Reducing air emissions in a container terminal

OVERVIEW OF MEANS RELATED
TO CARGO HANDLING EQUIPMENT

AUTHORS

ARI HIRVONEN
HEIKKI SALONEN
PETER SÖDERBERG

KALMAR

Contents

Executive summary

This white paper addresses common causes of airborne emissions at container ports, focusing on cargo handling equipment related sources that can be directly influenced by the terminal.

Container terminals utilise a wide variety of manually driven and automated container handling equipment. This can be divided into horizontal transportation (straddle and shuttle carriers, terminal tractors and automated guided vehicles (AGVs)); yard cranes (ASCs and RTGs); ship-to-shore (STS) cranes; mobile equipment (reachstackers, empty container handlers and forklift trucks) and road vehicles operating at the terminal. The potential for emissions reduction differ substantially between these areas. Vessels and road trucks are the most significant sources of air pollution at container ports, but this text addresses primarily container handling equipment, including ship-to-shore (STS) and yard cranes, horizontal transportation as well as mobile equipment .

New developments such as electrification, hybrid technology and energy regeneration have significant potential to reduce or even completely eliminate on-site air emissions caused by container handling equipment. The choice of horizontal transportation system itself has a major impact on emissions. A terminal concept based on terminal tractors will necessitate a relatively large fleet, as each container needs to be placed on top of the vehicle, while horizontal transportation with straddle or shuttle carriers requires fewer machines to handle the equivalent number of containers.

Technologies & innovations	Fleet management applications	Other possible actions
Efficient diesel engines Energy regeneration Hybrid technologies Electrification of equipment Equipment automation	Optimising fleet size Optimising route Minimising waiting time	Educating operations and drivers

Overview of typical means to reduce air emissions produced by container handling equipment

Source: Kalmar conference paper by Jouni Kyllonen for GreenPort Congress 2016

Hybrid horizontal transportation equipment typically operates on battery power with the engine switched off up to 30% of the time, which translates to commensurate reductions in emissions and fuel consumption. The most efficient hybrid straddle carriers on the market can consume up to 40% less fuel compared to traditional diesel-powered models, and emit on average over 50 tonnes less CO_2 per year per vehicle. For heavy mobile equipment, the development of fully electrical solutions leading to zero emissions is also progressing, and solutions will soon be available on the market.

In mobile equipment operating at container terminals, electric powered solutions have been scarce. With full electrification gradually making its way to heavier container handling equipment such as reachstackers, it is reasonable to expect that diesel power will eventually be replaced by other power sources. A major contributor to mobile equipment electrification has been the transition from traditional lead batteries to rapidly progressing Li-ion technology. Manufacturers are also looking into fuel cell power for mobile equipment, but this technology will likely take several years to mature.

In addition to hybrid technology and electrification, equipment and process automation can reduce emissions by optimising fleet usage, reducing equipment engine idle times and ensuring that machines are always driven optimally. For manually operated horizontal transportation equipment, driver training offers the possibility of moderate improvements in fuel consumption and airborne engine emissions.

For yard cranes, RTG (rubber-tyred gantry crane) electrification offers the most immediate way of reducing fuel consumption at the terminal and significantly decreasing emissions on-site. Noise emissions are covered briefly, as they are of significance particularly for terminals located in densely populated urban areas. Adopting hybrid and all-electric technology for horizontal transportation systems and/or RTGs can significantly reduce the noise footprint of the terminal.

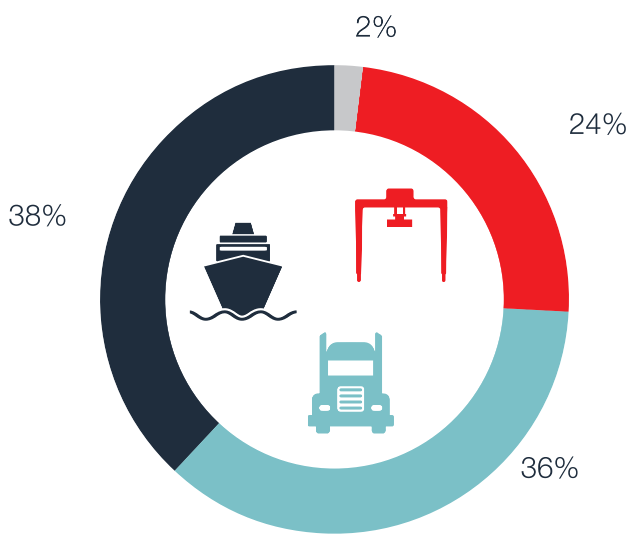
Emission sources at container terminals

SHIP EMISSIONS

Industry studies show that typically the most significant source of airborne emissions at container terminals in developed countries is the container ship itself[1]. Tightened IMO regulations on nitrogen oxide and sulphur oxide emissions, along with increased requirements for the use of shore power, have considerably reduced vessel emissions at many ports.

Some ports have implemented incentive programs that offer reduced fees for ships that meet predefined emissions criteria. Examples include the Port of Vancouver, which enables ships to obtain up to 47% off the harbour rate provided that they follow voluntary industry best practices such as obtaining third-party environmental designations or using alternative fuels[2]. A wider discussion of vessel emissions is outside the scope of this paper, except to note that faster ship turnaround times enabled by optimised terminal processes will also indirectly contribute to reduced emissions.

Average 2% breakdown of emission sources in a container terminal.[3]



Kalmar SmartTrucks and SmartLane use tagging technology and location sensors to reduce congestion at port terminals.

ROAD VEHICLE EMISSIONS

Road vehicles are a major source of emissions at the landside areas of container terminals. However, since these vehicles are not under the ownership or control of the terminal, there is little possibility for terminals to influence their emissions directly. In countries with less strict regulations on truck fuels, a significant share of port emissions is typically generated by trucks and locomotives.

The only way that terminals can indirectly reduce the amount of emissions from road vehicles is to optimise vehicle flow through the terminal, thus reducing idling time for waiting trucks. This can be accomplished through process automation that optimises truck routes, as well as automated gate solutions that enable quicker vehicle processing and faster turnaround times.

The most advanced process automation solutions utilise radio frequency identification technologies, which enable the terminal to track trucks in real time. The trucks can be equipped, for example, with radio frequency identification (RFID) tags and reported and followed up in the terminal area. The results of real time tracking are encouraging. For example, the Port of Long Beach in California, US, reported reducing air pollution at the port by 80 percent in one year by using RFID technologies as part of its green trucks program[4].

Horizontal transportation

Current horizontal transport solutions for containers include straddle and shuttle carriers, terminal tractors and automated guided vehicles. Despite the increasing adoption of hybrid technology and electrification, most of this equipment is still powered by diesel engines.

Engine manufacturers need to keep pace with increasingly stringent regulations in most areas of the world, and latest-generation diesel engines are superior to their predecessors in fuel economy and emissions levels. Nevertheless, horizontal transportation equipment remains one of the most significant sources of emissions at terminals.

Straddle carriers with hybrid systems are rapidly becoming the default choice

HYBRID SYSTEMS AND ENERGY REGENERATION

Approximately 80% of straddle carriers currently deployed worldwide are diesel-electric machines[5], and many terminals in countries with less advanced emissions regulations continue to operate traditional

Kalmar FastCharge™ enables zero emissions on site for shuttle and straddle carriers

Learn more about considerations of fully electric powered horizontal transportation solution:

all-diesel machines. However, hybrid systems account for a significant portion of new units sold, and are rapidly becoming the default choice for new terminals. At the time of writing, the only factor still keeping diesel-electric as a competitive choice is the low price of fuel worldwide, compared to the cost of the advanced battery technology required for hybrids.

In the latest hybrid straddle carriers, a regenerative energy system converts electrical braking and spreader lowering energy into electric power that is stored in a battery. This system can save 10–15% in total energy consumption and emissions per vehicle per year.

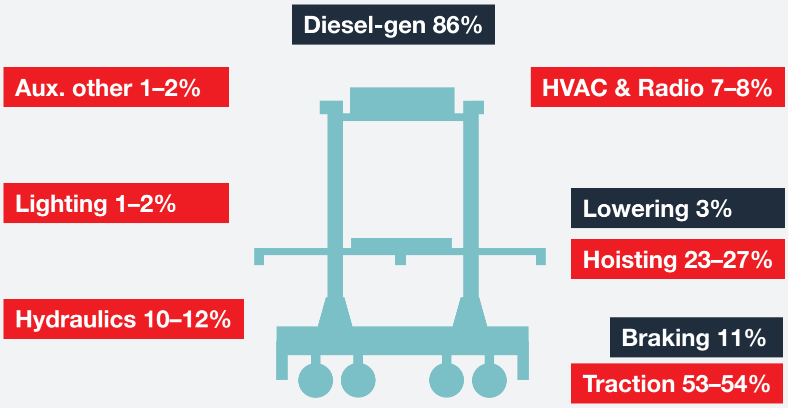
Hybrid machines typically operate on battery power with their engines switched off up to 30% of the time. This translates to commensurate reductions in emissions and fuel consumption. The most efficient hybrid straddle carriers on the market consume up to 40% less fuel than diesel-powered models, and emit on average over 50 tonnes less CO_2 per year.

ELECTRIFICATION OF HORIZONTAL TRANSPORT

Fully electric equipment decreases noise levels and enables zero emissions at the point of use. The latest generation of horizontal transport equipment includes fully electric straddle and shuttle carriers, as well as fast charge technology that enables charging at idle times during the equipment work cycle.

Straddle Carrier Energy Balance Sheet[6]

Figures as percentages (%) of total energy (kWh) CONSUMPTION and GENERATION on average



The choice of horizontal transportation system itself has a major impact on emissions. Maintaining maximum productivity for the STS cranes is the single most critical factor for ensuring optimum performance for the entire terminal, so the horizontal transportation fleet needs sufficient capacity to avoid bottlenecks at the quayside. Resultantly, a terminal concept based on terminal tractors will require a relatively large fleet, as each container needs to be placed on top of the vehicle. When horizontal transportation can be handled by straddle or shuttle carriers, the containers can be placed on the ground and fewer machines are required to handle the equivalent number of containers.

Converting to fully electric opportunity charging based shuttle or straddle carriers, such as the Kalmar FastCharge™, will eliminate direct emissions from horizontal transport completely.

ENERGY BALANCE AND DISTRIBUTION OF HYBRID STRADDLE CARRIERS DURING OPERATION

The two main operative energy consumers in straddle or shuttle carrier operation are machine traction and hoisting. The energy cycles of machine traction play a major role in the energy balance, so they should be evaluated carefully when seeking ways to improve energy efficiency.

The percentages in the illustration on the previous page illustration will change as a function of the number of hoisting and driving cycles, and theoretically could saturate to a level dictated by energy chain efficiencies involved in both operations (e.g. electric drives, motors and reduction gears).

However, the energy characteristics are highly dependent on operational factors and can vary greatly between terminals, and even between types of cycles inside a given terminal. The driving style of the machine operator also has a measurable impact on energy efficiency, as discussed later in this document. Automation further optimises the energy efficiency[7].

Kalmar Hybrid Shuttle Carriers have been operating in the Virginia International Gateway since late 2015.

When comparing to a traditional machine, Kalmar Hybrid Shuttle Carriers produce about 50 tons less carbon dioxide emissions in a year.

Case study: Virginia International Gateway

Kalmar Hybrid Shuttle Carriers in operation at Virginia International Gateway (VIG) are reducing fuel consumption by as much as 40% over traditional diesel driveline shuttle carriers, according to vehicle reporting data.

In early 2016, The Port of Virginia and Kalmar released machine monitoring figures assessing the performance at Virginia International Gateway, one of the port's two primary container terminals. Based on the machine data during the reporting period, the average fuel consumption in operation was around 10 litres per operating hour, while achieving an average productivity of 10.5 moves per operating hour. This means significant cost savings and reduced emission levels for the terminal without compromising productivity.

The port estimated that one machine produces about 50 tonnes less CO_2 emissions in a year compared to traditional shuttle carriers. Data was collected from October 2015 to January 2016 when the shuttle carriers had become operational.

KALMAR

Yard and STS cranes

RUBBER-TYRED-GANTRY CRANES

Rubber-tyred gantry cranes (RTGs) are the most popular equipment choice for container stacking at terminals around the world. With a global installation base of some 8,000 machines, approximately 60% of the world's container terminals use RTGs. Some 75% of installed RTGs are diesel-electric, but a significant percentage of new cranes are operating on grid power[8].

RTGs have historically been powered by large constant-speed diesel generators, which are not optimal from the perspective of fuel consumption. In recent years, constant-speed generators have increasingly been supplanted by variable speed generators as well as smart power solutions that help reduce fuel consumption and emissions.

RTG electrification is a major trend at container terminals worldwide. In addition to cost savings due to reduced fuel consumption at the terminal, RTG electrification significantly decreases emissions on-site. The two major options for RTG electrification are bus bar and cable reel systems, each with their own benefits. The choice of method depends on the specific requirements of the terminal.

Potential CO_2 emission reduction of RTG electrification[9]

Diesel Electric RTG (5,000 hours per year)				
Consumption l/h	CO_2 kg/hour	CO_2 kg/year	Annual CO_2 reduction in a 5 RTG fleet	Annual CO_2 reduction in a 20 RTG fleet
13 litres/hour	34.8	173,940	869,700	3,478,800
15 litres/hour	40.1	200,700	1,003,500	4,014,000
17 litres/hour	45.5	227,460	1,137,300	4,549,200
19 litres/hour	50.8	254,220	1,271,100	5,084,400
21 litres/hour	56.2	280,980	1,404,900	5,619,600
23 litres/hour	61.5	307,740	1,538,700	6,154,800
Electric RTGs produce zero CO_2, NO_x and PM emissions at the point of use				

Emission factor used for calculations is 2.676 kgCO_2e/l[10]

RTG electrification options are cable reel and bus bar.

AUTOMATIC STACKING CRANES

Automatic stacking cranes (ASCs) always operate on grid power, so they are, by default, zero-emissions systems on-site. They include a kinetic energy recovery system, which feeds the energy harvested during deceleration back to the grid. Additionally gantry operation on rail is more efficient than on rubber tyres so ASCs also exhibit very high efficiency ratios. Along with electric RTGs, ASCs are used at several ports worldwide that are undertaking zero-emissions transition programs over the next few years.

SHIP-TO-SHORE CRANES

Like ASCs, ship-to-shore (STS) cranes are always powered electrically, so they can be considered zero-emissions systems if the scope of discussion is limited to airborne emissions generated at the container terminal.

Mobile Equipment

Mobile equipment, such as reachstackers, empty container handlers, forklift trucks and terminal tractors are widely used in ports and terminals around the world. In larger terminals, terminal tractors are widely used for moving containers between the quay and the stack, as for in smaller or medium-sized terminals, reachstackers are very common due to their flexibility and high stacking and storage capacity.

NEW OPPORTUNITIES AND ENGINEERING CHALLENGES

Electric drive is fundamentally different from diesel-powered driveline technology, offering several compelling long-term benefits for manufacturers and equipment users alike. Electric power in Mobile Equipment is a relatively new development, but electric drives are a highly mature and commoditised technology. At the same time, due to continuously tightening emissions regulations, OEMs must devote significant resources to re-engineer their equipment to meet each new emissions target, without a commensurate increase in value that can be directly translated as a benefit into their own customer offering. Transitioning to zero-emissions electric drive will enable longer and more stable product lifecycles, which ultimately benefits manufacturer and customer alike.

Likewise, for the end users at terminals, the total lifecycle costs of electric-powered machines are radically lower than for diesel-powered equipment, as a result of the completely different maintenance paradigm. These benefits hold even when considering the need to replace the battery packs during the expected 10–15-year lifespan of the equipment. The main reason for improved lifecycle costs with fully electric equipment is the simplified drive installation in trucks due to fewer wearing parts as well as less consumables such as engine and lubrication oils. Savings are further increased once new equipment generations are designed for electric drive from the very beginning. Currently, manufacturers are still re-engineering diesel-powered equipment to electrical drive, which means that some design compromises are inevitable due to structural constraints that cannot be altered.

The technical aspects of electrification, hybrid technologies and regenerative energy transfer vary widely between machine types. For example, straddle carriers and forklifts are heavier than the weights they carry, while terminal tractors routinely tow loads that are over ten times the weight of the vehicle. Resultantly, tailoring the regenerative system to capture e.g. braking energy poses an entirely different set of engineering challenges for each type of vehicle.

The development of battery technology has recently enabled the electrification of medium forklifts (9 to 18 tons).

The environmental impacts of Mobile Equipment can also be reduced by downsizing diesel-powered engines and developing more intelligent control systems in the equipment. For example, the drive train system of Kalmar K-Motion reachstacker combines hydrostatic and hydro-mechanical transmission technologies, leading to increased productivity, reduced fuel consumption and lowered emissions. Based on the customer field reports, Kalmar K-Motion can contribute to reductions of as much as 40% in fuel consumption and exhaust emissions.

KEY ENABLERS FOR ELECTRIFICATION: LI-ION AND FUEL CELLS

A major contributor to mobile equipment electrification has been the transition from traditional lead batteries to rapidly progressing Lithium-ion (Li-ion) technology. A challenge for battery-powered mobile equipment is managing the charging and/or battery replacement procedures of the machine so that availability is maximised. This is particularly relevant for machines in continuous three-shift operation.

Until recently, lead batteries have not been able store enough energy to run heavy machines in tough driving conditions. The advance of Li-ion technology is making it increasingly feasible to electrify machines beyond the lightest categories of forklifts and other mobile equipment.

Light forklifts (5 to 9 tons lifting capacity) are already routinely electric-powered. The development of battery technology has recently enabled the electrification of medium forklifts (9 to 18 tons). In the coming years, this development will extend to the heavier product ranges with lifting capacities of over 18 tons.

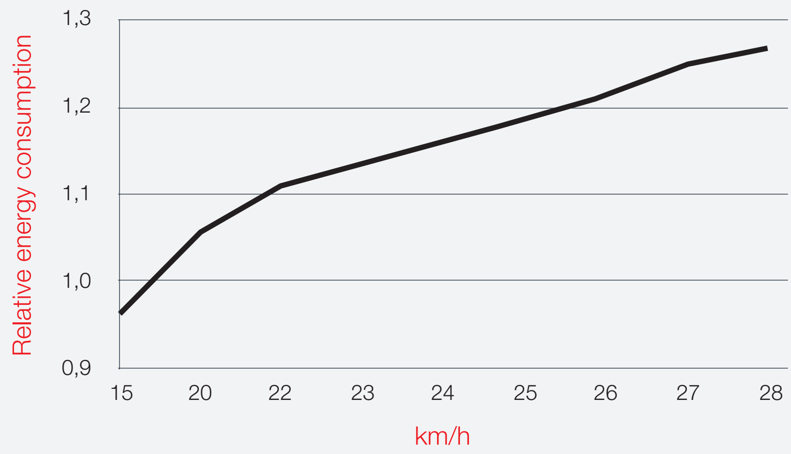
Concurrently with this development, fast-charge technology holds great potential and has already been successfully deployed in heavier machines such as straddle carriers as well as in various applications outside container terminals, including buses and on-road trucks.

Manufacturers are also looking into fuel cell power for mobile equipment, but this technology will likely take several years to mature. The core benefit of fuel cell technology is that it could enable longer all-electric operation in comparison to more frequent battery charging or swapping. Especially for large machines where battery capacity and size currently limit electrification, the economical availability of fuel cell technology may prove to be the future tipping point for widespread electrification. However, an added challenge will be to establish the required infrastructure for supplying the hydrogen gas needed to power the fuel cells.

Driver training

For manually driven container handling equipment, driver training can make a measurable contribution to reducing fuel consumption and emissions. “Frugal driving” courses can be taught in a few days and encompass topics such as economical driving and lifting techniques; improved understanding of revolutions per minute (RPM) versus engine torque; learning to interpret information provided on vehicle displays; and how the driver can directly affect fuel consumption and emissions. Typical results indicate fuel savings of 5–10% for drivers that have completed such training[11]. Based on a simulation study, reducing the top speed from 28 km/h to 25 km/h decreases relative energy consumption by 6.5%. If the speed is reduced from 25 km/h to 20 km/h, the consumption drops by 11%. However, due to variations in the operational environment and machine operator habits, the results are only indicative[12].

Energy consumption

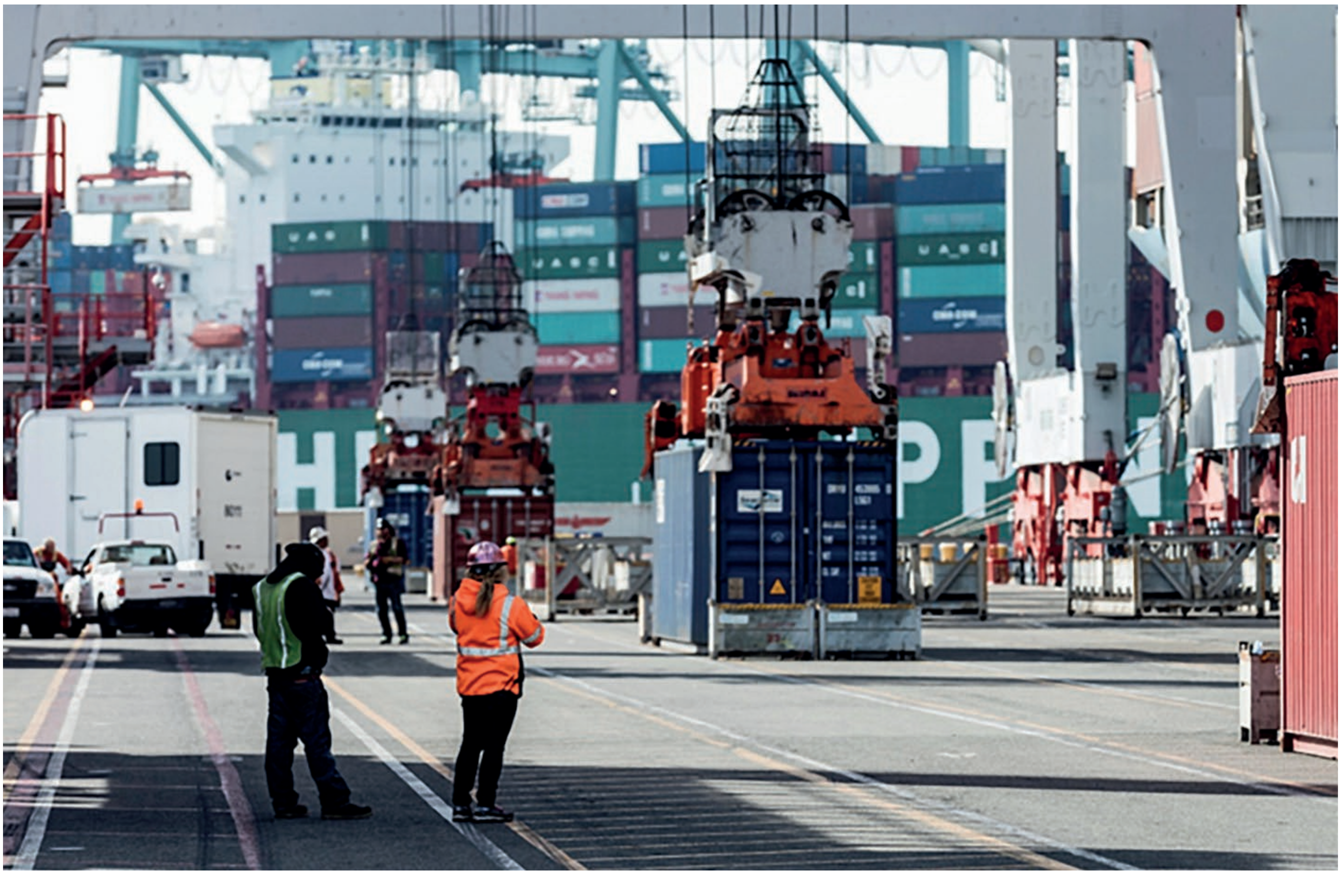


Relative energy consumption as a function of top speed.

Terminal automation

Increasing the automation level of a terminal with products that automate a single part of the operation or the whole process is recognised as the next step towards improving performance at today's container terminals. The benefits of automation include lower operational costs as well as improved terminal productivity, capacity, safety and security.

Additionally, automation reduces fuel consumption – and therefore also emissions – by removing inefficiencies and optimising fleet sizes. Automated equipment is always driven optimally, which saves fuel, reduces emissions and contributes to extended equipment lifespans.



Listen to a driver from Virginia International Gateway sharing his experience in operating a Kalmar Hybrid Shuttle Carrier:

Noise emissions

In addition to CO_2 and airborne particulate emissions, noise is an important consideration especially for container terminals located in densely populated urban areas.
Noise measurement of container handling equipment is complicated by the fact that standard industry measurements have been designed for smaller machines and cannot be practically applied to, for example, yard cranes. As a result, noise measurement of terminal equipment typically entails some adaptation from standard methods.

With the exception of handling noise from containers, noise at container terminals is primarily related to diesel and diesel-electric equipment, as electric machines can be considered practically silent in operation. Adopting hybrid and all-electric technology for horizontal transportation systems and/or RTGs can significantly reduce the noise footprint of the terminal.

TraPac LLC automated terminal in Long Beach, California.

Industry Outlook

As container ports face increasingly stringent environmental regulations as well as a highly competitive global business landscape, port operators will need to focus on reducing emissions from their operations.

Currently, the demand for low-emissions and/or electric technology for container handling varies widely between geographies and industries. For example, in the US, port customers generally require on-highway engines with lower emissions for their terminal tractors. On the other hand, terminals in nearly all regions outside Europe, the US and Canada still run primarily Tier 3 diesel engines in their trucks mainly due to fuel quality requirements. For the immediate future, widespread electrification of terminal transport will likely be limited to developed markets due to the extensive new infrastructure that is needed to build and support electric vehicles.

Many manufacturers believe that new container handling equipment will be, by default, electric-powered in ten years' time. Manufacturers including Kalmar are focusing significant resources on deploying electric drives in equipment, and the field is developing rapidly. This development parallels that of other industries that have outlined even more ambitious roadmaps. For example, Volvo has announced that it will stop developing new-generation diesel engines for cars, as the cost of reducing nitrogen oxide emissions is becoming too high[13]. With its relatively smaller equipment volumes, the container handling industry may well be slightly behind, but the direction for the future is clear.

Several container ports around the world have already unveiled roadmaps that bring together all aspects of emission reduction or even eventually enable them to reach zero on-site emissions. Examples include the Port of Los Angeles, which has been working with a zero emissions roadmap for several years[14]; the APM Maasvlakte II Terminal in the Netherlands, which aims to reach 100% sustainably sourced energy usage in the future[15]; and the EUROGATE Container Terminal in Hamburg, which aims to cover 25 to 50% of the terminal's total energy requirement from its own production. By operating its own wind turbine, the company hopes to lower energy costs over the medium to long term and become largely independent of price developments in the power and energy markets[16].

Further developments may include, for example, increased adoption of wind turbines at container ports, where aesthetic considerations are typically not as relevant as in other areas. In the future, large STS and ASC cranes could provide natural mounting places for wind turbines and solar panel arrays that could be used to power the terminal. As the technology matures, wave or tidal power may also prove a natural match for container ports.

Sources

1) *Shipping Emissions in Ports: Discussion Paper No. 2014-20. Olaf Merk, OEDC International Transport Forum, December 2014, pp. 10. http://www.itf-oecd.org/sites/default/files/docs/dp201420.pdf*

2) *http://www.portvancouver.com/environment/air-energy-climate-action/marine*

3) *Adopted from IMO/www.nrdc.org/air/pollution/ports1/overview.asp*

4) *http://www.joc.com/trucking-logistics/transportation-firms-hailed-itinnovators_20100603.html*

5)-9) *Kalmar*

10) *World Resources Institute (2015). GHG Protocol tool for mobile combustion. Version 2.6.*

11) *Kalmar Training Academy*

12) *Kalmar*

13) *www.euronews.com/2017/05/17/volvo-cars-to-stop-developing-new-diesel-enginesceo*

14) *https://www.portoflosangeles.org/environment/zero.asp*

15) *APM Terminals Signs Contract for Wind-Power Generated Electricity, APM Terminals press release 16.12.2014, http://www.apmterminals.com/news pressreleases/2014/12/apm-terminals-signs-%20contract-for-%20wind-power*

16) *Startup of first wind turbine, EUROGATE Group press release 14.8.2013, http://www1.eurogate.de/en/About-us/Press/Press-release/Startup-of-first-wind-turbine*

ABOUT THE AUTHORS

ARI HIRVONEN
works as Product Manager for Intelligent Horizontal Transportation Solutions at Kalmar Automation and Projects Division managing Kalmar straddle and shuttle carrier portfolio. During his career of 23 years in Kalmar he has held various positions in product development, engineering, sales and during the past 6 years in product management.

HEIKKI SALONEN
works as Product Manager, Cranes Offering Development, Intelligent Solutions at Kalmar Automation and Projects Division. Heikki has been working for Kalmar since 2006. During the past five years, he has worked with product management, first responsible for the development of Kalmar's offering in Automatic Stacking Cranes (ASC) and currently in Rubber-tyred Gantry (RTG), and Ship-to-Shore (STS) cranes. Heikki has over 25 years of experience in product development, engineering and product management in machine industry.

PETER SÖDERBERG
Vice President R&D, Kalmar Mobile Equipment. Peter is responsible for Product Portfolio Development at Kalmar Mobile Equipment Division including Reachstackers, ForkLift Trucks and Terminal Tractors. Peter has over 30 years of wide experience from the field of Engineering, R&D, Strategy and Business Development. He has held various research and development leadership positions and has an extensive experience from related industries such as the Volvo Group (Trucks, Excavators and Articulated Haulers) and BAE Systems (Bofors and Hägglunds).

KALMAR

KALMAR

Making your every move count

www.kalmarglobal.com