ENERGY AND ENVIRONMENTAL EFFICIENCY IN PORTS & TERMINALS

A PEMA INFORMATION PAPER

This Information Paper is intended to provide an overview of the energy saving and emissions reduction possibilities available today in the design and operation of port equipment.

The goal is to provide ports, terminals and other interested parties with information on the state-of-the-art in equipment technology, plus practical advice to help maximise energy and environmental efficiencies when specifying and operating port equipment.

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INTRODUCTION

DOCUMENT PURPOSE

This Information Paper is intended to provide an overview of the energy saving and emissions reduction possibilities available today in the design and operation of port equipment.

The goal is to provide ports, terminals and other interested parties with information on the state-of-the-art in equipment technology, plus practical advice to help maximise energy and environmental efficiencies when specifying and operating port equipment.

Although some general energy efficiency topics will be mentioned, the focus of this paper is on port equipment installations and, in the case of electrification, on efficiency at the terminal level.

The technologies and approaches outlined in this Information Paper are designed and proven to save fuel and reduce emissions, with positive impact for users' bottom line, environmental stewardship, social responsibility and public image.

PEMA cannot advocate or decide which solution, or combination of solutions, is the right choice for any particular facility. However, the intent here is to contribute to industry awareness of the different possibilities now available, and the issues and options that ports and terminals consider when making their selection.

ABOUT THIS DOCUMENT

This document is the first in a series of Information Papers to be developed by the Environment Committee (EVC) of the Port Equipment Manufacturers Association (PEMA).

The series is intended to inform readers about the design and use of equipment and technology to reduce energy consumption, enhance sustainability and minimise the environmental impact of port and terminal operations.

This document does not constitute professional advice, nor is it an exhaustive summary of the information available on the subject matter to which it refers.

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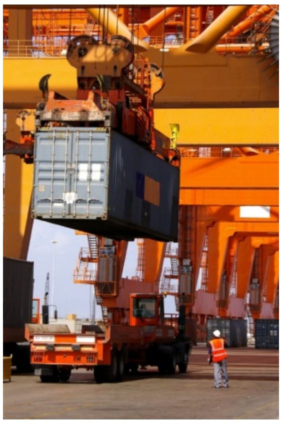


1 | EXECUTIVE SUMMARY

Back in 1994, the United Nations Framework Convention on Climate Change (UNFCCC) came into force, setting an overall framework for intergovernmental efforts worldwide to tackle the challenge posed by climate change. The Convention recognized that our climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases (GHGs).

Then in 2005, the Kyoto Protocol was born as an international agreement linked to the UNFCCC.

The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European Community for reducing GHG emissions.

GHG reduction targets laid down in Kyoto equate to an average of 5% against 1990 levels over the five-year period 2008-2012. For developed countries, this might even be increased to 30% by 2020 and 60-80% in the lead-up to 2050.

We might not all be aware of the background for today's international efforts to reduce GHG emissions, but we certainly all recognise rising global energy prices and the green trends which are linked to this.

As emissions controls continue to become ever more stringent, and with ongoing volatility in global fuel prices and availability, new approaches are clearly needed to lessen ports' reliance on fossil fuels and reduce overall energy consumption.

To date, diesel engines have been the main source of power for port handling equipment and vehicles. Reducing emissions from diesel engines is now one of the keys to mitigating the hazardous effects of nitrous oxide (NOx), carbon dioxide (CO_2) and particulate matter (PM) in and around terminals, as well as helping to meet national greenhouse gas (GHG) reduction goals as part of international climate change efforts.

Responding to this need, the port equipment industry has made considerable progress in improving the performance of fossil-fuel driven equipment, as well as developing alternative power sources.

As outlined in this Paper, the major current areas of focus include:

- Hybrid technologies, principally diesel-electric
- Power management systems to conserve fuel when equipment is idling
- Energy storage and reuse technologies and techniques
- Full electrification

2 | ENERGY EFFICIENCY IN HANDLING EQUIPMENT

The starting point for any energy policy should be to *save* energy. Simply using energy better is a cost-effective way of cutting greenhouse gate (GHG) emissions. It is often the cheapest and quickest route to success, certainly in the short-term.

It is estimated that businesses in general waste 10–20% of the energy they consume through poor control of heating, air conditioning and ventilation, and through leaving lights and appliances on when not in use. For example in the case of ports and terminals:

- Floodlights on during daytime
- Walkway lights on during operation
- Diesel engines running during a break or shift change

Good working day/night sensors to control floodlight operation, auto switch-off for walkway lights, the use of energy saving bulbs (for example LED), and optimal cooling and heating systems for running diesel engines are some of the basic steps that will reduce total energy consumption at port facilities.

2.1 THE IMPACT OF CRANE DESIGN

Another major influence on energy consumption is crane design. Here, influencing factors include:

- The weight of the crane and its moving parts (i.e., trolley and boom)
- Auxiliaries (lights, heating, air-conditioning, controls etc.)
- Efficiency of the components
- Size and operation of diesel engines
- Loads, speeds and ramp times of the hoist, gantry and trolley
- Utilization

Some of the factors, such as load, are virtually impossible to influence: the weight of the container and its contents is what it is. However, the spreader and headblock are another matter.

For example, over the years, RTGs have been equipped with twin-spreaders and cranes have been designed for twin-lift operation, but in reality they have rarely been used for it. It is estimated that the twin-lift on RTGs is currently used in less than 10% of operations. This means that for 90% of the time the hoist has to lift the extra weight of the spreader when it is not needed, wasting energy.

To demonstrate, we use the simple energy formula *Energy = mass x gravity x height*, where we neglect the efficiency factor of the system. A single-lift empty hoist run with a 10 tonne spreader and an average height of 10m will consume about 0.27 kWh per move, while a twin-lift run with a 15 tonne spreader will consume in the region of 0.41kWh. This is about 35% more energy per move.

Of course, in practice the hoist does not move for an hour, but only for a matter of seconds. Nonetheless, the comparative energy savings are still valid. The same applies for gantry travel. Moving a crane of 140 tonnes versus one of 180 tonnes can yield an efficiency saving of around 20%.

So the general advice is to make the right choice in the design phase of your terminal and in the selection of equipment and components. If you already have your products in place, then optimise what you have. Modern engines are inherently more efficient in their design. Just installing these could already bring savings.

2.2 DIESEL-ELECTRIC VEHICLES

Terminal vehicles such as mobile cranes, RTGs, straddle carriers, mobile container handling equipment and trucks have generally been designed with diesel combustion engines due to their greater durability, reliability and fuel efficiency compared with petrol engines. Today, many of these vehicles are already equipped, or can be, with a diesel-electric system.

Switching to diesel-electric systems automatically improves energy efficiency, as they are more fuel-efficient than diesel or hydraulic-driven systems. Using a common DC-bus rather than separate inverters for the different motions can confer an additional 10% saving in energy consumption.

In a DC-bus configuration, several movements take their energy from the same source. This allows regenerative energy from one movement to be used for other movements provided they occur simultaneously. In some cases where movements are not simultaneous, energy can still be stored for reuse. Section 2.4 reviews this aspect in more detail.

For all combustion engine vehicles, the emission standards in the land of use apply. For terminals, the focus is on “nonroad (offroad) diesel engines” as defined for example in European Commission Directive 2001/116/EC.

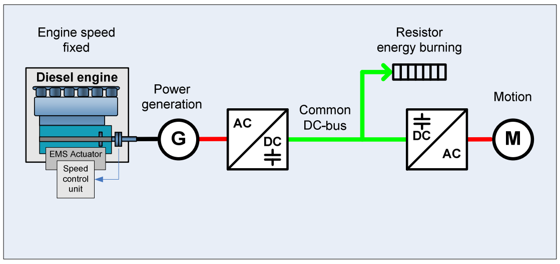
While the engine manufacturer is responsible for complying with legislation, the user has to ensure that he employs the engine as intended. Engines that form part of an electrical system powered by a generator set also have to comply with these standards.

Diesel-electric systems can reduce emissions and energy consumption in general, but cannot change the particle content produced by the engine in use. Of course, an engine that offers a potential energy saving of 20% will provide a corresponding reduction in emissions. However, there is currently no commercial measurement standard to certificate this reduction from an environmental perspective.

2.3 POWER MANAGEMENT

Starting from the principle that we have a diesel-electric driven vehicle, power management can be introduced as a further energy saving solution.

Conventional diesel-electric engines run on either 1500rpm for a 50Hz or 1800rpm for a 60Hz board-net. However, most of the vehicles in a terminal yard are not energy efficient due to waiting times for containers, street truck etc. During this waiting period, the engine remains on full speed, wasting fuel.



Typical conventional control with resistor

Reducing the engine speed during waiting times is an easy route to save fuel. There are two main solutions to achieve this: speed switching and speed controlling.

2.3.1 SPEED SWITCHING

With speed switching, the engine speed is reduced to idle when equipment is not moving, for example from 1800rpm to 750rpm and back in the case of a master controller action on RTGs. During this idle time, the generator will produce less voltage and less frequency.

The rectifier and inverters must be interlocked and switched off. Non-essential auxiliaries should be switched off. Essential auxiliaries, such as air conditioners and lights, should be kept running by an inverter-controlled supply which can generate a board net 380-440 VAC from low input voltage. In this case, a clean-power-filter should also be considered.

Speed switching can reduce fuel consumption by up to 25% on average, depending on the operation and utilisation of the crane or vehicle.

2.3.2 SPEED CONTROLLING

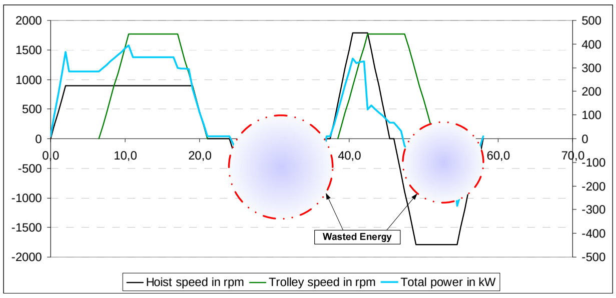
With full speed control, equipment movements are possible at every engine speed. The engine speed is based on the power requirement of the system. The regulator should select the optimal lowest speed compared to the power demand of the movements.

Not every generator is capable of providing enough power at the optimal low speed of the engine. In some cases, the engine, generator, drive system and interface must be replaced to achieve the maximum savings. An inverter with clean-power-filter must be used to keep the auxiliaries alive during every engine speed.

Speed controlling can reduce energy consumption by up to 50% depending on the operation and utilisation of the equipment.

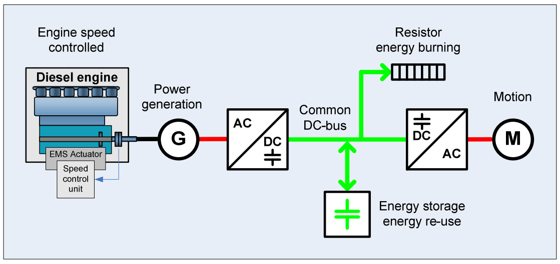
2.4 ENERGY STORAGE AND REUSE

Electricity reuse is a key element in any strategy to save energy and reduce emissions. The graph below shows the energy used during load hoist and trolley travel, plus the *wasted* energy expended during lowering.



Hoist trolley wasted power example

To optimise a diesel-electric vehicle, an energy storage solution can be used to capture wasted energy instead of burning it.



Typical hybrid control

A variety of these solutions are already available and in commercial use today. These include:

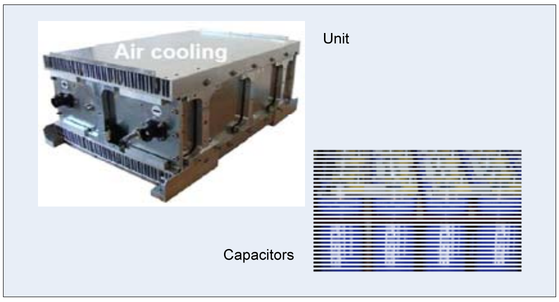
- Super capacitors (electric)
- Batteries (chemical)
- Flywheel (mechanical)

To make the diesel engine as efficient as possible, it should run constantly at its optimal working point. The optimal speed is that where the most energy can be generated from 1 litre of fuel. This optimum will be slightly different for every engine.

For maximum benefit, an energy storage solution should be combined with a power management system to ensure that the engine runs variable speeds at the optimal point.

Some highlights of the different energy storage technologies are mentioned below, but it should be noted that their usability depends on the specific vehicle and manufacturer.

2.4.1 SUPER CAPACITORS



Capacitor module and cells

Super capacitors are already in commercial use. There have been some questions regarding their safety and lifespan, but with the right software, safety and control measures this should not be an issue. Running capacitors within specification can yield a lifespan of 10 years or more with a minimum of maintenance.

Due to their high efficiency and performance, super capacitors are mostly used for quick charging and discharging sequences (i.e., hoisting). There are two solutions: passive and active.

Passive is an extension of the common DC-bus configuration and offers fairly limited energy storage capacity.

Active systems control energy storage via an inverter or a DC/DC converter. With DC/DC in particular, the storage capacity range is extended, thereby improving the energy saving potential.

Typical pack sizes are 0.6 kWh module compositions. Multiple packs can also be installed in parallel. Combining power management with super capacitor storage can achieve energy savings of 70% and more.

2.4.2 BATTERIES

Li-Ion battery example

A short lifespan of 3-5years, weight of up to 20 tonnes and safe use issues might seem to militate against the use of batteries as an energy storage solution. Set against this, however, the battery market is highly competitive and is making significant investment in R&D.

Batteries such as the lead-acid and Lithium-ion varieties are widely available commercially and are used by a number of equipment manufacturers as their chosen energy storage solution.

Batteries are generally used for constant power, which is mostly necessary for travelling.

Combining power management and battery-based storage, depending on the package size, operation and utilisation of the equipment, can offer potential energy savings of 70% and more.

2.4.3 FLYWHEELS

Flywheels store regenerative energy by bringing a mass into rotation. By braking the mass, energy is generated and brought back into the system on demand.

Flywheel example

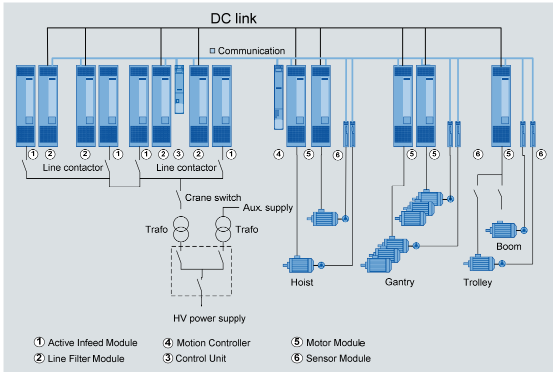
Flywheels have a lifespan of up to 20 years with hardly any maintenance. Typical package sizes for cranes are 0.4kWh.

Combining power management and flywheel storage offers potential energy savings of up to 40%, depending on crane operation and utilisation factors.

2.5 GRID-FED INSTALLATIONS

To increase the energy efficiency of an electrical system, energy losses in the system should be offset by the same output of active energy in a continuous two-way flow. Energy waste should not be produced, or should become available as reused energy for the next cycle. The basic principal is not to have energy disappear into thin air.

Regenerative energy from motion braking or lowering a load can be reused as working energy through the use of a common DC link within the drive system.



Common DC link example configuration

The regenerative energy which comes back from a drive feeds into the common DC link and can be used for accelerating or hoisting of the load by the other drives in the common DC link.

As noted at the start of this article, regenerative energy from one movement can only be used for other movements if they occur simultaneously. If this is only rarely the case, energy can be stored as discussed above in mechanical, electrical or chemical energy storage buffers connected to the common DC link

These energy buffers are particularly valuable if they are used to cover energy peaks. An additional effect for common DC link drive systems is that in-feed power can be calculated for the *real* maximum simultaneous required driving performance. This is normally smaller than the installed power of the drives.

For example, on a ship-to-shore (STS) container crane the installed power of the drives consists of the hoist, boom, trolley and gantry. However, in-feed power calculations can be based only on the drive power needed for hoist and trolley.

On grid-fed installations, brake energy can be directly fed back into the main grid by an active in-feed converter, transforming lost energy into new working energy for other consumers.

To further increase energy efficiency, the dissipated heat from power electronics within the in-feed and drive modules can be re-used.

Water-cooled drive modules and motors allow this heat to be stored in a water cycle. Water-cooled systems can be more efficient than air-cooled, as many air-cooled conditioners are oversized.

The dissipated heat can then be used over heat exchangers for other processes (i.e., heating, hot water). Additionally, the energy consumption of air conditioning in crane electrical rooms will be reduced.

Energy efficiency can also be increased by ensuring that the crane drive system is set at the optimal operating point during the design of the crane. The components of a drive system, inverters and motors all have an optimal energy efficient operating point.

From an energy efficiency point of view, it is better to select the operating point of the most common load case, for example 27 tonnes, rather than the rare maximum load case of 40 tonnes. While the maximum load case must of course be available for operating, this can be achieved by changing the speed and acceleration conditions for this load case.

The components of the drive system will then work more frequently at their designed operating point, instead of in the partial loads operating points. In the best case, it is possible to select a smaller drive component and reduce costs in electrical system and crane design.

2.6 FULL ELECTRIFICATION

For full electrification, the combustion engine will no longer be the main source for the power on the vehicle. An energy storage system like a battery, or a connection to the grid, can support these kinds of solutions for stack-to-stack movements where no grid in-feed is connected. Full electrification can be achieved in various ways. However, operators should expect to make major modifications at the terminal level.

2.6.1 ELECTRIFICATION WITH STORAGE

The energy storage solution selected as the main source must be chargeable, because regenerative energy is never enough to keep the vehicle running. In addition to energy losses, there are always auxiliaries which need constant power.

In many cases, batteries are selected to provide constant power. However, battery lifespan reduces rapidly when they are constantly operating on a full charge-discharge cycle. Alternatively, super capacitors can be selected, but these are rather expensive in larger quantities unless there are enough charging points.

The recommended strategy is either to change or charge the battery/capacitor set at a charging station, although this will mean that more vehicles are needed to replace the machines that are in the charging station. Battery-operated vehicles with changing and charging stations are already in commercial use.

Inductive charging could be another alternative. Here, inductive charging loops could be installed in the ground at strategic locations throughout the terminal, for example under STS cranes and in the stacking area. This will allow equipment to be recharged while stopping or driving over the inductive loops.

Depending on the driving distances involved, an inductive loop system should provide significant charging power in a short time. Systems are already available for this, but do not seem yet to have found commercial applications in ports and terminals.

For charging/changing stations and inductive ground solutions, large electrical infrastructure provisions are needed at the terminal level. However, fuel consumption and emissions from vehicles will be reduced to zero.

2.6.2 GRID-FED ELECTRIFICATION

Clearly, not every vehicle used in the terminal for moving containers can be connected to the grid. Vehicles such as straddle carriers and mobile handling equipment are not likely to be connected to a fixed grid and instead need either an energy storage system or an alternate energy source like fuel cells to operate without the use of carbon fuel.

However, an RTG is a good example of a machine that indeed can be connected to the grid. For a good implementation, the availability of a strong grid and enough power from local power plants is essential.

To change from a combustion engine to a fully electrical operation with grid connection, the RTG must be equipped with either a cable reel or a bus-bar connection. Both systems require crane modifications.

2.6.2.1 RTG electrification by cable reel

For the cable reel option, the RTG must be installed with both a reel and a high voltage transformer. However, hardly any additional infrastructure is needed in the stacking area.

Cable reel example

In the middle, at the start or end of the stack, a grid connection is needed. A small floor duct is required to protect the cable from being driven over by the crane. The crane remains quite flexible for driving in the stack across the gantry travelling line.

Due to the fixed connection, the cable must be unplugged to allow the crane to leave the stack. A small diesel engine or energy storage system is needed to drive the crane without grid connection to another stacking area.

2.6.2.2 RTG electrification by bus-bar

The bus-bar connection involves only minor modifications on the RTG itself, namely the installation of a pantograph and a connection box at the sill-beam level to provide the power on the crane.

Bus-bar installation example

The bus-bar installation next to the crane in the stacking area is, however, quite substantial. This involves civil works for a foundation and a metal base frame on which to mount the bus-bar-rail. Protection measures must also be taken to prevent trucks from driving into the bus-bar construction. Depending on the pantograph, the crane is limited for driving in the stack across the gantry travelling line by +/- 25cm.

Auto steering systems can assist RTG operators to drive in a smooth and predicted way along the bus-bar construction. Due to the fixed connection, the pantograph must be disconnected to allow the crane to leave the stack. Automatic drive-in and drive-out systems are also now available as options. A small diesel engine or energy storage system is needed to drive the crane without grid connection to another stacking area.

2.7 INFLUENCES OF ELECTRIFICATION

Connecting more machines to the grid will have an influence on the power factor, which must be compensated for. Operators need to consider whether to achieve this at vehicle level or at the terminal level. Suppliers can assist you to determine the right solution for your plant.

Having more machines on the grid will influence energy stability and can bring more energy peak moments. Multiple machines hoisting or multiple machines lowering causes energy spikes. The best scenario would be if both support and counter-balance each other, but we know that in real life that will not always be the case.

If regenerative energy is sent back into the grid outside the terminal and does not generate any more revenue, this might be considered a waste. On the other hand, having an energy contract where peaks are charged double also wastes money.

Stationary energy storage systems can support facilities in overcoming these energy peaks and ensure smooth operation of the terminal grid. These will prevent peaks by storing energy during general operations and releasing it during times of peak demand.

2.8 CONCLUSION

Optimising crane design in terms of weight and optimal working point will have a positive influence on the design and selection of the electrical components, which on the electrical side will automatically result in a less energy-hungry crane.

Reducing energy consumption by 25-70% or more through the adoption of measures such as power management and energy storage promises a healthy return on investment.

Reducing the running hours of the engine or even completely removing the engine by electrifying equipment will also reduce or eliminate maintenance costs.

Supplies like spares and consumables will be dramatically reduced or even eliminated. Some investment in training people for the new technologies will be needed, but is a modest price to pay set against the potential benefits and savings for a cleaner and more energy efficient facility.

3 | ENERGY EFFICIENCY IN GRID-FED CRANES

Compared to fossil fuel power sources, fully electric operation of quay and yard cranes at container terminals is clearly the most environmentally-friendly option. But, unless it is produced using nuclear or renewable energy sources, the manufacture of electricity also has an environmental impact. And of course electricity costs money.

It is therefore imperative to ensure that electric cranes are as energy-efficient as possible, both by avoiding unnecessary power consumption and by recovering electricity for reuse. Although there is no 'one-size-fits-all' solution, saving energy and using it responsibly must be a key consideration, regardless of the type of industry or operation.

3.1 ELECTRICAL DRIVE SYSTEMS

Modern electrical drive systems are of the four-quadrant type, which means that they can feed energy back into the supplying grid. Feedback occurs when there is a pulling load. In container crane applications this is mainly when a load is lowered.

Typically, around 75–80% of the energy released when a load is lowered can be captured and fed back to the grid. The remainder is not recoverable, due to mechanical losses in gearboxes, ropes and sheaves, as well as a small percentage energy loss in the electrical system, such as in motors and frequency converters.

The majority of all ship-to-shore cranes in the world are now connected to a terminal supply grid, and in principle all new cranes are equipped for AC operation with some form of four-quadrant supply to the drive system. The conditions for saving energy are thus already fulfilled.

Regenerative energy fed back into the supply grid can either be used by neighbouring cranes or by other power consumers on the grid. In this way, the volume of energy taken from the local power utility can be decreased, further reducing energy costs compared to when electrical power is generated on-board cranes with diesel generators.

3.2 THE IMPACT OF AUXILIARY POWER

Measurements made on relatively large and modern ship-to-shore container cranes reveal that total auxiliary power amounts to about 60 kW (see table 2.1 below). Total energy consumption per move was measured at 6 kWh. Based on 30 moves per hour, auxiliary energy consumption was 2 kWh per move.

Area	Power
AC motor cooling fans	10kW
Spreader pump	15kW
Floodlights	25kW
Walkway lights	7kW
Total	**67kW**

Table 3.1 Measured auxiliary power consumption
Source: ABB Crane Systems

Note that air conditioning is not included in this summary. Depending on power dissipation in the electrical room, the size and the required temperature in the cabin, and the ambient temperature, energy consumption by air conditioning systems can be substantial. To rectify this, the drive system configuration must be changed - for example to a water-cooled type. This topic, however, is beyond the scope of this paper.

With auxiliary equipment accounting for around 25% of total power consumption for work that contributes to crane production, finding ways to reduce this can have a significant impact on overall energy demand. Table 2.2 below shows a few examples of measures that can be taken here.

Area	Possible improvement
AC motor cooling fans	Temperature and/or speed controlled
Spreader pump	For new cranes specify electrical spreader
Floodlights	Sectionalise and switch off when not needed
Walkway lights	Switch off automatically

Table 3.2 Possible measures for improvement
Source: ABB Crane Systems

Even a minor change to auxiliary consumption can have a clear impact, as the energy is being continuously consumed and is not actually performing any productive work. Just halving energy consumption for floodlights, for example, will reduce total auxiliary power needs by 25%.

Ship-to-shore crane automation also contributes to energy reduction, primarily as a result of cranes handling more moves per hour, but also by never lifting a load higher than necessary.

3.3 AUTOMATIC STACKING CRANES

Automatic stacking cranes (ASCs) are energy-efficient by definition since they are electrified. However, energy and power measurements carried out on ASCs with cantilevers reveal that there are also a number of options for saving additional energy in these applications.

ASCs are supplied with electrical energy from terminal grids and roll on steel wheels with low friction. The cranes' drive systems feed energy back when loads are lowered. Moreover, the need for floodlights and other lighting is minimal, due to work being conducted without operators. In principle, the cranes do not need any lighting at all. Under these conditions, it is important to look at how the cranes work, both independently and in interaction with one another.

3.3.1 UNSYNCHRONISED MOVES

The greatest saving is in being able to operate several cranes simultaneously and in doing so, to even out their energy consumption. In other words, when energy is generated at one location, it can be used by another crane in the same supply grid.

Studies show that even with just ten cranes operating at the same time, an optimum situation can be attained whereby energy is simultaneously generated and consumed, resulting in savings of about 30%.

Once the ASCs are installed, this system should work on its own with little interaction from users or operators. Moreover, neither planning from the terminal operating system (TOS), nor the movements or operations of any cranes, are affected. At a busy terminal, it should almost always be possible to utilise recovered energy.

3.3.2 SYNCHRONISED MOVES

With synchronised moves, an additional energy saving of around 5% can be achieved with the same number of cranes as in the example above. Depending on the debiting principles of the local power utility, it may be necessary to immediately utilise this recovered energy. If movements are coordinated between the cranes, recovered energy can generally be used while at the same time reducing peak power demand.

A reduction of peak power demand saves money in installed power because smaller transformers, substations and lighter cables can be used to supply the cranes with electrical energy. Less installed power means lower capex and subsequently lower opex as well.

This rationale concerning synchronised movements for saving energy and power on ASCs can also be applied to automated ship-to-shore cranes.

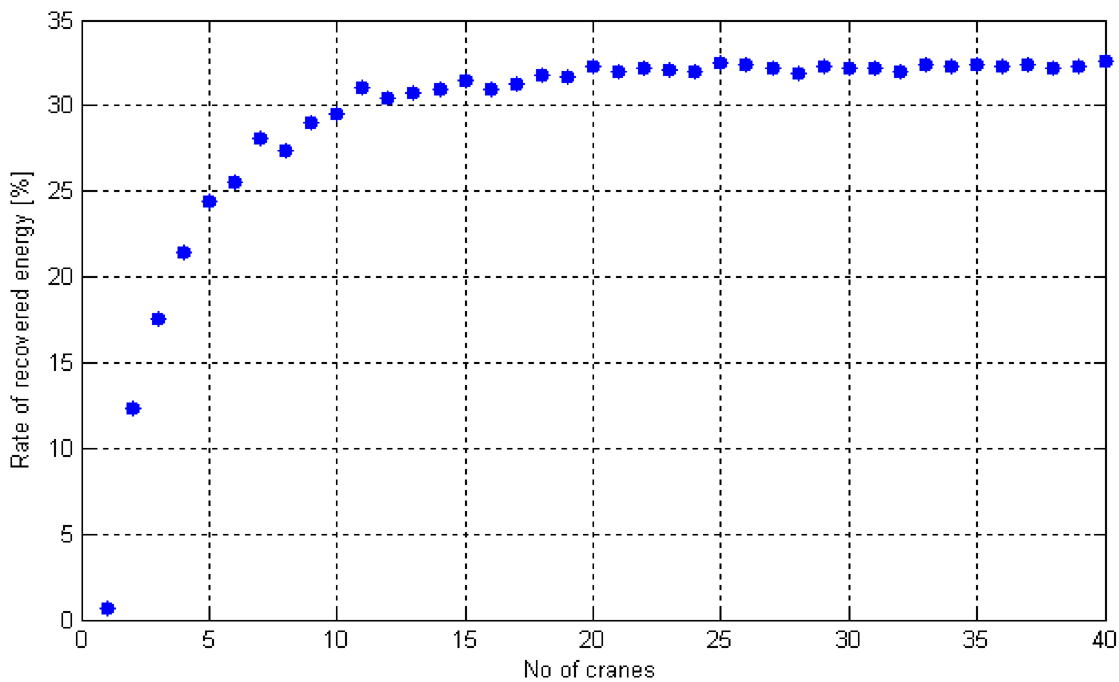


Figure 3.1 Rate of recovered energy depending on the number of independently connected cranes
Source: ABB Crane Systems

4 | ALL-ELECTRIC SPREADERS

Compared with hydraulic units, all-electric spreaders offer considerable environmental and operating benefits for port and terminal users. They are simultaneously lighter and quieter; faster, easier and less costly to service; consume up to 85% less power; and help reduce crane power consumption due to their lower weight. Additionally, all-electric spreaders have none of the clean-up costs traditionally associated with oil spills from hydraulic units.

4.1 WEIGHT REDUCTION

The reduced weight of all-electric spreaders is environmentally, operationally and financially significant, as spreader weight has a direct correlation with crane power requirements - the heavier the spreader, the higher the energy consumption.

The removal of the hydraulic pack decreases spreader weight by around 1.5 tonnes. Over the lifetime of a spreader, this will save approximately 94 tonnes of CO_2 emissions, while reducing crane power costs significantly.

The removal of the hydraulic power pack also means that all-electric spreaders can be constructed from lighter weight steel, thereby reducing CO_2 emissions from steel production, as shown in figure 4.1.

For ports, the lighter construction of all-electric units compared to hydraulic spreaders reduces GHG emissions by around 25,000 CO_2-equivalent per spreader. For an average port with around 25 spreaders this will contribute to a difference of 625,000 CO_2-equivalent.

4.2 NOISE REDUCTION

Another important and rising demand for ports and terminals is the reduction of noise, especially for facilities with residential or commercial communities nearby. Following the

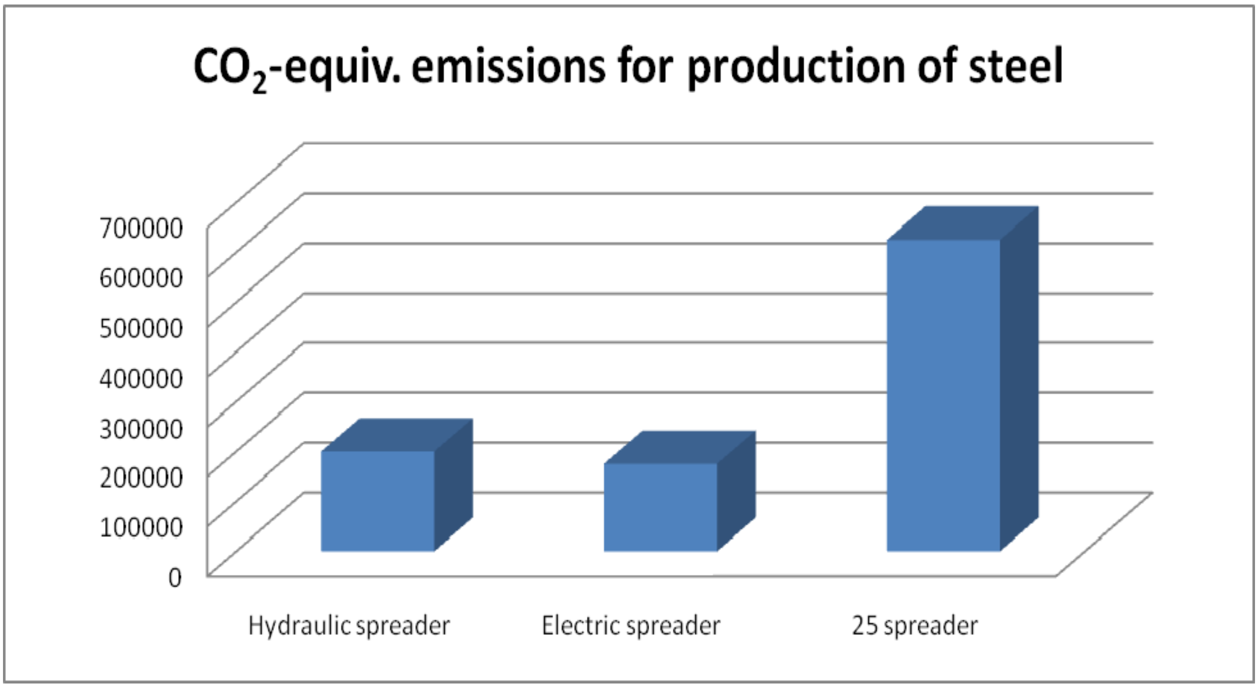


Figure 4.1 Emissions of CO_2-equivalent due to different steel weight during production
Source: Bromma Conquip

publication of the European Noise Directive, this type of pollution is now a top environmental priority for the European port sector in particular.

The all-electric spreader has a significant lower noise level, principally due to the loss of a continuously running hydraulic power pack.

4.3 REDUCED ENERGY CONSUMPTION

The loss of an idling power pack, plus the fact that the electrical motors only consume power when an operation is performed, reduces all-electric spreader energy consumption by an average 90% compared with hydraulic units. The lifetime reduction of 150,000 kWh corresponds to 113 tons CO_2 less emissions per spreader, assuming 50,000 lifetime spreader operating hours on a diesel-driven RTG. In cost terms, use of an all-electric spreader will reduce lifetime diesel fuel costs significantly.

4.4 ELIMINATION OF HYDRAULIC OIL

Another cost and environmental improvement in the all-electric spreader is the elimination of hydraulic oil. With all-electric spreaders, there is no risk of oil leakage and groundwater contamination. Other benefits include fewer consumables and reduced service expense (no oil, no filters, etc.).

5 | ALTERNATIVE FUELS AND HYBRID SYSTEMS

The concept of 'peak oil' is pretty simple. The world's supply of oil is limited and for any finite resource there comes a point when dwindling supplies make it too expensive to continue extracting more. The term for that point is production peak.

Even if there are decades before we hit production peak for oil, it is critical that we are now developing and commercialising alternative energy sources.

As discussed elsewhere in this Information Paper, a long-term solution is likely electric, whether provided by super-efficient battery, by fuel cell, or in the case of port cranes, by grid-fed installations.

In the transport world, researchers and vehicle makers are already looking to electrify the drive train, powering vehicles only with electricity and electric motors rather than with petrol and diesel combustion engines.

In addition to full electrification, however, alternative fuels and hybrid technologies also have a role to play. These are the subject of this chapter.

5.1 SYNTHETIC FUELS AND BIOFUELS

Synthetic fuel is a liquid fuel obtained from coal, natural gas, oil shale or biomass. The commercialisation of synthetic fuels is now gaining speed worldwide, with a number of major production facilities under development.

One example is ethanol, an alcohol produced from either biomass waste or coal, which is already used in gasoline blends with up to 85% ethanol.

Biodiesel, created by processing vegetable oil, can be used as a direct substitute for petrodiesel, either in blends or neat.

Biogas is a mixture of methane, a natural gas, and other gases produced from the decomposition of organic materials. It is produced naturally in landfills and from the processing of animal waste, sewage and crop waste. Biomethane is a pipeline-quality natural gas substitute produced by purifying biogas

5.2 NATURAL GAS

Natural gas is composed of combustible gases in the Earth's crust. Today, natural gas is used in industrial processes, to heat houses and to power vehicles and is the world's third most important energy source after oil and coal.

While it is a fossil fuel, natural gas does not contain sulfur or heavy metals. When burned, it also emits lower levels of CO_2 than naphtha, coal, oil or liquefied petroleum gas (LPG). For example, natural gas produces 20% less CO_2 than gasoline. It is therefore considered the cleanest of the fossil fuels.

Both natural gas and biogas have a high proportion of methane, which means that they can be mixed. Natural gas technology is therefore excellent as a back-up for biogas. The main differences are that these fuels are not produced in the same way and that the combustion of biogas does not give a net addition of CO_2 in the atmosphere.

5.2.1 LIQUEFIED NATURAL GAS

Liquefied natural gas (LNG) is natural gas, mostly methane, which has been cryogenically super-cooled and condensed into liquid form for storage and transport. LNG is lighter than air, so when gas leaks out it evaporates into the atmosphere. By contrast, liquefied petroleum gas (LPG) is heavier than air and falls to ground level when released.

5.2.2 COMPRESSED NATURAL GAS

Compressed natural gas (CNG) is made by compressing natural gas to less than 1% of its volume at standard atmospheric pressure. CNG is stored and distributed in hard containers at high pressures of 200-248 bar.

CNG costs less to produce and store than LNG, but has a reduced volumetric energy density (around 42% of LNG). It requires a much a much larger volume to store the same mass as petrol, plus very high pressures.

CNG is increasingly used in traditional petrol cars that have been converted into bi-fuel vehicles. Leading the way are South Asia (Pakistan is the world's largest user), South America and South East Asia. A growing number of countries are also turning to CNG to fuel public transport vehicles including buses, coaches and trains.

5.3 THE USE OF ALTERNATIVE FUELS FOR PORT EQUIPMENT

The past few years have seen increased R&D work by both the equipment sector and the port industry itself into the use of alternative fuels.

In particular, stricter emissions legislation from the US Environmental Protection Agency (EPA) and port clean air action programmes on the West Coast and elsewhere in the US have already helped spur development of terminal tractors running on natural gas, both LNG and CNG.

Hybrid drive terminal tractors have also been developed and these are discussed further in the next section. In addition, ports including Vancouver in Canada and North Carolina Ports on the US East Coast have worked on the introduction of biofuels for vehicles and heavy equipment, generally as a 20% biodiesel/80% petrodiesel blend.

5.3.1 LNG-POWERED TERMINAL TRACTORS

A key advantage of LNG is that it offers an energy density comparable to petrol and diesel fuels, extending vehicle range and reducing refuelling frequency.

A disadvantage, however, is the high cost of cryogenic storage on vehicles and the major infrastructure requirement for LNG dispensing stations, production plants and transport facilities.

According to the engine manufacturers, particulate matter emissions from LNG engines amount to 0.009 parts per million, compared to 0.01ppm from a standard diesel engine. LNG gas engines emit 0.1 ppm of NO_x, compared to 0.13ppm for standard off-road diesel engines. LNG engines effectively use 90% of the fuel for traction, compared to 60-70% for a conventional diesel engine.

5.4 HYBRID SYSTEMS

Hybrid systems, which use at least two power sources, have emerged as a technology that allows fuel consumption and exhaust emissions to be reduced without impairing vehicle or equipment performance.

Currently the most common system worldwide is the petroleum-electric hybrid. These vehicles use internal combustion engines running on petrol or diesel. The combustion engine turns a generator, which in turn charges batteries and/or super capacitors. The batteries and/or super capacitors then store this energy, which is used to power an electric motor.

There are a number of different approaches, including series hybrids, parallel hybrids and combination hybrids. With the series hybrid vehicle, the combustion engine never directly propels the vehicle. In the parallel hybrid system, combustion engine and electric motor are both connected to the transmission, propelling the vehicle together.

5.4.1 HYDRAULIC HYBRID DRIVE TERMINAL TRACTOR

Hydraulic hybrid drive terminal tractors are equipped with a parallel system that simultaneously transmits power from two distinct sources – the primary diesel engine and the secondary hydraulic accumulator for energy storage. The coordination of these power sources maximises fuel economy and satisfies performance constraints. Although fuel consumption varies depending on driving style and the operational application, in the typical port environment, fuel savings of 20% and an even greater reduction of NO_x and particulate matter emissions can be achieved.

Besides improving fuel economies and reducing emissions, a terminal tractor equipped with the optional hydraulic hybrid drive system offers smoother acceleration, helping to reduce driver fatigue and driveline wear. The machine's inching function also allows the vehicle to advance without engine power, further saving fuel and eliminating emissions.

5.4.2 DIESEL-ELECTRIC HYBRID DRIVE STRADDLE CARRIER

Hybrid diesel-electric technology offers significant future potential for straddle carrier applications, reducing annual CO_2 emissions by up to 50 tonnes per unit and requiring 25-30% less fuel compared to conventional hydraulic or diesel-hydraulic designs.

Diesel-electric hybrid straddle carrier designs include super capacitors to store energy when the machine is braking or the container is being lowered. The regenerated energy is then used to reduce diesel engine power usage when hoisting or accelerating. Energy storage is combined with a variable-speed diesel generator (VSG) to further improve performance.

As outlined in Section 2.3 of Chapter 2, VSG systems optimise engine use by determining whether equipment needs increased power for heavy lifts or little power when idling. This improves energy consumption and reduces noise, as the winch system operates more quietly.

6 | SHORE-TO-SHIP ELECTRICAL CONNECTION

Studies carried out by port authorities, local agencies and national government bodies have unanimously found that the use of ships' diesel-powered auxiliary engines to run on-board services during port calls is one of the most significant sources of air pollution and emissions in ports.

In this regard, investigations made in 2001-2 by the US West Coast ports of Los Angeles and Long Beach delivered clear findings regarding the major sources of pollution in the port area (see figure 6.1).

The conclusion from these and other reports has been that reducing emissions from ships during their port stay would substantially improve the air quality in the immediate harbour area, as well as having a positive impact on neighbouring, often populous, areas.

One way to achieve this is to switch from using ships' auxiliary engines to electricity provided from the shore. This process is variously known as cold ironing, alternative maritime power (AMP), shoreside power supply, shore-to-ship power, shore power and shore-to-ship electrical connection (SSEC). For the purposes of this paper, SSEC is used as the common terminology.

Several studies have confirmed that the average emission from onshore electricity production is significantly lower than that from ships' engines, even when the onshore electricity supply involves fossil fuel distillates (see figure 6.2 overleaf).

In most countries, the use of electricity generated from the power grid rather than by 'non-road' engines will lead to further a reduction in total GHG emissions.

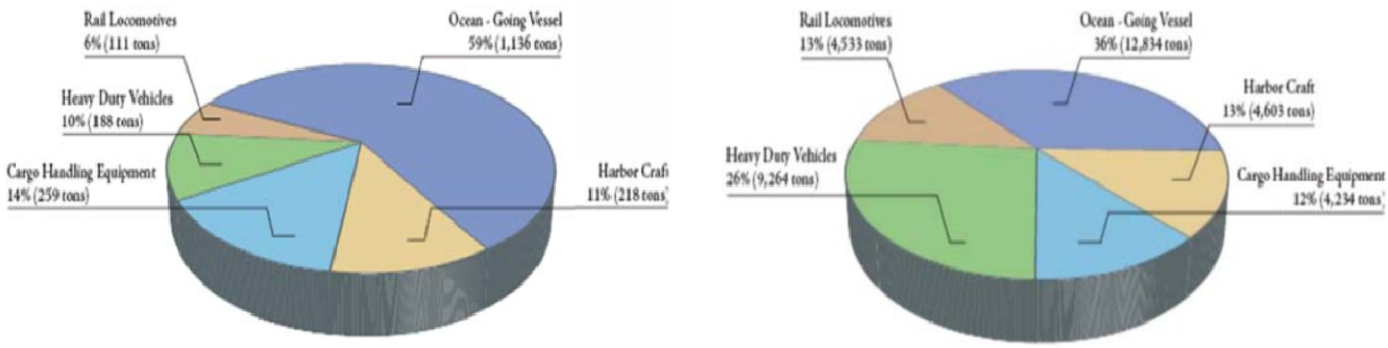


Figure 6.1 Baseline Year DPM / NOx Emission Contribution by Source Category in Port of Los Angeles and Long Beach (POLA-2001 and POLB-2002) - San Pedro Bay Ports – Clean Air Action Plan - Overview

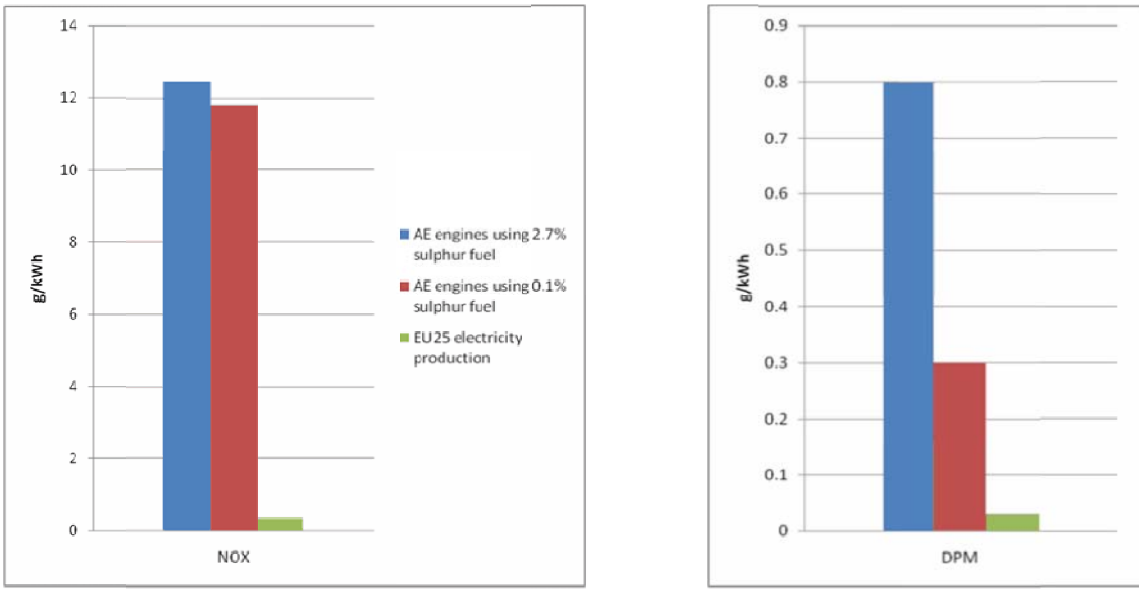


Figure 6.2 Assessment of CO_2 and priority pollutant reduction by installation of shore side power - W.J. Hall
Source: Resources, Conservation and Recycling 54(2010) 462-467

Auxiliary engines emit 690-722 grams of CO_2 per kWh of electricity generated, depending on the type of engine and fuel used. This is significantly higher than CO_2 emissions from onshore electricity generation. Figure 6.3 highlights these differences in various countries around the world. Note that CO_2 emissions per kWh are calculated at the consumer site and not at the production site.

This current paper is based on experiences from different ports operating Medium voltage shore-to-ship electrical connection (SSEC) for commercial ships, taking into account new equipment designs and solutions under development. High voltage systems are also in operation.

Country	National grid power generation g CO_2/kWhe
Japan	461
United States	651
United Kingdom	543
Italy	523
South Korea	507
Singapore	598
Spain	447
Netherlands	612
Norway	3
Indonesia	917
Germany	612
Russia	811
France	108
Malaysia	603
Taiwan	690
Turkey	565
Belgium	310
Brazil	106

Figure 6.3 Shore-Side Electricity – Final Report, Entec UK Ltd Report for European Commission, Directorate General Environment, Directorate C – Unit C1

The scope of the report is as follows:

- Overview of the key components of an SSEC system
- Analysis of electrical and mechanical equipment required for connection of ships to a shore power grid
- Analysis of the critical issues to ensure compatibility of an SSEC system
- Discussion of the different technical approaches and systems available

6.1 SHIP TYPES & DOCKING PATTERNS

The installation of SSEC equipment, specifically the interface equipment, varies depending on ship type and docking pattern. Drawing on the Entec UK report, vessels can be divided into two main categories for this purpose:

A. No cranes, dock in the same position: This category includes all ships which always dock in the same position and normally do not require cranes along the berth for loading and unloading operations. Tankers, LNG ships, ro-ro vessels, cruise ships and ferries all fall into this group. This category allows for space on the wharf to install the required cable management system (CMS).

B. Cranes, dock in different position: This category includes vessels such as containerships, conventional reefer ships and dry bulk carriers, which can dock in different positions at the berth and normally require cranes along the wharf for loading and unloading operation. Space restrictions, due to the crane operations, need to be considered.

6.2 SSEC SYSTEMS

6.2.1 SYSTEM OVERVIEW

The supply of electricity to a ship may require the frequency and voltage of the port grid electricity to be converted. Depending on their type and size, ships can be designed for frequencies of 50 Hz or 60 Hz. Voltages may vary between 380 V and 11 kV. Similarly, onshore electricity can be available at 50Hz or 60 Hz, depending on country, and at different voltages, depending on the port itself. Consequently an SSEC system requires at least the following main elements:

6.2.1.1 Connection to the national grid

This includes all equipment necessary to connect the national grid to the SSEC network. Normally, equipment is installed inside sub-stations located at the port. For example, container terminals have sub-stations providing power to their quayside gantry cranes. If these are not available a new sub-station should be built.

6.2.1.2 Step-down transformers

Electricity delivered from the national grid to the port has a higher voltage (20-100 kV) than the electricity produced on-board. Transformers will therefore need be installed on-board or onshore or both.

To reduce the number of cables needed, electricity can be supplied at MV. The Port of Los Angeles, for example, supplies electricity at 6.6 kV. This approach requires a voltage step-down both onshore and on-board when ships are designed for LV or a different voltage level.

For berths where ships normally dock that are designed for MV, it makes sense to supply electricity at the same voltage level used on-board, thereby avoiding power loss in the on-board transformer. Vessels designed for MV include large container vessels at 6.6kV, cruise ships at 6.6-11 kV and LNG ships at 11 kV.

6.2.1.3 Frequency converter

Where the grid frequency differs from that of the ships, a converter is required. This can be installed onshore or on-board. However, all known installations to date have been onshore.

6.2.1.4 Cable management system (CMS)

On-board electricity is supplied through a number of cables. To handle these, a cable management system (CMS) needs to be installed. The CMS provides a number of critical benefits:

- Avoids the need to lay cables on berth, which would otherwise interfere with quay operations (see figure 1)
- Avoids the need for personnel to directly handle the cables in the case of medium voltage SSEC system
- Due to the power requirements of large ships, cable weights can be quite considerable. In such cases, cable handling is only feasible by mechanical device
- The CMS will automatically compensate for the movement of ships due to the tide, displacement variations during loading or unloading operations, wind influences etc.

For Category B ships (see 6.1) the CMS must be placed on-board. For Category A ships it can be either on-board or onshore if its installation does not interfere with berth operations.

6.2.1.5 Plug/socket connection

Plugs and sockets reduce operational time to establish an electrical connection between the ship and shore. Where the CMS is placed on-board, the socket outlet JB is installed on the berth, and vice versa when the CMS is onshore.

6.2.1.6 Connection to the ship network

This includes all the necessary equipment to connect the cables coming from the shore to the ship network. Normally a shore connection panel, comprising a circuit breaker with an interlocked earthing switch, is provided close to the socket outlet JB or CMS.

The shore connection panel is wired to the ship's main electrical switchgear through fixed cables. Normally these cables are wired to a part of the main panel, known as the shore incoming panel, where a synchronising device is generally installed.

6.2.2 MINIMUM REQUIREMENTS

6.2.2.1 Minimum on-board equipment

Minimum SSEC equipment requirements on-board are as follows:

- Shore connection panel: In the case of Medium Voltage SSC, an earthing switch has to be interlocked with the circuit breaker in order to ground the cables shore-side during plug/socket mating and un-mating.
- Transformer if ship voltage is different from shore voltage.
- Shore incoming panel
- Synchronising device to ensure power change-over without black-outs

6.2.2.2 Minimum interface equipment

Minimum SSEC interface equipment requirements are as follows:

- Cable management system
- socket outlet JB

6.2.2.3 Minimum onshore equipment

The minimum SSEC equipment required onshore to supply electricity to one single ship is as follows:

- Main circuit breaker to switch the connection to the national grid
- Transformer
- Frequency converter if ships require a different frequency from the onshore frequency
- Secondary circuit breaker to switch and operate the socket outlet JB or CMS. For Medium Voltage SSEC, an earthing switch has to be interlocked with the circuit breaker in order to ground cables ship-side during plug/socket mating and un-mating.

6.3 CONNECTION COMPATIBILITY

Compatibility between the equipment installed on-board and onshore is a crucial requirement for successful SSEC operations.

6.3.1 MECHANICAL REQUIREMENTS

Mechanical compatibility between ship and shore equipment is obtained when the designs of the plug /socket and CMS position, on-board or onshore, are standardised.

6.3.2 ELECTRICAL REQUIREMENTS

A detailed review of electrical requirements for SSEC compatibility falls outside the scope of this report. However, any future industry or regulatory initiatives to establish SSEC standards should consider the following items to set an international compatibility between shore installations and ships:

- Voltage range at the connection point
- Frequency range at the connection point
- Maximum allowable short circuit currents onshore and on-board
- Selectivity
- Grounding method
- Transformer in-rush currents
- Monitoring

6.4 TECHNICAL SOLUTIONS

Existing applications and projects currently under development employ different technical solutions. This section describes the different main approaches, with particular focus on the interface equipment.

The installation of cable management systems can be divided into two main categories:

6.4.1 SHIP-BASED SYSTEM

Here, the CMS is installed on-board the ships and the socket outlets JB are placed on the berth. The CMS in these installations consists of a cable reel which can recover and release cables automatically to compensate for ship movements, and a retractable arm that allows cables to be lowered directly to the berth without interfering with the ship's hull and fenders.

Containerships and similarly configured ro-ro vessels in the Baltic Sea have adopted this solution. Ship-based systems may be MV or LV type.

6.4.1.1 Ship-integrated systems

In ship-integrated systems, the shore connection panel and, if any, the transformer, are located in appropriate spaces inside the ship. The CMS is installed in a fixed position on the open deck or in a dry space under the mooring deck.

The CMS should be installed on one side only if mooring always occurs on that side or on both sides if the mooring position varies from port to port.

Provided it is included in the design phase, ship-integrated system is cheaper than other solutions for newbuild vessels. However, equipment cannot be removed if the ship is re-routed to ports where an SSEC is not required.

6.4.1.2 Semi-fixed containers

In this design, the CMS and shore connection panel are both installed inside one or more special container. These containers are linked to the ship's electrical system by permanently laid cables or removable cables. Cables are then directly attached with a plug/socket connection to the shore incoming panel or to a terminal box. The semi-fixed container(s) remain on-board during seagoing operations.

This solution is the most suitable for ship refurbishment projects or for newbuilds where the design cannot accommodate appropriate spaces inside the ship for the electrical equipment.

The containers can be removed from one ship and re-installed on another.

6.4.2 SHORE-BASED SYSTEM

Here, the CMS is installed onshore, while the socket outlets JB are placed on-board. The CMS can be a cable reel, as described above, or a different system.

Shore-based solutions are technically acceptable for ships belonging to category A, but not for ships belonging to category B, where the CMS interferes with gantry crane operations on the quayside.

6.4.2.1 Fixed systems

The CMS is permanently installed on the berth in a position where it does not interfere with quayside operations. SSEC applications and developing projects adopt different technical approaches to this installation:

6.4.2.1.1 Cable reel

This solution is the most suitable where there is likely to be significant movement of the ship during docking, for example tankers and LNG ships. Cable reels can be positioned on one side of the jetty, thereby keeping the manifold area free.

JB connector receptacles are normally placed on both sides of the ship in a dry space accessible through an opening in the ship's hull. To lift the cables on-board the ship a crane is required. This can be an on-board service crane or a crane placed on the jetty for this specific purpose.

6.4.2.1.2 Articulated arm

If ships are subjected to very significant movements during docking, an articulated arm similar to those used to load and unload LNG ships can be used to handle the SSEC cables. A shorter and easier to operate articulated arm is already in use at the Port of Seattle, USA, for visiting cruise ships.

6.4.2.1.3 Mobile system

In a mobile system, the CMS can be moved along the berth and stored somewhere else when it is not needed.

The caddy itself can be rail or rubber tyre mounted and normally needs one or more socket outlets JB to be connected to the port grid.

6.4.3 BARGE SYSTEM

The barge is a hybrid solution mixing shore- and ship-based systems, where the CMS, transformer and switchgear are all placed on-board a floating barge.

Two CMS cables reels are installed on-board, one to handle the cables to the ship and one to handle those to connect the system to the socket outlets JB onshore. The barge is docked alongside the ship and cables are lifted on-board and connected to a terminal box.

The barge system is very flexible and requires minimal modifications on-board ship, where only a terminal box and a shore incoming panel need to be installed.

A barge can be shared between different ships calling the same port. However, the cost is very high even when split over multiple vessels. Connection is also time-consuming and labour-intensive. Operating a barge system takes three people ashore and another two on-board and requires approximately 40 minutes, not counting the initial time needed to position the barge alongside the vessel.

The barge system is currently in operation at Pier 100 at the Port of Los Angeles. In this particular case, the solution is acceptable because ships always dock in the same position and the barge does not need to be moved often.

No other ports or ship-owners are known to be currently considering the barge as a viable solution.

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Founded in late 2004, the mission of PEMA is to provide a forum and public voice for the global port equipment and technology sectors, reflecting their critical role in enabling safe, secure, sustainable and productive ports, and thereby supporting world maritime trade.

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