Shipping Infrastructure

HIGHLIGHTS

■ **TECHNOLOGY STATUS –** Ships have the largest carrying capacity of any freight mode and maritime ports handle more freight than all other types of terminal combined. Thus, shipping infrastructure requirements are substantial. The infrastructure elements include port terminals (docking areas, bunkering, shore-side power, storage); port operational equipment (cranes, tugboats, dredgers) and man-made global maritime routes. Port terminals usually provide specialised facilities (cranes, grabs, storage) for different types of cargo. *Containerization* of cargo has revolutionised the industry, drastically reducing labour requirements - by almost 97% for a modern containership compared to *uncontainerised* cargo. Technology options to reduce the energy consumption and GHG emissions from port infrastructure and operations include the use of alternative fuels, fully electric port equipment (e.g. cranes), port-side electricity supply (cold-ironing) and hybrid or re-engineering of tugboats and dredging vessels.

■ **PERFORMANCE AND COSTS –** The construction of port facilities constitutes a minor percentage of lifecycle energy use and CO_2 emissions (<1%). The cost of adding shore-side electricity supply infrastructure is estimated to range between US $1 million and $7 million per berth, with typical in-dock CO_2 savings of around 50% over running conventional ship diesel engines, and associated fuel savings. Emission reductions can also be achieved for port operational equipment by switching to alternative fuels (e.g. biodiesel), fully-electrified equipment or through operational means. Modern full-electric cranes can recapture 75-80% of the energy released when a load is lowered. Simultaneous operation of many cranes can deliver savings of up to 30%, while synchronising movements can realise an additional 5% energy saving. Tugboats can be retrofitted with pollution control devices or use cleaner alternative fuels. Electric-hybrid tugboats are just entering the market, with reported CO_2 savings of 27% over conventional types. Dredging consumes between 2270 and 2680 litres of diesel per hour. Abatement options for dredging vessels include alternative fuels and upgrading engines. In order to handle the growth in the number of transits and vessel sizes, several expansion works are underway for global maritime routes, e.g. a project is currently underway to double the capacity of the Panama Canal.

■ **POTENTIAL AND BARRIERS –** In 2009, global seaborne trade volumes contracted by 4.5% due to the economic recession. Total goods loaded fell from 8.2 billion tons to 7.8 billion tons. With the exception of major dry bulks (coal, iron ore), all shipping segments were negatively affected. The economic recovery is expected to bring renewed demand for seaborne trade, although the fragile financial position of some advanced economies is a source of uncertainty. Sea ports and global maritime routes are experiencing greater pressure from larger container ships, which require bigger capacities, larger storage areas, specialized cranes and dredging at increased frequencies and depths. The future is expected to bring progressively more stringent limits on CO_2 emissions from ships in port, increased taxes on pollution sources and tax incentives for shore-side power. Emission reductions for port operational equipment are subsidised by several programmes in the US, which have encouraged greater penetration of efficient engine technology. Uptake of renewable generation technologies in ports is gaining greater interest, for example wind power and solar energy.

TECHNOLOGY STATUS - This brief outlines energy consumption, greenhouse gas (GHG) emissions and costs arising from construction, maintenance and operation of shipping infrastructure. Ships have the largest carrying capacities of any mode. For instance, a typical barge has a capacity of 1,500 tons, which is significantly greater than that of a semi-trailer truck (26 tons) or a 747-400F aircraft (124 tons). A VLCC (very large crude carrier) has a capacity of up to 300,000 tons, whereas a 100 car train unit can carry up to 10,000 tons [2]. Due to these large carrying capacities, infrastructure requirements for maritime vessels are substantial. They can be broadly categorised as:

- Port terminal infrastructure - static structures such as buildings, docking areas and power supply;
- Port operational equipment - vehicles or machinery needed to provide port services including towing, cargo handling and dredging; and
- Global maritime routes - man-made passages which are vital to international trade.

Port facilities are determined by the type of cargo they handle. **Liquid bulk** cargoes, such as crude oil, are moved using pumps and pipelines; they require only limited handling equipment but may need significant storage capacity. **Dry bulk** products are unpackaged goods such as ore, cereals and coal. Sophisticated equipment is used to handle these goods such as cranes, specialized grabs and conveyor belts. Some terminals have specialized storage structures such as grain silos or refrigerated warehouses. **General cargo** requires a lot of labour to handle because dimensions and weights are not uniform. Containerization, which allows mechanized handling, is becoming progressively more common. **Container** terminals have minimal labour requirements, but generally require large amounts of space for moving and stacking containers. The larger the containerships handled by a port, the larger the required storage area. Intermediate or **transhipment ports** are used for ship-to-ship operations; containers must be stored in the port temporarily, rather than being transferred directly. Their importance is growing as they increase connectivity between global ports.

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The increase in containerized cargo was more than fivefold between 1990 and 2010; containerized trade now accounts for around a quarter of total global dry cargo [1]. This has manifested a change in the configuration of port terminals, which have shifted focus away from conventional bulk to containers since the 1960s. A modern containership requires around 750 man-hours to be (un)loaded whereas the same volume of uncontainerised cargo requires 24,000 man-hours [2].

■ **Port terminal infrastructure** provides essential connections between seaborne and land-based modes of transport. The main functions of a port are to supply services to freight (for example, storage or transhipment) and to vessels (refuelling, repairs etc). Maritime ports handle more freight than all other types of terminal combined [2]. The trend towards increasing ship sizes (see ESTAP Brief T13) means the infrastructure needed to support them must be upgraded or replaced. • **Docking areas** are provided to receive ships and transfer cargo, where ships can be docked for as little as one hour or up to three days. Economies of scale favour larger ships; however the maximum size is limited by the ability of the port to accommodate them. For example, a typical 5,000-10,000 TEU post-PanaMax[1] vessel ranges from 275-340m in length, 38-45m beam and 13-15m draught [3] and docking area (and crane reach) must be large enough to service this. • **Bunkering** is the process of supplying fuel to ships for their own use. The majority of ships use heavy fuel oil (~98% total marine fuel in the EU[2]) and marine diesel/gas oil fuels; ships using alternative fuels such as LNG or nuclear power require ports that are able to store and handle these fuels. • **Cold-ironing** - i.e. shore-side power for ships while at dock - allows ships to turn off their diesel-powered auxiliary engines. The technology is well-known and has been used routinely for decades at US Navy ports worldwide [5]. Power demand can be up to 6 MW for large containerships and up to 15 MW for cruise ships [6]. A transformer is often needed before ships are able to use shore-side electricity, and the local grid connection to the port must be upgraded. An alternative is to use natural gas power generation. For instance, the Wittmar cold-ironing system can burn either compressed or liquefied natural gas. In addition to specialised structures, ports comprise buildings for warehouses and administration offices.

■ **Port operational equipment** relates to mobile machinery or vehicles which provide port services. • **Cranes** are used to load and unload ships, or move cargo to and from storage. The cranes are usually powered either by diesel-driven generators or electric power from the dock. • **Tugboats** are used for pushing or towing ships into berth. They have large engines relative to their size (~ 5,000 horsepower) with high fuel consumption [7]. • **Dredging vessels** ensure and maintain sufficient water depth. The process consists of six stages, namely: sailing empty, dredging, sailing loaded, connecting, discharging and disconnecting.

■ **Global maritime routes –** These routes are located between major industrial regions such as Western Europe, North America and East Asia. Maritime passages can form chokepoints because they are often shallow and narrow. The most important passages are the Panama Canal, the Suez Canal, and the Strait of Malacca. So vital are they to global trade that several vessel size classes have been named according to the limitations imposed by each of these routes; that is, the PanaMax (5,000 TEU[3]), SuezMax (12,000 TEU) and Malaccamax (18,000 TEU). • The **Panama Canal** connects the Atlantic and Pacific oceans across the Isthmus of Panama. It is around 86km long and saves a detour of 8000km – 21,000km around South America [2]. Over 14,000 ships pass through the canal each year, carrying more than 275 million tonnes of cargo, of which 70% is destined for or coming from the United States [8]. This represents ~ 8% of global trade volume [9]. • The **Suez Canal** joins the Mediterranean Sea with the Gulf of Suez. In 2009, 17,993 ships made transits, down from 21,415 in 2008 [10]. Total cargo carried was 735 million tonnes in 2009 (910 million tonnes in 2008) [10]. This decrease was due to lower goods traffic while oil and LNG tonnage increased over this period. Trade volumes through the Suez canal are around 4% of the global total [9]. • The **Strait of Malacca** connects the Pacific and Indian Oceans. Around 60,000 vessels transit each year [11]. It is around 800km long, with a width of 250km in the north, narrowing to only 65km in the south [12]. Shipments from the Middle East to the Far East can save up to 1600km by using the Malacca Straits [12].

PERFORMANCE AND COSTS

■ **Port terminal infrastructure -** The construction of port facilities constitutes a minor percentage of lifecycle energy use and CO_2 emissions. A study based on information from the Ecoinvent database calculates that total lifecycle CO_2 emissions from construction of port facilities accounts for 0.01% [13]. Other studies have estimated the emissions from ship production and port construction to be 2.7% for an LNG tanker (200,000 DWT) to 11.3% for an LPG tanker (200,000DWT) [14] on a lifecycle basis. Literature on in-use energy consumption and emissions of ports is scarce, however, the outcomes of some case studies have been provided in Table and Figure 1 which illustrate the breakdown

[1] See explanation below
[2] Based on the Maritime Transport dataset from EX-TREMIS *("Exploring non-road transport emissions in Europe")* project, available from: http://www.ex-tremis.eu/ [4].
[3] TEU: Containership capacity is expressed in Twenty-foot Equivalent Units (TEU) which is the number of 20' x 8' x 8'6" containers it can carry

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between direct operational emissions (e.g. fuel combustion) indirect operational emissions (e.g. from electricity generation) and other emissions (e.g. from staff commuting and business travel). Port buildings can reduce energy demand by conforming to general construction good practice guidelines, i.e. using energy efficient lighting, improving insulation in cold regions and installing efficient air conditioning systems in tropical climates.

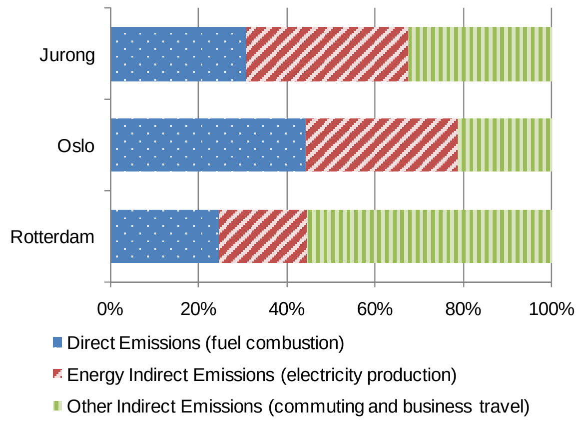

Figure 1 - Breakdown of port operational GHG emissions for three major European ports [24, 25, 26]

Information on the contribution of total port operational emissions to overall shipping lifecycle emissions is not readily available. The only such study suggests GHG emissions from port operations could be as much as 15% of the lifecycle total for shipping, based on information from the Ecoinvent database [13] (see Figure 2 below). However, this figure (based on a transoceanic tanker) includes emissions from both port-side operations and ship emissions. It is also not clear how representative the figures would be for shipping in general.

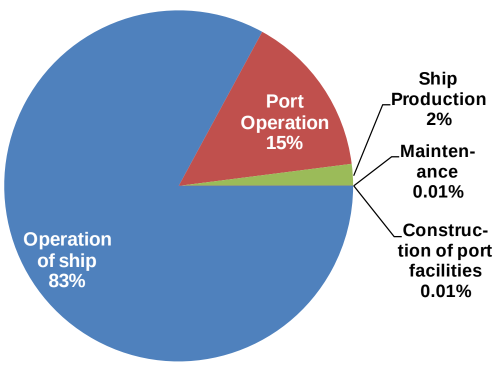

Figure 2 - Lifecycle GHG emissions of a transoceanic tanker according to data from Ecoinvent [13]

In order to use **shore-side electricity**, ships usually require a step-down transformer, additional electrical switchboard and cables. The average cost for retrofitting a ship is US$500,000 without an on-board transformer and US$1.5 million with transformer [7]. Adding shore-side infrastructure costs between $1 million and $7 million per berth [7]. High voltage and current power conduits are needed to connect the power grid to the pier. Using shore-side electricity instead of diesel reduces CO_2 emissions by an estimated 50%, assuming the current European electricity average generation mix [6]. Wittmar's natural gas cold-ironing system costs between $1 million and $ 2 million per unit. The estimated CO_2 reduction for a typical 2-day dock is 57% [15].

■ **Port operational equipment** - The US EPA regulates most air pollution sources at ports, including cargo-handling equipment and tugboats [16]. Significant emission reductions can be achieved by switching to alternative fuels, replacing the equipment or repowering with more efficient engines. Alternative fuels include biofuels and compressed natural gas (CNG). Pure biodiesel offers CO_2 emissions reductions of around 50% and blends of 80% with conventional diesel show a 10-20% improvement over regular diesel [17]. Onsite fuelling stations are suitable for port equipment as it operates within confined areas. • **Cranes -** Initial capital outlay for a container crane is in the region of US$5 million, with an assumed life of 20 years [18]. The most significant components of operational cost are labour and consumables, respectively around $630,000 and $50,000–100,000 per year [18]. In comparison, energy costs are only a small part of operational costs. Energy for electrically-powered lifting, based on 4500 operation hours per year, costs only $54,000; auxiliary power for lighting costs $6210 [18]. Typical energy demands for cranes are shown in Table 2**Table** .

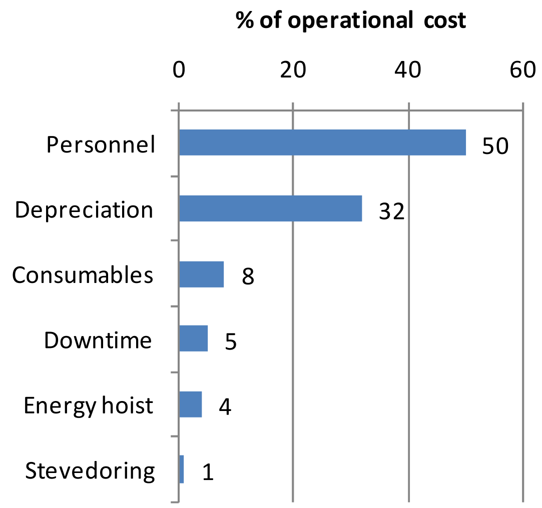

Figure 3 - Operational cost for crane [18]

Full-electric operation of cranes has a lower environmental impact compared to using diesel; modern electrical drives are four-quadrant systems which can feed energy back to the supplying grid, thereby recapturing 75-80% of the energy released when a load is lowered [19]. Greater automation ensures that loads are not lifted higher than is necessary, and reduces auxiliary power demand because lighting needs are minimal. Simultaneous

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operation of many cranes evens out their consumption so that energy generated on the supply grid can be used by other cranes elsewhere. Savings of 30% are expected when ten cranes operate at the same time [19]. Synchronising movements in this example can realise an additional 5% energy saving [19]. Operational costs for cranes are shown in Figure 3. • **Tugboats** - Tugboats may stay in service for over 30 years. They can be retrofitted with pollution control devices or use cleaner alternative fuels. Replacement engines cost around US$400,000 and can reduce NO_x emissions by up to 73 tons per year [17]. The first diesel battery-electric hybrid tugboat built by Foss Maritime began operation in 2009. It reportedly achieves emission reductions of 73% for PM_{25}, 51% for NO_x and 27% for CO_2 over similarly-sized conventional tugboats [20]. Automatic engine shutdown systems can also be effective in reducing emissions; tugboats spend around half of their time idling. • **Dredging vessels** - Fuel consumption for dredging vessels differs substantially between the different stages of the dredging process. Typical values are presented in Tableable 4. Sailing and pumping are the most energy-intensive activities with fuel (diesel) demands of over 3500 l/hr. Dredging consumes between 2270-2680 l/hr depending on whether the material is silt, sand or clay. Abatement options for dredging vessels include alternative fuels and upgrading engines.

■ **Global maritime routes -** In order to handle the growth in the number of transits and vessel sizes, several expansion works are underway for global maritime routes. Two examples are provided here. A project to double the capacity of the **Panama Canal** was agreed in 2006 and is expected to be finished in 2014, at a cost of US$ 5.25 billion [21]. This will increase the depth from 12m to 18.3m, the width from 106ft to 190ft [22]. This will improve efficiency by allowing larger vessels (post-Panamax) to transit with higher cargo volumes, but result in greater construction emissions. In 2009, the typical toll for a fully laden containership was US$72 per TEU [30]. The **Suez Canal** is 193km long and saves around 6,500km over a route around Africa [23]. The Suez Canal Authority plans to increase the depth of the western channels of the Suez Canal from 48ft to 52ft to allow passage to giant containerships.

Depending on its size, the Suez Canal toll for a containership can be US$50 to US$80 per TEU [31]. In comparison, the average charter rate for an Asia-Europe route was just over US$1,000 per TEU in 2009, and for an Asia-US route it was around US$1,400 per TEU [1].

POTENTIAL AND BARRIERS - In 2009, total international seaborne trade volumes were 7.8 billion tons, down from 8.2 million tons in 2008 (a 4.5% reduction) due to the global recession of 2009 [1]. Minor dry bulks (manufactures, agribulks, metals and minerals) and containerized trade suffered the most; conversely, iron ore and coal trade demand remained strong due to China's robust import demand. As a result of the recession, many port developments were curtailed or delayed. The global recovery is expected to bring renewed trade growth and port development. In particular, the rising demand for containerized goods shipping to fast-growing Asian countries, and China's appetite for raw materials are expected to reverse the 2009 trend. IEA baseline projections formed in 2008 indicate that shipping activity (on a t-km basis) could increase by a factor of 1.5-1.8 against 2005 levels by 2030, and by a factor of 2-2.9 by 2050 [29]. It is clear from these projections that without further action, demand for shipping transport is likely to grow to the extent where reducing emissions from the sector would be very challenging.

Some of the biggest port development projects are taking place in Latin America. Brazil hopes to raise US$20 billion of private sector finance between 2010 and 2015 for port projects [2]. In Europe however, the number of new port projects has decreased compared to recent years. In India, new terminal facilities at Jawaharlal Nehru and Tuticorn have been delayed [2]. Sea ports are experiencing greater pressure from larger container ships requiring bigger berths, larger storage, more dredging and specialized cranes. Ports are often located near urban areas where there may be congestion problems and lack of available land. Local communities may resist expansion of port capacity. The trend towards larger ships has also prompted expansion projects for global maritime routes, which are forming chokepoints in the international trade. Investment in these routes is needed to maintain competitiveness with alternative intermodal systems.

It is expected that regulatory authorities will set more stringent limits on emissions from ships in port, increase taxes on pollution sources and make tax exemptions for shore-side power. California has mandated that half of a carrier's fleet of containerships, passenger ships and refrigerated cargo ships must use cold-ironing when berthed in California's ports by 2014. By 2020, this rises to 80% of vessels. However, the modifications needed to ships before cold-ironing can be used, along with potential strains on local power infrastructure, are significant barriers. There are several voluntary initiatives and subsidies to encourage emission reductions. Although these are usually targeted at improving air quality, they tend to have beneficial effects on GHG emissions. For example the EPA's Voluntary Diesel Retrofit Program and California's Carl Moyer Memorial Program provide financial support for emission reduction of port equipment. These programmes encourage the introduction of new technologies, but also make it difficult for developing countries to follow changes without financial incentives.

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Advances and investment in renewable energy technologies could be beneficial. For instance many ports are located in windy regions and investment in wind power is growing as well as the reliance on solar energy. Some ports are now touting their green credentials, e.g. Port Authorities of New York, New Jersey and Belfast all aim for a zero carbon footprint, and efficiency measures will increasingly be adopted.

Security is also a major concern for shipping infrastructure. In 2014 the US will require foreign ports to scan all containers bound for the US. Cargo scanning may bring technical and economic challenges. Trials show that the technology for effective scanning does not yet exist. The European Commission estimates that investment until 2020 would require US$ 280 million, and operational costs would be US$ 270 million [1].

Table 1 - Lifecycle Port Emissions [24, 25, 26]

Port	Year	Direct Emissions		Energy Indirect Emissions		Other Indirect Emissions	
		No.	%	No.	%	No.	%
Oslo [24]	2008	594	44	463	34	289	22
Rotterdam [25]	2007	8,960	25	7,230	20	20,100	55
Jurong [26] [a]	2009	7,020	6	8,314	6	115,266	88
Jurong [b]	2009	7,020	31	8,314	36	7,426	33

a) Other Indirect Emissions' in this LCA study includes shipping and tugboat operational emissions; b) Emissions for shipping and tugboat operations have been removed.

Table 2 - Energy Consumption for a Range of Crane Types [27]

Energy	Type of equipment	Description	Consumption per container move	
			Fixed	Variable
Electric	Quay Crane	Used to (un)load ships by picking up containers directly on a tractor/automatic guided vehicle or making containers ready for straddle carriers	6.00kWh	n/a
	Barge Crane	Used to (un)load barges - have smaller reach than quay cranes	4.00kWh	n/a
	Rail Crane	AKA ganrty cranes. Can run over rail tracks. Used to directly transfer containers at a terminal	5.00kWh	n/a
	Automated Stacking Crane	Unmanned cranes used to stack containers	5.00kWh	n/a
	Rail-mounted Stacking Crane	AKA ganrty cranes. Can run over rail tracks. Used to pick up or position containers	7.25kWh	n/a
	Platform		5.00kWh	n/a
Diesel	Automated Guided Vehicle	Design for horizontal transport terminals. Unmanned.	1.10 litres	1.8l/km
	Straddle Carrier		0.80 l	3.50l/km
	Terminal Tractors		n/a	4.00l/km
	Multi Trailer System		n/a	4.20l/km
	Reach Stacker/Top Lifter	The most flexible handling equipment as they are able to rapidly transport containers short distances and stack them	n/a	5.00l/km

Table 3 - Crane Operating Costs [18]

Operating cost	Personnel [a]	Depreciation [b]	Consumables [c]	Downtime [d]	Energy hoist [e]	Stevedoring [f]
% of total operating cost	50	32	8	5	4	1

a) Assuming crane is operating 4,500 hours per year, at US$ 140/hour for personnel; b) assuming initial capital outlay of US$5,000,000, lifespan of 20 years, interest rate of 6%; c) range of US$50,000 – 100,000; d) assuming 98.9% availability, cost of a Panamax Ship is US$1,250/hr, around 50 accumulated breakdown hours; e) average weight of twin containers of 45tons, average lift height 20m, 30 containers handled per hour, energy needed per move 2kWh, cost of electricity of 0.2US$/kWh; f) stevedoring staff for 50 accumulated breakdown hours.

Table 4 - Fuel Consumption for Dredging Activities [28]

Activity	Sailing	Dredging			Dumping	Pumping
		Sand	Silt	Clay		
Fuel consumption (diesel) (l/hr)	3590	2680	2270	2540	1540	3530
Typical duration	10 mins – several hours	2 hrs	2 hrs	2 hrs	10 mins	2 hrs

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