

These include safety loops, direct communication with the vessels, equipment status checks, control through programmable logic controllers (PLC), direct electrical interlocks and an additional safety control relay system. These design elements result in a system that is simple, safe and reliable.

An important consideration is the positioning of shore power connections. In order for a vessel to connect to a shore power system, it must extend cables from its on-board Alter-nate Marine Power (AMP) equipment to a receptacle pit located on the berth. Due to the limited length of the cables, the AMP equipment on the vessel must be aligned within 20 meters of a receptacle pit. Factors such as berthing configurations, vessel sizes, and the location of the on-vessel AMP equipment dictate whether a vessel will be able to connect to a given receptacle. This issue is usually addressed by installing receptacle pits at regular intervals along the berth face (typically every 60 meters). This solution works well in greenfield installations where receptacle pits can simply be cast into the new berth face, but this approach is very costly when installing receptacle pits at an existing terminal.

Project budgets dictate the number of receptacle pits that can be installed. In order to maximise the number of ships able to connect to the shore power system, the Port of Vancouver conducted a a detailed berthing study. An analysis was made of the container lines serving the Pacific North West region. An outreach survey was performed to the various container lines to determine their vessel sizes, the location of on-board equipment, and their plans to build new vessels. A comprehensive analysis and summary study were conducted to optimize the receptacle pit locations, taking into account vessel length, number of vessels berthed simultaneously, location of AMP equipment, berth configuration and berthing orientations, length of connection cables, and tidal fluctuations and vessel buoyancy during on- and off-loading.

BC Hydro is a Crown corporation that supplies the power and invoices cruise ship lines directly for using shore power at the Canada Place cruise ship terminal. Container terminal operators (DP World Vancouver at Centerm and Global Container Terminals at Deltaport) are in the process of establishing a shore power connection fee. This will include the cost of energy using BC Hydro Tariff Supplement 86 (TS86) and other administrative and labour fees associated with the connection. In July 2017, BC Hydro released an addendum to their Interconnection Requirements for Power Generators, with specific provisions for terminals supplying ships capable of running in parallel with BC Hydro.

A third-party contractor, hired directly by cruise ship lines, is responsible for the operation and maintenance of shore power equipment at Canada Place cruise ship terminal. Once the system is fully commissioned, container terminal operators will be responsible for operating the shore power equipment. The connection requires one electrical supervisor and two electricians. The repair and maintenance of the shore-to-ship power facilities in accordance with the manufacturer's specifications are the responsibility of the respective terminal operators. Vancouver Fraser Port Authority (the organisation that installed the shore power infrastructure) will retain ownership of the shore power facilities.

The use of shore power is voluntary at Port of Vancouver terminals.

In terms of pricing, BC Hydro has established a specific shore power rate. The price per kWh is constant (independent of the time of day and/or season). This rate enables terminal operators to provide shore power at a predictable unit electricity cost (i.e. without unit cost uncertainties resulting from the presence of a demand charge). There is no demand charge in TS86 – vessels are charged for metered energy use (kWh) only plus a nominal administrative fee. BC Hydro is able to provide a preferential rate to port customers based on the provision that the service is non-firm and interruptible if BC Hydro needs the energy for any reason. Because the power is non-firm, BC Hydro was not required to construct an extension to increase the capacity of its distribution system to provide the shore power service. This leaves the ships a risk of supply interruptions, but reduces the capital cost for BC Hydro. However, the system is continuously monitored by the ships' systems and the ship can restart its auxiliary engines if necessary. Shore-to-ship power has not caused any vessel failures at Port of Vancouver terminals.

There are no specific subsidies but the absence of a demand charge offers a significant advantage, especially to vessels that would trigger high peak demand charges while connected, i.e. cruise ships. The cost of BC Hydro electricity is one of the lowest in North America.

If regular rates were applied, it would be very difficult to distribute the cost of the peak demand charge among the connected vessels, because the regular monthly charge combines charges for energy ($/kWh) and peak demand ($/kW) (monthly highest average kW measured over 15 minute intervals). A demand charge would be a disincentive for shore-to-ship power, which is why the Port of Vancouver considers a special shore power rate integral to the successful adoption and growth of shore power technology. A further incentive is that all vessels capable of shore power connection can apply for discounted harbour dues through the Port of Vancouver's EcoAction Program.

For the new container terminal installations, the expected initial shore power uptake is one to four vessels per month. Container ships able to connect to shore power make up 34 % of all container ship calls to Vancouver. Approximately 80 % of the cruise vessels equipped for shore-to-ship connect to shore power. Table 4 shows the typical demand profiles for container ships and cruise ships.

Assessment

The experience of the Port of Vancouver shows that it is possible to develop a voluntary shore-to-ship power system that provides sufficient incentives for almost all cruise ships to use the system for all their port calls. This is due to the combination of supporting factors. Most importantly, many cruise ships in the North West cruise market are fitted with shore-to-ship power equipment. To a considerable extent, this is the effect of the US clean air legislation for ports. Together with the lower price sensitivity in the cruise market com-pared to container or bulk markets, cruise ship operators are prepared to undertake extra investments. The US ports of Juneau and Seattle also provide shore-to-ship power and cruise lines have invested in shore-to-ship equipment here as well. Furthermore, when operating in areas that depend on their environmental attractiveness, cruise shipping lines in general are facing increasing pressure to operate ships that minimise their environmental impact. A further supporting factor is the relatively low price of shore power for cruise vessels, which depends on a special price and conditions for ships compared to other BC Hydro customers. The demand-independent, fixed power rate is lower than the rates for other customers. In return, the contract is for a non-guaranteed or 'non-firm' electricity supply. This is an imaginative and effective measure to reduce the extra cost of shore power compared to running ships' auxiliary engines.

The uptake of shore-to-ship power by container vessels is still to be demonstrated. However, a significant proportion of container vessels calling at Vancouver are fitted for shore-to-ship power. If the cost of shore power is competitive with ships' auxiliaries, container ships can also be expected to use shore-to-ship power.

Vessel type	9500 TEU container	Cruise ship
Auxiliary demand at berth	1.55 MW average, depending on amount of refrigerated containers on the vessel	6-12.5 MW
Time at berth	60 hours	8 hours Average connected time: 5-7.5 hours
Total power used while at berth	106 MWh	

Figure 6: Typical demand profiles for container and cruise ships at the port of Vancouver

4.2.3 Gothenburg

The Swedish Transport Administration provided data on monetary values for emissions and the Port of Gothenburg conducted a feasibility study for possible shore-to-ship implementation. This showed a social benefit for Ro-Ro installations, but installation costs were much higher than the avoided external costs for the energy and container ports.

The current shore-to-ship system has three connections for two ferry/Ro-Pax ferry termi-nals and one connection for freight Ro-Ro/car carriers. The supply is at 60 Hz per berth, rated at 0.6 MW to approximately 1.5 MW.

The power is supplied by the local electricity utility, Göteborg Energi Nät AB. The shipping company has a contract directly with the power supplier.

The price per kWh does not depend on the time of day or season and there are no peak load charges. Several financial incentives are in place. The variable cost of shore supply is tax-free in Sweden: the government cut the tax on electricity for ships last year from 0.28 Swedish Kroner per kilowatt-hour to a symbolic 0.05 per kWh. There is a further discount for vessels with good environmental performance based on the ESI. Harbour dues are discounted for vessels using shore-to-ship power supply, because these score higher on the ESI than vessels using auxiliary diesels.

Shore-to-ship power supplies 75 % of the electricity required by ships in the ferry/Ro-Pax berths and 25 % of the power for freight Ro-Ro/car carriers.

One operational difficulty that can occur is that connecting the ferries to the grid some-times takes longer than the planned layover time in the port.

Assessment

As was the case in Vancouver, market decisions by ship operators combined with decisions by the ports to invest in shore-to-ship power systems. The requirements of a logistics operator, Stora Enso, led to the investment in shore-to-ship power for freight Ro-Ro vessels on a specific trade route. These vessels also use shore-to-ship power at another port, Zeebrugge. The use of shore-to-ship power by the Stena Ro-Pax vessels is a result of Stena Lines‘ policy of developing shore-to-ship power for its operations at several ports in Scandinavia. Both these shipping lines use shore-to-ship power in ports with subsidised power prices and shore-to-ship power systems at both ends of their voyages.

4.2.4 Trelleborg

Trelleborg port launched a shore-to-ship system for two Stena Line ferries in 2017. Four of the six Stena Line ports in Sweden, which represent 17 % of the Swedish ports, have shore-to-ship power.

The connection is rated at 3.2 MW. The electricity is supplied by the local electricity utility. The Ro-Pax ships connect to the shore power when docked for more than two hours. In Trelleborg, this takes place 10-16 times per week. This is calculated to save 12,500 tonnes CO2 annually (Harbours Review 2017).

The price of electricity comprises a fixed fee as well as a price per kWh. The fixed fee is high for the high-voltage supply. The price per kWh does not depend on the time of day or season and there are no peak load charges. As at Gothenburg, the shore supply's variable price per kWh is tax-free.

The ferry/Ro-Pax shore-to-ship supply is used by two vessels, which covers 100% of their energy requirements.

Assessment

Trelleborg has benefitted from the Stena Line policy of developing a network of services with shore-to-ship power on its ships and at many of their ports of call. The subsidies from the Swedish government have made shore power competitive with ships' auxiliary motors. These benefits are combined with a high level of utilisation, as the ships in this case are ferries operating short sea services and therefore spending a relatively high proportion of time in ports. The provision of shore-to-ship power at both ends of a ferry route ensures that a high utilisation of the shore-to-ship equipment is possible on these routes. This improves the rate of return on the capital cost for the ships.

4.2.5 Los Angeles

The successful trials of shore-to-ship power systems, in particular the Los Angeles power barge from 2004 and the 6.6 kV high voltage connection from 2005, enabled the Califor-ni-an Air Resources Board (CARB) to implement legislation requiring ships berthing in Cali-fornian ports to use shore-to-ship power. Ports covered by the legislation are: Port of Los Angeles, Long Beach, Oakland, San Diego, San Francisco and Hueneme. The At-Berth Regulation gives vessel fleet operators visiting these ports two options to reduce at-berth emissions from auxiliary engines: 1) turn off auxiliary engines and connect the vessel to some other source of power, most probably grid-based shore power, or 2) use alternative control technology that achieves equivalent emission reductions. Californian ports had already implemented shore-to-ship power policies. The relevant leg-islation required that, from 1st January 2014, 50 % of all container, refrigerated cargo and cruise ships calling regularly at these ports must use shore-to-ship electrical power at berth. These fleets must also cut their total emissions by 50 % while berthed. These requirements were extended to 70 % of ships and a 70 % emission reduction from 2017 and to 80 % of ships and an 80 % emission reduction from 2020 (CARB 2019).

The high-voltage shore-to-ship power supply installed at the Port of Los Angeles complies with the specifications of the IEC/ISO/IEEE 80005-1 international standard (POLA 2019). Plugs and socket-outlets comply with IEC 62613-1 and IEC 62613-2.

- Shore-side power supply: 6,600 volts (6.6 kV) 3-phase power at 60 Hz. The supply has A-B-C counter clockwise rotation according to the international standard.
- Each shore-side AMP-HVSC vault has two outlets. Socket-outlet rated shore circuit current: 16 kA/ for a period of 1 second. Current rating of each socket-outlet: 320 Amperes Socket-outlet voltage rating: 7.2 kV

The shore to ship power connections in the Port of Los Angeles were developed to meet the emission target defined by the Los Angeles municipal authority under the No Net Emission Increase programme for the port. This was the authority's reaction to the California Air Resources Board legislation of 2007.

Electrical power is provided by the Los Angeles Department of Water and Power (LADWP). LADWP power consumption invoices are sent to the port and reinvoiced to the terminal tenant where ships used shore power.

The port has invested in shore-to-ship connections and provided financial support of US $ 800,000 in total for the installation of the on-board equipment required to connect and receive shore-to-ship power. The scheme was successful, with shipowners investing in shore-to-ship equipment in a total of 52 new-build (5000 TEU) container vessels between 2005 and 2008.

Charges from the electricity utility (LADWP) are based on the following factors (LADWP 2019):

- Fixed service charge $ 150
- Facilities charge - per kW $ 1.33
- Energy charge - per kWh $ 0.05910
- Reactive energy charge: charge to reflect peak loading of the grid

The measured power consumption of the ships may not match the total electrical power consumption shown on the LADWP invoice, usually due to shore equipment power consumption and service fees.

“Ocean going vessels that are supplied electric current at the Port of Los Angeles by the Department of Water and Power of the City of Los Angeles through facilities of the Harbor Department and invoiced by the Harbor Department for the purpose of reducing air emis-sions at the Port are exempt from the 15 % the service charge otherwise applicable to the cost of such electric current“ (POLA 2005).

Most container ships use the shore-to-ship supply. Figure 7 summarises the activity for 2018 and 2019.

Assessment

The example of the Port of Los Angeles is particularly important, because it demonstrates the conditions under which general commercial shipping will convert to shore-to-ship power. As Figure 7 shows, most container vessels calling at the Port of Los Angeles, the largest container harbour in the US, now use shore-to-ship power. This has been achieved through a long-term, consistent environmental policy applied by CARB. The long tradition of rigorous environmental policy in California provided a regulatory environment that convinced ports they would have to develop policies and systems to reduce air emissions. The ports in California were therefore willing to install shore-to-ship power technology to enable them to comply with the environmental legislation. This development in turn enabled CARB to pass legislation requiring major reductions in emissions from ports. This created a framework in which Californian ports were able to develop plans including shore-to-ship power and specific targets and time limits for the shore-to-ship power systems used by the shipping lines calling at these ports. An important aspect here, which is also relevant to the cruise ship operator in the North West of the US and Canada, is that all ports in the region are regulated.

These regulations were supported by incentives for shipowners that reduce the additional costs involved in capital equipment and the higher cost of shore electricity compared to running ships‘ auxiliary motors.

	Calls using shore-to-ship power	Shore-to-ship power equivalent calls	Total calls	% shore-to-ship
2018 January – December	759	61	1016	81
2019 January – March	116	9	173	72

Figure 7: Use of shore-to-ship power in the port of Los Angeles (POLA 2019)

4.3 Assessment of current international best practice

The ports featured in section 4.2 provide examples of the 'state of the art' in the development of shore-to-ship power systems. This section draws general lessons on the goals of using ship-to-shore power systems and describes successful examples in the areas of technical systems, policy and contractual arrangements.

The first conclusion is that shore-to-ship power systems are introduced as an environmental measure, with the goal of reducing both local air pollution and greenhouse gas emis-sions from port areas. The information obtained for Vancouver and Los Angeles, as well as the data for Tianjin Port, show that this goal can be achieved. It has been demonstrated that shore-to-ship power saves a considerable quantity of the fuel otherwise needed to power auxiliary engines in port. This achieves the objective of reducing local air pollution in ports. The reduction in greenhouse gas emissions compared to running the ships' auxiliary engines depends on the greenhouse gas emissions associated with the shore power generation system as well as the reduction in the use of diesel or HFO. If the shore power comes from renewable power sources, large GHG reductions can be achieved.

However, there are a series of barriers to the development of shore-to-ship power systems, which need to be overcome if these systems are to be more widely adopted. There are additional capital costs for ships and ports, additional operating costs that depend on the difference between the shore-side electricity price and the ship's fuel price, as well as management, maintenance and training costs. A new contractual and regulatory frame-work has to be developed. These barriers have different levels of importance for different trades.

The examples chosen cover cruise ship operations, container and bulk operations, as well as Ro-Ro and Ro-Pax ships. Cruise lines and Ro-Pax ports such as Vancouver and Gothenburg have been quicker to develop systems and regulatory frameworks. This is because emissions from ships in port are considered to have a negative effect on market demand, while cruise ships have high capital and operating costs, so that the increased cost due to shore-to-ship systems can be more easily accommodated in their business model than is the case for container and bulk ships. Vancouver and Hamburg provide examples of shore-to-ship power for cruise ships, while Los Angeles has developed a successful framework for implementing shore-to-ship power for container and bulk operations. Ro-Ro and Ro-Pax operations feature some of the market factors of cruise ships. Ports such as Hamburg and Gothenburg and shipping lines such as Stena Line are committed to developing shore power as part of a policy to improve their environmental impact. Ro-Ro and Ro-Pax operations have the further advantage that they operate between a fixed, limited number of ports so that the ships' shore power systems can be used for all port calls. They often operate over short routes, so that the ships have a high number of port calls and spend a relatively high proportion of their time in port, compared to deep-sea container ships or bulkers/tankers.

There are two types of network effects that can hinder or promote the use of shore-to-ship power systems: the number of ships fitted to receive shore power and the number of ports where a ship fitted with such equipment can use a berth with shore-to-ship power.

A major problem for ports wishing to promote shore-to-ship power is that many ships are not fitted with the required equipment. However, many international operators are currently converting their fleets. The operators listed as having used shore-to-ship power or performed the equivalent at the Port of Los Angeles are listed in POLA (POLA 2019):

- American President Lines Ltd
- CMA CGM (America)
- COSCO
- Evergreen Marine Corp
- Hapag-Lloyd AG
- Hyundai Merchant Marine Co Ltd
- Maersk Line
- Mitsui OSK Lines Ltd
- Mediterranean Shipping Co
- Nippon Yusen Kaisha
- Ocean Network Express
- Orient Overseas Container Line
- Pacific International Lines
- Wan Hai Lines Ltd
- Yang Ming Marine Transport

This suggests that most of the largest container operators have fitted many of their ships for shore-to-ship power. Bulk carriers and tankers have not been fitted to the same extent. Since the bulk and tanker trades have a wide range of routes and operators, stronger regulations and incentives will be required for them to invest in shore-to-ship power equipment.

The number of ports with shore-to-ship systems used in a particular trade is also an important consideration. If a ship can use shore power for all its port calls, the ship's equipment can be used more intensively, strengthening the business case for investment. This can be seen most clearly in the Ro-Pax trade in the examples of Gothenburg and Trelle-borg. The Ro-Pax ferries operate on a few routes, where most of the ports have shore-to-ship systems. Since ferries berth very frequently, the benefits of shore-to-ship power are particularly high in this market.

4.3.1 Equipment

While the early shore-to-ship systems supplied power at low voltage to ensure compatibility with ships' on-board distribution systems, all the ports examined have since adopted high-voltage systems with frequency changing. For seagoing and coastal vessels, systems are now installed to the IEC/ISO/IEEE 80005-1 standard for High Voltage Shore Connection (HVSC) systems, usually 6.6 kV rated at 7.5 MVA. The vessels using the port are assessed. The assessment estimates a power demand of up to 12.5 MW for large cruise ships, but lower power requirements for container vessels, dry and wet bulk vessels or Ro-Pax. Frequency converters are usually included for the conversion from 50 Hz to 60 Hz.

A further consideration is the positioning of the equipment. In the example of Vancouver, a survey of all the potential ships for shore-to-ship supply determined the optimal number of supply points and their positioning on the berths.

Recent installations, e.g. at Hamburg and Kiel, have simplified and partly automated the connection and disconnection procedures, in order to speed up the process and enhance the safety of operation (Kiel 2018).

4.3.2 Policy measures and support

Both the shore-side equipment and the installation of the receiving equipment on-board require significant investments by the port and by shipowners. Shipowners must have a strong market incentive or have to comply with a regulation to be willing to undertake this investment. A further barrier is that the cost to the ship operator of using shore power is often higher than the cost of using the ship's motors, because of the relatively low price of HFO or diesel fuel compared to electricity from the shore utility.

There are two cases to consider. Firstly, cruise lines and cruise ports have been prepared to take the initiative in developing shore-to-ship power supplies. Vancouver is a leading example, together with other cruise ports in the region Juneau and Seattle. This is because both the ports and the cruise lines believe that removing soot and other emissions from ship exhausts improves their image on the cruise market and brings in more business. Cruise lines have been willing to invest in on-board equipment and cruise port authorities have also been willing to invest. This is also true for Ro-Pax terminals and ship-owners in Gothenburg and Trelleborg, where a limited investment in one or two berths that are visited very frequently by the same vessels has brought about large emission reductions at the port and only requires equipping these specific vessels.

Gothenburg and Trelleborg are also benefitting from a network effect in the Baltic. Stena Line has cooperated with the ports in developing a network of Ro-Pax and Ro-Ro terminals with shore-to-ship systems This makes it easier to deploy ships equipped with shore-to-ship systems.The situation is different for container, wet bulk and dry bulk ships. For these trades, the extra investment and operating costs do not yet offer a clear positive benefit in terms of maintaining or improving the market demand for these shipping lines. Therefore, the port state authority must require these shipowners to install shore-to-ship equipment. This policy should be combined with financial incentives for the shipowners and shipping lines such as investment subsidies, discounts on port fees for ships using shore-to-ship power and discounts on the total price of electricity. This combination of policies has proven effective in Californian ports and the port of Los Angeles in particular, which have achieved a high rate of utilisation of their shore-to-ship power installations for container ships.

In China, Shenzhen appears to have a potentially effective combination of support policies.

- Port electricity facility construction subsidy: 30 % of the construction cost.
- Ship equipment to receive shore power: 30 % of the construction cost.
- Application fee for ships‘ use of shore supply is set to zero.
- Ship's first port use of shore electricity test fee subsidy: ¥30,000.
- There is a cap on the price of shore power. The government guide is that the cost of shore power may not be more than 30% higher than the cost of running the ships' auxiliaries in the first year of the scheme, 40% in the second year and 50% in the third year.
- Ships using shore-to-ship power every time they are berthed receive an extra electricity price reduction of 0.1 ¥/kWh.
- There is a subsidy for the maintenance cost of port power facilities, dependent on the utilisation rate of shore-to-ship power achieved by the port.
- There is also a subsidy for shipping companies, dependent on the shipping company‘s utilisation rate of shore-to-ship power.

4.3.3 Contractual arrangements and organisation

The contracts and prices for shore power depend on the particular electricity supply companies. Typically, ports do not own the power generation and transmission network and have contracts with their local electricity utility. It is possible for the port to supply power, in which case shipowners have a contract with the port, or for the electricity utility to have a contract directly with shipowners. In the cases of Hamburg, Vancouver and Los Angeles, shipping lines have contracts with the electricity utility. There are also contracts between the ports and the utilities for providing shore-to-ship services. Various contractual arrangements are possible depending on the legal system that applies to the port.

Operating the shore connection is usually the responsibility of the port and ports define the necessary procedures for shore-to-ship power systems. The shore power equipment is part of the port's electricity supply and distribution system. Therefore, the responsibility for maintaining shore-side equipment can be assigned to the owner and operator of the port's electricity system. Usually, this will be the port authority. This means that the port will have to invest in training personnel and possibly employing new workers to operate and maintain the shore-to-ship power systems if a large number of installations are involved.

The ship is responsible for operating and maintaining the on-board equipment and for controlling the ship's auxiliary motors and on-board distribution system.

5. Status of shore-to-ship power at Tianjin Port

Figure 8: Tianjin Port in China

5.1 Policy to develop shore-to-ship power in China

The Law of the People's Republic of China on Prevention and Control of Atmospheric Pollution 2016 states “new wharfs should plan, design and construct shore-to-ship power supply system; the completed wharfs should gradually implement the transformation of shore-to-ship power supply system. Ships shall first use shore power after docking.“

The Ministry of Transport's Shore Power Layout Scheme of 2017 sets a target of 50 % coverage. The “Implementation Plan of Ship Air Pollutant Emission Control Zone“ of 2018 proposes shore-to-ship power for a range of ship types: publicly-owned vessels, inland waterway vessels (except liquid cargo) and river-sea direct ships on some routes, domes-tic coastal container ships, cruise ships, Ro-Ro ships, passenger ships of 3,000 tons and above, dry bulk carriers of 50,000 tons and above.

China plans to have 366 coastal berths and 127 inland waterway berths fitted with shore-to-ship power by the end of 2020. The following vessels shall have shore-to-ship power equipment fitted: Chinese-flagged inland waterway vessels built from 2019 and from 2020, Chinese-flagged passenger ships of 3000 GRT or more, dry bulk carriers of 50000 DWT or more, container ships, Ro-Ro, and cruise ships. They should use shore-to-ship power if available.

5.2 Development of shore-to-ship power at Tianjin Port

Tianjin Port is developing a shore-to-ship power supply system and already has experience with the operation of low- and high-voltage

Ship type	Shore-to-ship power berths in service	Berths to be converted for shore-to-ship power	Total number of berths
Container	1	11	23
Cruise	0	2	3
Dry bulk	0	8	14

Figure 9: Berths equipped for shore-to-ship power at Tianjin Port

shore-to-ship power systems. Considerable savings in fuel and CO2 emissions have been made (see Figure 11). In 2016, a berth was fitted for low-voltage (400 V/50 Hz) shore supply, with another low-voltage berth completed in 2018. At the end of 2018, Tianjin had seven container, seven bulker, two Ro-Ro and three general berths fitted for 6.6 kV/60 Hz, 6.6 kV/50 Hz shore-to-ship power with plans to fit further container berths and two cruise berths (see Figure 9).

Connection and disconnection are not automated. Instead, passive grid-connected disconnection is employed. This is mainly controlled on board the ship and many of these installations exist at present because of their simple operation and the ability to support many on-board systems from one shore installation. All Tianjin Port electric power is supplied by the Tianjin Port Electric Power Co. Ltd.

There are various local administration policies supporting shore-to-ship power. The Ministry of Transport subsidised coastal and inland waterway power projects from 2016 to March 2018, including both onshore and on-board equipment. The incentives from 2016 to 2018 were 60 %, 50 % and 40 % of investment costs respectively. Tianjin Port provided a 20 % investment cost subsidy up to a maximum of 2 million yuan in 2018 and 2019.

Between 2016 and 2018, shore-to-ship power was used 57 times as shown in Figure 10. It can be seen that while the low-voltage systems have been used since 2016, the number of calls and the power delivered by the low-voltage systems are still quite low. The much larger potential reductions from high-voltage, high power shore-to-ship systems are indicated by the data for the single container berth for operations in 2018, where 71.8 MWh were supplied to a single berth.

Estimate of potential emissions savings from shore-to-ship power in Tianjin Port

It is estimated that shore-to-ship systems have made annual savings of 1682.9 tonnes fuel and 5446.9 tonnes CO_2 so far. This estimate is calculated based on the fuel consumption data per month shown in Figure 11.

Type	Date in service	Number of calls	Electricity consumption kWh
Container	2018	8	71800
Bulk high-voltage	2017	6	2600
Bulk low-voltage	2016	37	18900
Bulk low-voltage	2018	6	1500

Figure 10: Use of shore-to-ship power in Tianjin Port (Source TIWTE)

The accumulated berthing time by month is also shown. These figures indicate that the berths were in almost constant use in most months.

Calculation of emissions savings

Assumed use of shore power by 50 % of the ships in port.

Average time at berth of a single ship for a single port visit is approximately 18 hours.

Average power supply capacity required is approximately 1550 kVA.

Substituted fuel volume for project = 50 % × (3215.8+3515.7) / 2 = 1682.9 tonnes

CO_2 emissions saved = 1682.9 × 3.366 = 5446.9 tonnes

No.	Date	No. 5 berth		No. 6 berth	
		Accumulated berthing time (in hours)	Fuel consumption (in tonnes)	Accumulated berthing time (in hours)	Fuel consumption (in tonnes)
1	2016.10	357.94	119.34	629.78	198.35
2	2016.11	523.93	190.96	656	190.67
3	2016.12	513.38	185.44	625.08	227.63
4	2017.1	654.42	275.72	780.35	350.35
5	2017.2	350.16	129.61	657.63	217.27
6	2017.3	664.92	353.11	681.44	357.96
7	2017.4	611.59	319.98	731.66	389.37
8	2017.5	666.34	364.78	689.09	345.79
9	2017.6	642.75	327.16	635.9	304.96
10	2017.7	696.18	349.96	700.1	316.4
11	2017.8	597.58	294.61	675.77	306.5
12	2017.9	658.02	304.91	670.58	309.92
Total		**6937.21**	**3215.58**	**8133.38**	**3515.17**

Figure 11: Calculated fuel use at two representative berths at Tianjin Port

5.3 Assessment of shore-to-ship power at Tianjin Port and problems identified

At present, only a small proportion of the ships use shore-to-ship power at Tianjin Port. Several barriers to the use of shore-to-ship power have been identified. Firstly, many ships calling at the port are not equipped to receive shore power. Secondly, given the current oil and electricity prices, shore power costs more than using the ships‘ auxiliary motors. Finally, there is no compulsory requirement for ships to turn off their auxiliary motors in port or to use shore-to-ship power. A further aspect is the limited promotion of shore-to-ship power at Tianjin.

At present, there are no regulations and standards established for construction, operation, maintenance and safety. As a result, some ship operators have concerns about the safety of shore-to-ship power systems. Another possible hazard is the position of quayside equipment, which is generally close to the berth. The installation of quayside electrical connections may lead to safety risks to the berthing and departure of ships.

Most of the currently installed shore-to-ship systems require a ship's electrical loads to be switched from the ship's auxiliary motors to shore power using interlocking signals and communication via handheld radio. This is a complex procedure requiring trained personnel, both onshore and on-board. Ships‘ crews may not have the necessary training to undertake the connection and disconnection procedures safely, thus increasing the poten-tial for safety hazards.

The necessary management structures at the port are not yet fully implemented. This limits the operation and promotion of shore-to-ship power and can lead to safety risks.

6. Recommendations for the Tianjin port

The problems with developing shore-to-ship power in Tianjin Port can be addressed by considering the international best practice identified in section 4. This chapter proposes measures that Tianjin Port could take to increase the proportion of ships using shore-to-ship power. Further measures are also suggested for the effective and safe management of shore-to-ship power systems.

The utilisation of shore-to-ship power can be maximised by a medium-term regulation of emissions from ships calling at Tianjin Port. Since a large number of ships calling at Tianjin Port are in the bulk and container trades, the experience of California and Los Angeles, in particular, is relevant here. A combined set of measures featuring both regulation and support for shipowners, ship operators and Tianjin Port will be required to ensure the extensive use of shore-to-ship power.

Regulatory measures should clearly state the requirements for all parties involved and set out a clear timetable for implementation, so that all parties can plan accordingly.

The following regulatory measures are recommended:

- A regulation requiring all ships calling at Tianjin Port to use shore-to-ship power. This requirement should be phased in over a period of 3 to 5 years for different types of ship, depending on the proportions of ships in the different trades that are already equipped to receive shore power.
- The contractual arrangements for using shore-to-ship systems should be clearly specified and communicated to shipping lines. Prices for shore power should be communicated to ship operators and shipping lines. Prices should be fixed per port call and kWh, ensuring that the costs to ship operators are transparent and predictable.
- The legal duties and powers of the port and the Port Electric Power Company should be clearly defined, including the power to make contracts with the shipowners.

At the same time, shipowners, ship operators and Tianjin Port should be supported in meeting the investment costs and any extra operating costs of using shore power. Possible measures for Tianjin Port are:

Tianjin Port should cooperate in developing shore-to-ship power with the origin and destination ports for ships using Tianjin Port, both within China and internationally, so that ships fitted for shore-to-ship power can maximise the use of this equipment.

- Tianjin Port should cooperate with shipping lines to promote investment in on-board equipment and agree standards and procedures for operation and maintenance, in particular for connection/synchronisation and disconnection of shore power. This will combat ship operators' uncertainty about how to utilise shore-to-ship power systems at Tianjin Port and increase confidence in the safety of such operations at Tianjin Port.

- Allocation of financial resources to Tianjin Port to help cover the considerable costs of rapidly expanding the shore-to-ship systems to most berths in the port and the additional management, contract and operating personnel needed to operate a much larger number of shore-to-ship installations.
- The pricing schemes and any discounts or other incentives should cover the costs of the port and the electricity supply company. The source of funding for investment and price subsidies should be planned, if the system is to expand successfully.

Possible measures for shipowners and operators are:

- Financial support for shipping lines to invest in shore power equipment. For example, financial aid to meet some of the capital costs of the equipment needed to receive shore power during the period in which the requirement for ships to use shore-to-ship power is introduced.
- Subsidising the cost of shore power to ship operators to make the operating costs for ships using shore-to-ship power competitive with the costs for running the ships' auxiliary motors. This can include a discount on port fees for ships using shore-to-ship power.

Possible measures for developing the management and operation of shore-to-ship power systems at Tianjin Port are:

- The safety of operation, in particular connection and disconnection, can be improved by developing systems with a high degree of automation. The latest systems check the connection, match phase, frequency and voltage and make the electrical connection and disconnection automatically. Shore-to-ship power systems should be developed with automated testing and power matching and power management similar to those installed in, e.g. north European ports such as Kiel, Oslo and Gothenburg. These enable simplified connection and disconnection procedures. Such simplified procedures improve the safety of the systems and lead to a better acceptance of shore-to-ship power by ships' crews and shipowners.
- The shore-side power equipment must be operated and maintained to a high standard to ensure safe operation. This requires allocating responsibilities to the relevant departments of the port and training the relevant staff in the respective operation,

maintenance and inspection procedures. It also requires a clear allocation of responsibilities to the electricity supplier and the ships‘ crew.

- Standards should be established for installing, testing and maintaining shore-power installations. These standards should be based on the existing international standards for high-voltage electrical power systems.

- Development of management systems and training port staff to operate and maintain the shore-side equipment. The management structure should clearly define the responsibility and measures in the relevant departments. It should ensure the supervision and management of shore-to-ship power system construction to international standards. It should ensure the operation and maintenance of the shore-to-ship power systems to international standards. This will ensure the safe operation of the shore-to-ship power systems and reduce safety concerns, thus increasing the acceptance of shore-to-ship power systems by ships‘ crews and shipping lines.

- At present, Tianjin Port is still dependent on the expertise of the shore-power equipment manufacturers for the safe operation of the shore-to-ship power systems. Therefore, responsibility for operating and maintaining the system must be defined. If operation and maintenance is to be the responsibility of the port authorities in future, the necessary personnel must be trained.

7. Conclusions

This report presented a comparative analysis of shore-to-ship power supply systems in Tianjin Port and selected other leading ports worldwide. Ports were interviewed that are leaders in the development and application of shore-to-ship power: Hamburg, Vancouver, Gothenburg, and Trelleborg. These interviews were complemented by a literature review, which enabled the port of Los Angeles to be included in the analysis. The experience of the Port of Vancouver shows that it is possible to develop a voluntary shore-to-ship power system that provides sufficient incentives for almost all cruise ships to use the system for all their port calls. The example of the Port of Los Angeles is particularly important, because it demonstrates the conditions under which general commercial shipping will convert to shore-to-ship power.

Shore-to-ship power in ports has the potential to make major reductions in fuel use by ships in ports. Compared to running diesel auxiliary motors, this can also achieve major reductions in local air emissions including NO_x, SO_x and particulate matter. If the electricity supplied comes from renewable generation, shore-to-ship power can also significantly reduce greenhouse gas emissions.

Shore-to-ship power systems are now technically mature and have been shown to be compatible with local power distribution systems, including Tianjin Port.

There is now considerable global experience in operating shore-to-ship power systems. While earlier systems delivered power at low voltage, modern systems deliver electricity at 6.6 kV 50 Hz and 60 Hz, minimising the transmission and distribution losses. Systems are now installed to the IEC/ISO/IEEE 80005-1 standard for High-Voltage Shore Connection (HVSC) systems, usually 6.6 kV, rated up to 12.5 MW. This requires power supply systems with transformers, frequency converters and power management systems onshore and transformers onboard. These systems require considerable investments by the port and by shipowners.

Shore-to-power systems also require new regulations and contractual arrangements. These have to cover the supply of electricity, the operation of the shore power equipment and the connection and disconnection procedures. The responsibilities for safe operation, maintenance and training in the electricity utility, the port and the ships have to be defined.

Tianjin Port is implementing China's policy of developing shore-to-ship power. At the end of 2018, Tianjin had seven container, seven bulker, two Ro-Ro and three general berths fitted for 6.6 kV/60 Hz, 6.6 kV/50 Hz shore-to-ship power with plans to fit further container berths and two cruise berths. While some ships have been using the systems, there are still barriers to realising the full potential of shore-to-ship power at Tianjin Port:

The utilisation of shore-to-ship power is low.

- The regulations and standards for construction, operation, maintenance and safety are not yet fully established.
- Most of the shore-to-ship systems installed require the ship's electrical loads to be switched manually from the ship's auxiliary motors to shore power using interlocking signals and communication via handheld radio.
- The necessary management structures are not yet fully implemented in the port. This limits the operation and promotion of shore-to-ship power and can lead to safety risks.

Recommendations have been made for measures to address these barriers. A combined set of measures that features regulation and support for shipowners, ship operators and Tianjin Port will be required to ensure the extensive use of shore-to-ship power. The most important measures are:

- A regulation requiring all ships calling at Tianjin Port to use shore-to-ship power.
- Allocation of financial resources to Tianjin Port to help cover the considerable costs of rapidly expanding the shore-to-ship systems to most berths in the port and for the additional management, contract and operating personnel needed to operate a much larger number of shore-to-ship installations.
- Tianjin Port should cooperate with shipping lines to promote investment in onboard equipment and agree on the standards and procedures for operation and maintenance, in particular for connection/synchronisation and disconnection of shore power.
- Subsidies for ship operators to help cover the cost of shore power.
- Improve the safety of operation, in particular connection and disconnection by developing systems with a high degree of automation.
- Develop management systems and train port staff in the operation and maintenance of the shore-side equipment.

8. Appendix: Port questionnaire

Background and objective

The installation of shore-to-ship power supply systems at berths has been a subject in the maritime domain for decades. Recently a rising awareness and increasing pressure regarding the requirements for cleaner air in port cities has triggered a new momentum. Ports are forced to act pro-actively installing shore-to-ship power supply systems.

With this study Fraunhofer aims at comparing the approaches and success stories in Europe and North America to the new approach in China, where through a governmental decision all ports and most berths will be equipped with power supply facilities in the near future.

General questions

- How long has the system been in operation?
- Why was the system developed?
- What are the expected benefits for the port?

What is the charging scheme and price per kWh?	
Is the price per kWh constant or dependent on the time of day / season or other variable? Is it included in a port fees package?	
Are any subsidies available to lower the price of electricity for this specific purpose?	
How is the issue of peak loads in the grid solved? Is this an issue for high energy prices?	

Figure 12: Cost of shore-to-ship electricity compared to fuel for ships auxiliary engines in the local markets (competitive situation of shore-to-ship electricity)

	Proportion of energy requirements of ships in port supplied by shore-to-ship electricity per vessel type in 2017 or a recent year	Number and percentage share of vessels using shore-to-ship electricity supply in the port per vessel type
Bulker		
Tanker		
Coasters, inland waterways vessels		
Ultra Large Container Vessel (ULCV) 14501 TEU or more		
New Panamax or smaller container vessel		
Feeder container vessel		
Ferry/RoPAX/small tourist cruise vessels		
Freight Ro-Ro / car carriers		
Cruise vessels		
Service vessels (tugs, dredgers, PSVs etc.)		

Figure 13: Energy consumption per vessel type (demand side)

	Please comment
Number type and capacity in kW of installations per berth	
Any custom-made solutions (e.g. electrical power supply via small scale LNG turbines)?	
Energy mix of provided on shore power supply (in % of renewables)	
Company supplying the power? (e.g. energy provider, port authority, terminal operator or else)	

Figure 14: Supply side, power supply

	Please comment
Are the port fees lowered for vessels using on shore power supply?	
Are there any additional incentives?	
Do any mandatory regimes apply? Is the use of the shore power supply mandatory for some vessesl/berths?	
Is there a bonus and malus system in place?	
Assessment of achievements comparing international co-operations vs. single local measures	

FIgure 15: Regulatory framework

	Please stress
Who is responsible for shore side system management and operation? Who is reponsi-ble for inspection and safety?	
Necessity to turn off all auxiliary engines be-fore plugging in? This is not feasible - so are therespecial power management systems for matching (frequency and voltage etc.) the shore power supply with ships' power systems	
Customized berthing system to serve as many as possible vessels? What are the arrange-ments for flexible high capacity cables on the berth to allow for different positions of the connections on different ships?	
Percentage share of severe failure in supplying vessels	
Any other issues to mention	

Figure 16: Operational issues

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