WORKSTREAM 3

Strengthening port power infrastructure and electric load management

enabling efficient terminal and port electrification

ZEPA Zero Emission Port Alliance

DECEMBER 2024

Strengthening port power infrastructure and electric load management enabling efficient terminal and port electrification

Ports play a crucial role in the journey towards reducing global emissions: they enable the construction of new infrastructure, such as offshore wind turbines; they are fast becoming transport hubs for low-carbon commodities, like hydrogen steel; and electrifying port operations promises a significant contribution to meeting carbon targets worldwide.

The transition of port tenants, especially container terminal operators, from diesel-powered to electricity-powered equipment is one of the main levers driving port decarbonisation. However, and the the electrification of other segments, such as refining and manufacturing, will also cause soaring demand for electricity in ports around the world, over the next 20 years, especially due to an increased peak-power demand at specific times. Ports need sufficient power infrastructure to support this unprecedented increase in demand. Even ports with abundant grid capacity today are likely to hit constraints in the future as the transition speeds up, leading to operational disruptions due to insufficient electricity. This puts individual port tenants at commercial risk and slows the pace of port-wide decarbonisation.

The decarbonization of ports is driving a sharp rise in electricity demand, calling for major changes: both in attitudes toward power and power infrastructure and in how port stakeholders engage with infrastructure providers, individually and collectively.

These trends and risks are transforming the significance of electric power and its supporting infrastructure in ports. They call for major changes: both in attitudes to power and power infrastructure among port authorities, terminal operators, and other port tenants and in the way these stakeholders engage with infrastructure providers, both individually and collectively. This document from the Zero Emissions Port Alliance (ZEPA) aims to identify those changes and highlights what terminal operators, port authorities and grid operators[1] should do to electrify ports more rapidly.

ZEPA was formed expressly to accelerate decarbonisation in ports and to support electrification of container terminal operations. ZEPA's members comprise four terminal operators, six equipment manufacturers (OEMs) and two port authorities. The secretariat is held by Systemiq. ZEPA's focus is on improving the affordability and accessibility of battery-electric container handling equipment (BE-CHE) to increase its adoption by container terminal operators (see page 19 for more details on ZEPA)

1. With "grid operators," we refer to the entities that own and operate the electricity grid. Depending on the region, this may be the same organization as utilities or energy companies. However, in this document, we will consistently use the term "grid operators."

Growing pressures on port electricity grids as container terminals and other port tenants decarbonize

Terminal and port-wide electricity infrastructure is set to become a strategic topic for ports in all locations as port tenants electrify their operations. In certain ports, grid capacity constraints are already compromising electricity supply to tenants and slowing down their energy transition. Research from the British Port Association suggests that "70% of UK ports are already at or near to their ceiling in terms of power."[2] The Port of Rotterdam has had to set up a task force to tackle grid congestion.[3] And Lloyd's List has called on all port authorities to support grid upgrades because "electricity supply is becoming the latest bottleneck for container terminals".[4]

70%

of UK ports are already at or near to their ceiling in terms of power.

"Electricity supply is becoming the latest bottleneck for container terminals"

Lloyd's List

Container terminal operators' switch to battery-electric container handling equipment (BE-CHE) is one of the earliest causes of an expected surge in their demand for electricity and power infrastructure (Exhibit A). To illustrate the impact at port level, a container terminal that switches to 123 terminal tractors over the next five years will place tens of MWs of additional demand on its port's grid by 2030.[5] When fully electrified, this container terminal's peak power demand will be about 10MW.[6] On a bigger scale, ZEPA members carry out roughly 15% of global container handling operations. They expect to purchase between 4,200 and 6,400 units of BE-CHE between 2025 and 2035 and will need an additional 800-1,200 GWh of electricity a year by 2035, corresponding to approximately 100-160MW a year, to operate this equipment. Please check the ZEPA Expected BE-CHE purchases document for more detail.

An illustrative example of the electricity demand in a port is visualized in the graph below. (Exhibit A). By 2030, the total electric load of an average terminal operator will be a multiple of what it is today, roughly about 4 to 6 times higher. Additionally, electrification of vessels, such as tugboats and other working vessels within ports, and truck transporting goods to and from ports is expected in the short-term. This will add several more tens of MWs to total

2. British Ports Association, 'Electrifying UK Ports'
3. Port of Rotterdam (2024), 'New Energy Taskforce to support with tackling grid congestion in the Port of Rotterdam';
4. James Baker, Lloyd's List (2023), 'Call for port authorities to support grid upgrades'
5. Illustrative port with 7 ship-to-shore cranes and 123 terminal tractors making approximately 4 million moves a year.
6. The peak power demand is between 2-29 MW, depending on the charging strategy. See the discussion later in this document, and find more information in the ZEPA 2024 Voluntary Standards report.

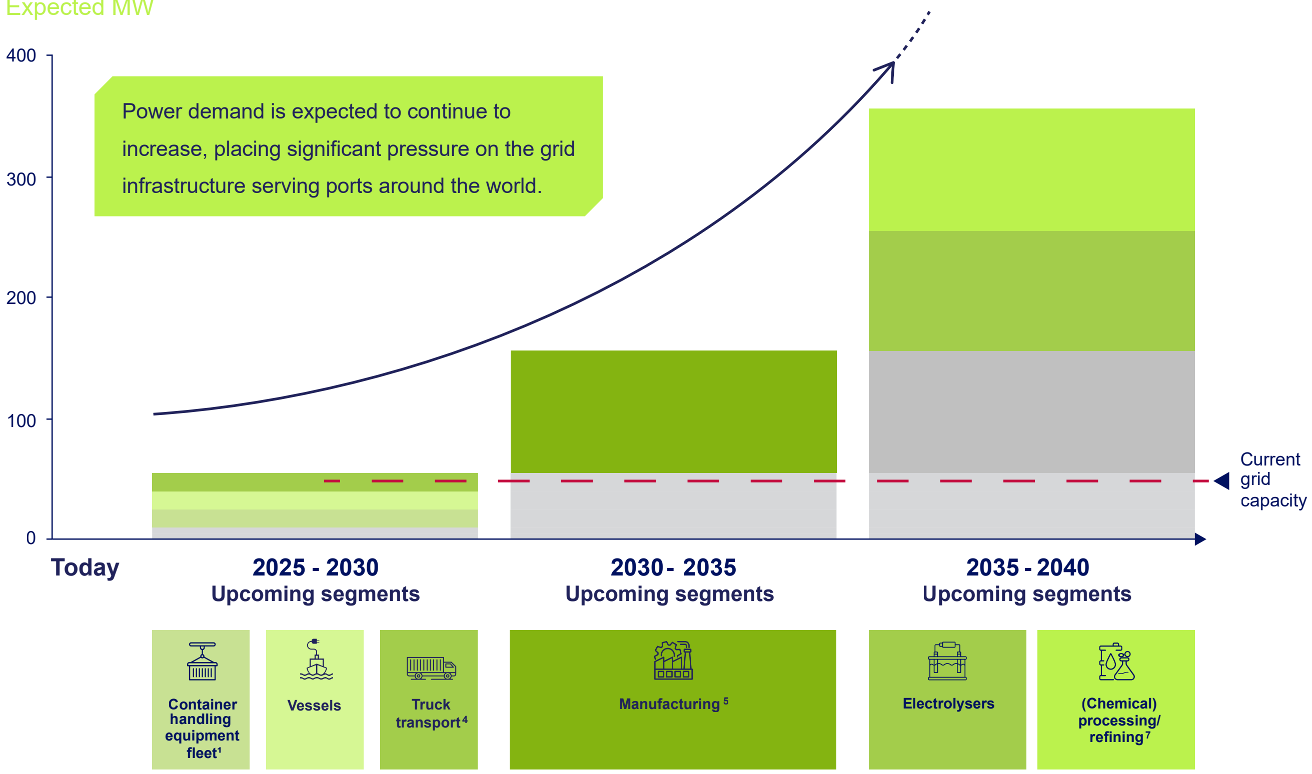
power demand from ports over the next five years. In the years following, other port tenants, like manufacturers and refiners, will also be electrifying their operations. In addition, ventures in emerging, electricity-intensive industries using technologies like electrolysis for hydrogen production, will continue to set up operations in ports. New power demand from these additional segments will reach hundreds of MWs, placing significant pressure on the grid infrastructure serving ports around the world.

EXHIBIT A

As the broader port electrifies, power demand will increase in each end-use sector, with container terminals as one of the first growth segments

Power demand of new segments over time in illustrative port

Expected MW



(1) Based on a fleet of 123 terminal tractors (operating in vehicle rotation) and 7 Ship-to-Shore cranes (2) Assuming individual Refrigerator Container Units require around 5.5 kW and the terminal holds ~100 RCUs. (3) Shore power based on 4 container ship shore power connections with a load of ~1 MW per connection. Also includes potential vessel electrification with battery swapping. (4) Based on two 4-bay charging stations for medium- to heavy-duty vehicles (5) Assuming one manufacturing plant decarbonizes through a ~10 MW e-boiler (6) Based on announced electrolyser projects in the Port of Rotterdam, which range from 200-800 MW (7) Based on a small-to-medium size e-SAF plant

Source: Systemiq Analysis, Port Electrification Handbook (2024) PNNL. Cluster Energie Strategie Rotterdam-Moerdijk (2022), Port of Rotterdam. Systemiq (2024) The Global ETES Opportunity.

That said, the local context at each port varies on many dimensions, such as the size and types of industrial activity, all of which have implications for terminal operators' plans to electrify. Terminals in some locations already face multiple constraints on their transition, including limited grid capacity and space, other port tenants in energy intensive sectors, volatile energy prices, and a lack of regulations and incentives, such as subsidies, to support decarbonization. In contrast, terminals in other locations face almost no constraints today: subsidies are in place and there is more than enough power infrastructure to meet the needs of today's port tenants. But ports on both greenfield and brownfield sites will see some constraints as the energy transition unfolds, so terminal operators everywhere need to evaluate the local context carefully as they plan and execute their transition strategy. port authorities need to understand the future needs of their tenants combined and grid operators need to be made aware of the expected electrification trends within ports.

RECOMMENDATIONS

Ensuring timely grid expansion and load optimization for efficient port decarbonization

For an efficient energy transition, terminal operators, port tenants and port authorities all need to adapt their roles and behaviours. Research undertaken for this report indicates that optimal use of scarce grid capacity requires close communication and coordination among all port community members as well as independent action from individual tenants. This will bring significant individual and collective benefits.

Three recommendations for port community members:

1 Container terminal operators and other port tenants should inform grid operators and port authorities about their growing electricity needs.

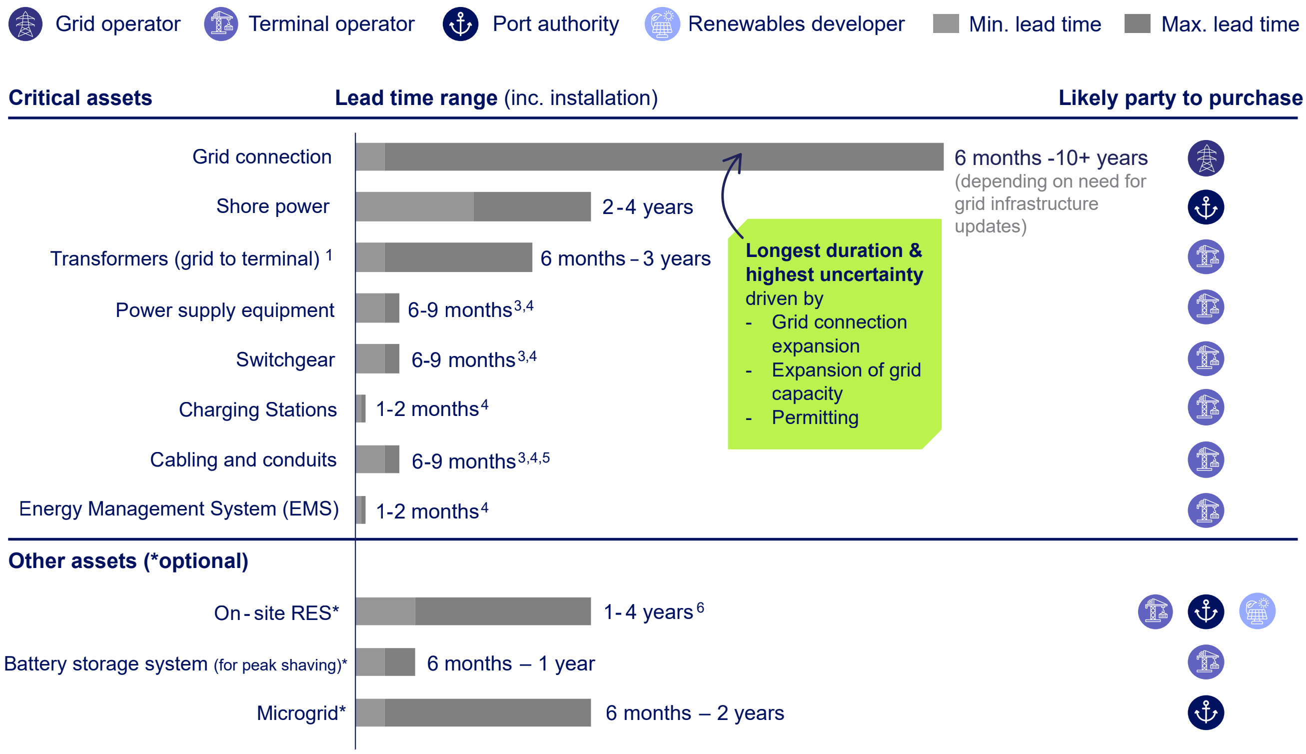
Specifically, terminal operators should assess future growth in their electricity needs, share the results of that assessment early with grid operators, and request any necessary upgrades in their grid connection well in advance, to ensure timely expansions in grid capacity when and where these are needed.

When a terminal operator establishes that its expected power needs are likely to exceed the capacity of its grid connection, it will typically request an upgrade from the grid operator to expand the connection. If the upgrade involves a contractual adjustment, it typically poses no problem, as it can use the existing hardware. The grid operator can proceed with the upgrade without delay if current grid capacity can accommodate the expected addition to total load. However, if a subsequent similar request from a port tenant means total future load will exceed current grid capacity, the grid operator will need to expand the grid, i.e. electrical assets further upstream. In this case, a physical upgrade is required, which introduces challenges such as lead times, planning, cost, and the installation of new hardware.

EXHIBIT B

Lead times for securing assets critical to electrifying container terminal operations.

(Critical) assets for container terminal electrification, their lead times and the likely party to purchase them



Note: Some phases of power infrastructure roll-out will require terminal downtime. Exploring potential synergies with other (power) infrastructure projects such as shore power could reduce total downtime.

1) Depending on the region, transformers may be included in the grid connection 2) Heavily dependent on transformer size, longer lead times for larger capacities 3) Based on The Commercialization of POLB Off Road Technology (C-PORT) Demonstration Final Report (2021), ex. permitting 4) Based on The Public Charging Toolkit for Heavy-Duty Trucks (2022), Port of Long Beach 5) timeline highly dependent on terminal schedule, operations and length of cable required 6) Highly dependent on size and type of RES, time indicated for solar 7) Based on Port of Long Beach Microgrid Factsheet (2022) Source: Wood Mackenzie (2024), 'Supply shortages and an inflexible market give rise to high power transformer lead times'; ETC (2023), 'Streamlining planning and permitting to accelerate wind and solar deployment'; The Port of Long Beach (2022), ' Electric Public Charging Toolkit for Heavy-Duty Trucks: Guidance for businesses'; The Port of Long Beach (2021), 'The Commercialization of POLB Off Road Technology Demonstration Final Report'; The Port of Long Beach (2022), ' Microgrid Factsheet'; Alfen (2021), 'A window to the future of EV charging convenience highlighted by Shell/Alfen Pilot'

Grid expansions take time to plan and execute, amongst others due to planning and permitting. As a result, grid connection upgrades have the longest and most unpredictable lead times of all the assets needed for electrifying a container terminal. Where a grid operator cannot upgrade a grid connection without expanding grid capacity, these lead times can exceed 10 years (Exhibit B). This makes grid capacity expansions the biggest potential bottleneck on the critical path to electrification for terminal operators and other port tenants.

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The energy transition is driving a step-change in the electric power and energy needs of terminal operators, as detailed in the previous section. To avoid potential grid expansion bottlenecks, terminal operators should communicate to grid operators their expected additional power needs and request increases in their grid connection capacity, if necessary, as early as they can, with as much foresight as possible. This will give grid operators a better chance of planning and executing any necessary grid expansion in time to meet the additional power needs of terminal operators as they arise.

2 Terminal operators should optimize their individual power load within the capacity of their available grid connection.

Terminal operators should optimize their individual electricity load within the capacity of their available grid connection, for example, by implementing a rotational or battery-swapping strategy for their BE-CHE (see Box 1: BE-CHE charging strategies).

Terminal operators should review their individual load profile and look for ways to distribute their load evenly to optimise the capacity of their current grid connection. Uneven load distribution can lead to inefficiencies, while optimising load may allow terminal operators to delay or even avoid costly upgrades to their grid connection.

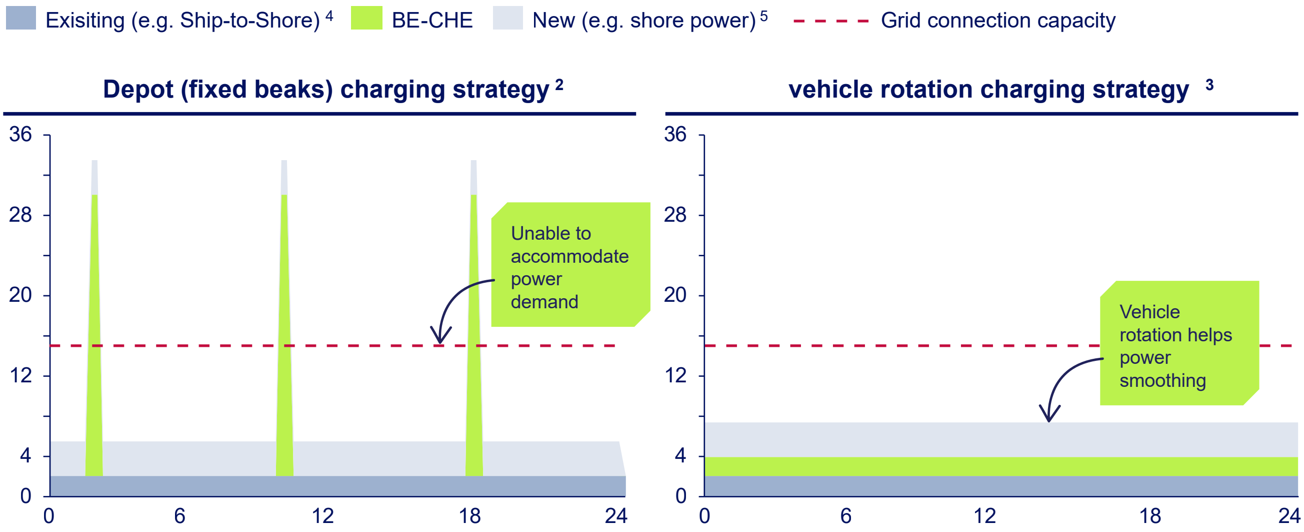
To illustrate, imagine an individual terminal operator switching to BE-CHE chooses a depot charging strategy[7]. This will produce total load peaks of about 30 MW, beyond the 15 MW capacity of the terminal operator's grid connection. (Exhibit C, right hand side). If that happens, the terminal operator may have to pay surcharges and be unable to electrify further. Moreover, if the grid operator cannot supply enough power to meet these demand peaks, the terminal's operations may be affected. In contrast, if the terminal operator chooses a rotational or battery swapping strategy for charging its BE machines, its daily load profile will flatten to ~2 MW and remain below its grid connection capacity (Exhibit C). As an example, the illustrative container terminal with 123 terminal tractors introduced earlier could lower its potential peak power demand by a factor of 15 by implementing a rotational charging strategy and by a factor of 6 by implementing battery swapping.[8] terminal operators can make themselves even more resilient to grid connection capacity constraints by introducing flexibility into the load profiles of their other sources of power demand, (i.e. ship-to-shore and shore power) and harmonizing the profiles to optimise total load for available capacity.

Optimizing load profiles requires a thorough understanding of power usage patterns. Ideally, this involves analyzing data on a minute-by-minute basis to identify opportunities for harmonization and to flatten demand peaks. While current practices may not yet consistently achieve this level of detail, improving the monitoring and understanding of load demand can significantly enhance planning and coordination, allowing tenants and terminal operators to make more informed decisions.

EXHIBIT C

At terminal level, BE-CHE operations should be designed to use the grid efficiently by avoiding high power demand peaks, reducing the risk of future grid capacity bottlenecks.

Illustrative cumulative power demand profiles for two BE-CHE charging scenarios[1]
MW



Notes: (1) Actual power demand profiles will show more fluctuations as operations will not be perfectly constant. (2) Depot charging based on 115 terminal tractors in operation, all charging 3 times per day at the same time a rate of 250 kW. (3) vehicle rotation based on 123 terminal tractors in operation, 2 terminal tractors charging at a rate of 250 kW. Similar load profile can be expected for battery swapping.(4) Existing power use based on 7 Ship-to-Shore cranes with a demand load that varies between 650-950 kW. (5) Shore power based on 3 container ship shore power connections, with a load that varies between 0.9 MW (one ship using the connection) and 4 MW (all three ships using the connection).
Source: Systemiq analysis, PNNL (2024) Total Loadprofile Workbook Port Electrification Handbook

7 Depot charging strategy means that all BE-CHE charge simultaneously during scheduled breaks and overnight
8 More on this and other calculations for charging strategies can be found in the report on the "ZEPA 2024 Voluntary Standards"

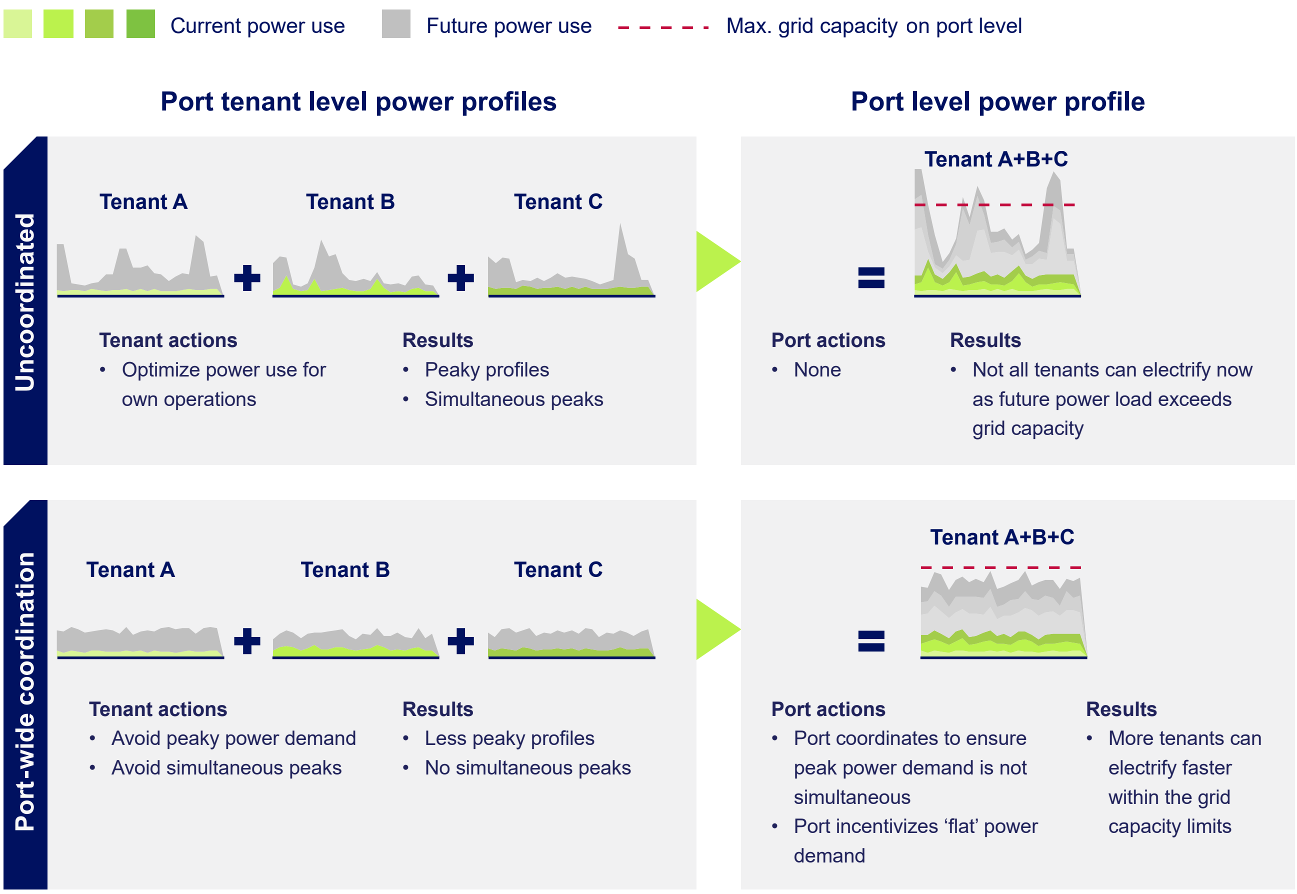
3 Port tenants and port authorities should coordinate to harmonize power loads port-wide, enabling more port tenants to electrify faster

If several port tenants create highly variable load profiles when they electrify, the resulting volatile port-wide load profile might exceed port-wide grid capacity at certain times of day (See Exhibit D, top half). A volatile port-wide load profile would also hold back other tenants from electrifying, even though the port's grid capacity could accommodate their electrification if all tenants were to harmonize their load profiles (Exhibit D, bottom half). Grid capacity should be treated as a shared resource, where tenants work together to balance demand and avoid overloading the system. Without collaboration, there is a risk of a "tragedy of the commons," where individual actions to optimize power usage for immediate needs could unintentionally strain the grid, limiting its ability to support long-term electrification efforts.

EXHIBIT D

Harmonising power loads port-wide enables more port tenants to electrify faster

Illustrative power demand profiles for individual tenants and total port, for uncoordinated and coordinated approach
MW load for 24 hours



Source: Systemiq analysis

Port authorities are the obvious candidate to take charge of harmonizing load across the port community. But port authorities generally have no mandate or responsibility for tenants' power demand. Nor are port tenants required to keep port authorities up to date on changes in their overall power demand and charging strategies. In addition, port authorities aren't always able to form the overview of future power demand from port tenants that would help grid operators' plan to expand the grid efficiently because some of this information is commercially sensitive. Lacking oversight of the load profiles of individual port tenants and their effects, port authorities are unable to start port-wide conversations on avoiding peaky profiles and optimising load to make best use of total grid capacity, now and in the future. terminal operators and other port tenants therefore need to share their electrification plans with port authorities as well as grid operators, so a port-wide view of future power use and individual tenants' load can be developed and evaluated. This will be critical to optimising port-wide grid capacity today and going forward. In addition, the port community can explore together different models for expanding port-wide grid capacity and distributing low-carbon power. For instance, the port authority could own battery storage on behalf of port tenants.

The port community can explore together different models for expanding port-wide grid capacity and distributing low-carbon power.

Table 1 shows the actions that individual members of port communities need to undertake to support efficient decarbonization. While the details of these actions may vary in different ports, their general features are summarized here to give the options that port community members can adapt to their specific local and regional contexts.

TABLE 1

Actions individual members of port communities can take to ensure efficient decarbonization.

Terminal operators and other port tenants need to:

- **Regularly take stock of their future power demands and understand their current capacity limitations.** How much will future asset purchases increase their power load? At what point will these investments trigger a need to expand their grid connection? Is this a hardware or contractual limitation? See exhibit F for more detail;
- **Discuss their electrification plans with grid operators** as soon as possible;
- **Take account of port-wide grid capacity constraints** as well as their own grid connection capacity when designing their daily load profiles;
- **Submit requests to grid operators for any necessary expansion** of their grid connections as soon as they can see these are needed;
- **Adopt a rotational charging strategy** (see box on charging strategies) to avoid demand peaks, for their own benefit and to optimise available grid capacity port-wide; and
- **Keep port authorities updated** on how their electrification plans affect their power needs and daily load.

Port authorities need to:

- **Develop and continually update a port-wide overview of changes** in (future) power needs and power use port-wide, based on regular communications with port tenants about their contracted electrification needs and plans;
- **Share this overview with grid operators;**
- **Liaise between port tenants to solve their grid capacity issues jointly**, making sure tenants charging strategies stay within existing grid capacity limits;
- **Harmonise power demand across the port,** taking a whole-port perspective, to make sure grid capacity is future-proof (see box on New Energy Taskforce);
- **Upgrade agreements with tenants** to include commitments from both tenant and port authority on optimising grid capacity through harmonising port-wide power load;
- **Perform energy and power management at the port level,** using both hardware and software tools, to help optimize power distribution and reduce inefficiencies;
- **Incentivize terminals to adopt energy-efficient practices** and behaviours that align with overall port objectives for long-term sustainability and operational efficiency; and
- **Explore different models for expanding port-wide grid capacity and distributing low-carbon power,** considering local legislation that may impose restrictions.

Grid Operators need to:

- **Proactively ask port tenants for discussions on their electrification plans** so grid operators have a clear picture of future power demand versus current grid capacity and when gaps will arise;
- **Where possible, invest to expand the grid in line with large jumps in future demand** ahead of time, while also ensuring that expanded grids are not under-utilized for long periods;
- **Help port tenants to find ways to meet their power needs** where grid capacity is a constraint; and
- **Meet regularly with port authorities** to develop and continually fine-tune the whole-port grid strategy.

The Port Electrification Toolkit

port authorities and terminal operators can use the three kinds of tools described below to speed up their electrification journeys.

1 Solutions for reducing peak power demand

There are several solutions for reducing peak power demand to explore. These vary by type, impact, cost and the partners they need to involve. (see Exhibit E) Some solutions don't require big hardware investments, but do have a significant impact on peak power demand, such as alternative charging strategies and grid optimizations within container terminals and within the larger port. Others require signficant investments, but also lead to a high reduction in the peak power demand and an increase in flexibility, such as microgrids.

EXHIBIT E

Alongside charging strategies, other solutions exist to reduce power peaks and to increase flexibility

Grid operator | Terminal operator (s) | Port Authority | Other port businesses | Charging OEM | CHE OEM

Low | Medium | High

Solution	Solution type	Potential impact	Indication of costs	Key partners to involve
Smart charging / alternative charging strategies	Software	High	Low	Terminal operator + Grid operator, Charging OEM, CHE OEM
Peak shaving & shifting with a battery system	Software + hardware	Medium	High	Terminal operator + Grid operator, Charging OEM
Optimize grid use within terminal (inc. other large power demands such as shore power)	Software	Medium	Low	Terminal operator + Grid operator
Optimize grid use between multiple container terminals in one container port	Software + partnership	Medium	Low	Terminal operator + Grid operator, Terminal operators
Optimize grid use within the larger port (combined with other businesses)	Software + partnership	High	Low	Terminal operator + Grid operator, Port Authority, Other port businesses
Microgrids	Software + hardware + partnership	High	High	Terminal operator + Grid operator, Port Authority, Other port businesses
Explore 'alternative' contracts with grid operator, e.g. non-firm contracts or time-bound contracts	Contract	Medium	Medium	Terminal operator + Grid operator

Note: Only existing technologies considered. Potential impact and Indication of costs are first indications and not tailored to a specific port or terminal.
Source: Systemiq analysis

2

Checklist of datapoints needed for terminal electrification

Terminal operators need to collect the datapoints in the checklist in Exhibit F to prepare for terminal electrification with other port community members and to electrify efficiently. Specifically data is required on the size and profile of power demand, on the timelines of deployment and on the location and space requirements.

EXHIBIT F

Terminal operators should collect crucial datapoints to prepare for (and implement) terminal electrification with stakeholders.

Checklist of Datapoints needed by terminal operators for efficient electrification.

Specific to BE equipment

Data on size and profile of power demand

Total hourly demand profile of (future) terminal operations [MWh/hr] & grid infrastructure requirements[1]
(e.g. transformers, converters, cabling)

Feed into

- Hourly demand profile of BE-CHE [MWh/h]
- Hourly demand profile of fixed-connection CHE[4] [MWh/h]
- Hourly demand profile of other BE equipment in terminal[5] [MWh/h]
- Hourly demand profile of other fixed-connection equipment in terminal[6] [MWh/h] (e.g. shore power)
- Option: hourly supply profile of local RES [MWh/h]

Feed into

- # of power connections (e.g. chargers, fixed-CHE)
- Peak capacity (MW/MVA) of power connections
- Available grid connection capacity and headspace (MW)
- BE-CHE technology and charging parameters[7]
- Expected scheduled use of power connections (defined by e.g. operational schedule & charging strategy)
- Available on-site grid infrastructure and headspace (cables, transformers, switchgear)
- Charging strategy (depot, vehicle rotation, opportunity, battery swapping)
- Charging rate (kW)
- Option: capacity of available (local) RES supply (MW)
- Option: peak shaving / smart charging (reduction in MWpeak)
- Option: battery system at charger (MW/MWh/h)

Data on timeline of deployment

- Greenfield or brownfield terminal
- Approach to replacing fleet (rolling basis or batch basis)
- Lead times specific components to purchase
- Grid capacity availability & roll-out timeline
- Wider port decarbonization roadmap/timeline

Data on location & space requirements

- Location of physical connections
- Space required for assets
- Option: Space required for local RES supply

-

(1) Ideally terminal operators collect 15-minute data to get a more granular view of the power demand over the day to spot demand peaks (2) Non-exhaustive, additional datapoints may be required based on specific terminal (3) Straddle carriers, terminal tractors, lift trucks and BE-RTGs (4) E.g., ship to shore cranes, RTGs (5) E.g., Drayage trucks, Reefers & EV charging for employees (6) E.g., shore power, office power (7) Technical parameters that inform the demand profile of the BE-CHE equipment, such as energy efficiency, battery size, state of charge ranges
Source: Systemiq analysis based on ZEPA member input

BE-CHE Charging Strategies

BOX 1

Four typical BE-CHE charging strategies for terminal operators were archetypically considered here: depot charging, vehicle rotation, Fast opportunity charging and battery swapping. The specific equipment-types and customer preferences define the operational specifications of pursuing each strategy, including charge rate and charger-to-CHE ratios. A single Terminal Operator may choose to combine different strategies.

Vehicle rotation

Equipment operators begin charging their BE-CHE unit when the battery reaches a low level during their shift and rotate to a charged BE-CHE vehicle to continue working their shift without significant downtime, while their original vehicle charges. Each charger can support approximately 6 to 14 CHE. This means terminals may need to purchase more BE-CHE units than the number of ICE units they replace. Chargers serving a few units are strategically located throughout the terminal to ensure easy access. This strategy generally leads to a relatively flat electricity demand profile without major peaks, using grid capacity most efficiently. Exhibit G shows a rotational charging setup for a BE-terminal tractor fleet.

Depot charging (during fixed breaks)

All BE-CHE units charge simultaneously during scheduled breaks and overnight. Each unit of BE-CHE has a dedicated charger, allowing equipment operators to use the same unit of equipment throughout their shifts without terminals needing to purchase additional units. Chargers are centrally located in areas such as break zones or maintenance facilities. Terminals can have multiple charging locations across the site to maximize accessibility and efficiency. This strategy generally leads to an electricity demand profile with very high peaks do to simultaneous charging.

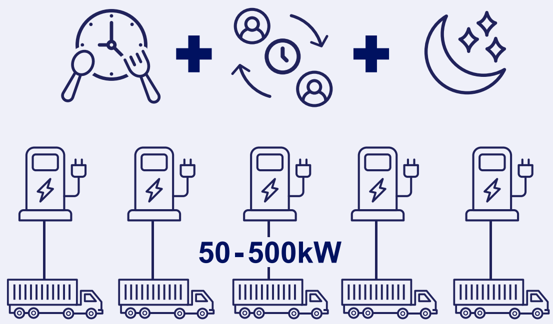
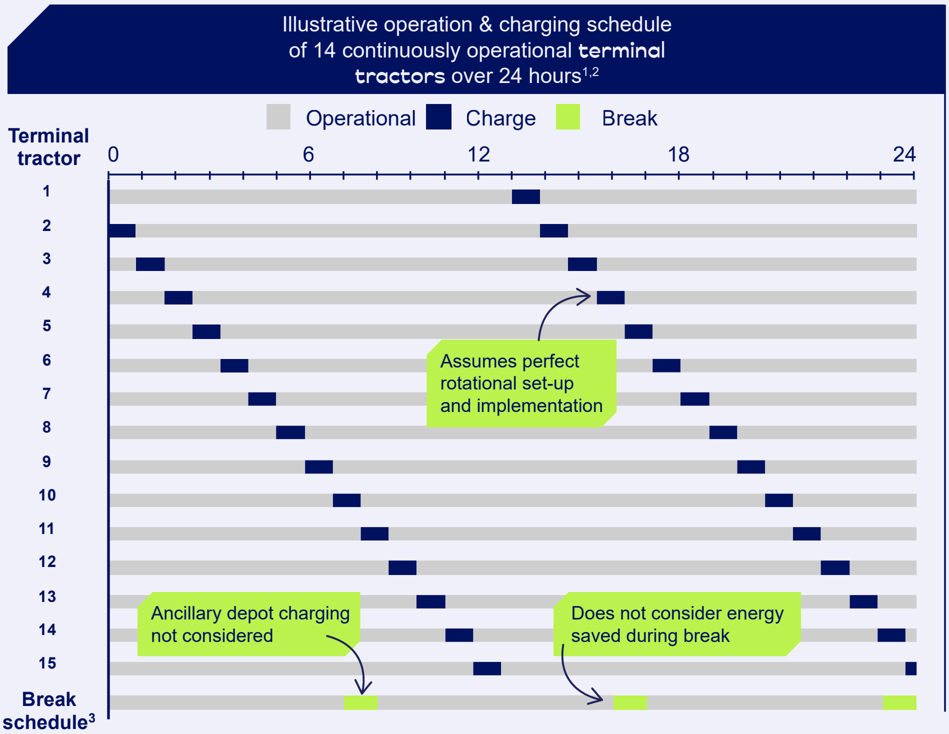
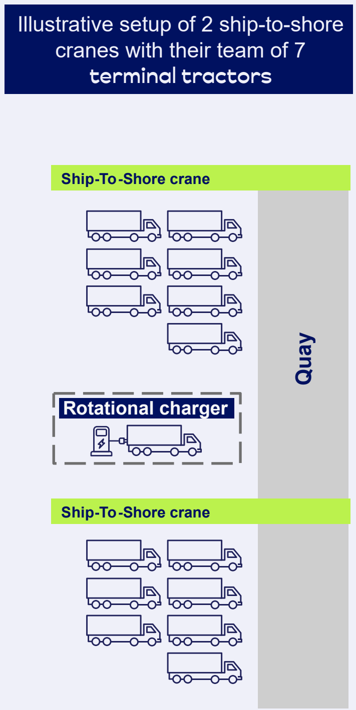


EXHIBIT G

Illustrative vehicle rotation charging set-up for terminal tractors

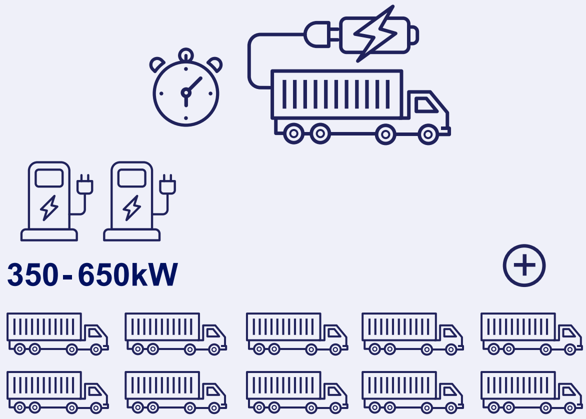




(1) One additional terminal tractor estimated for a fleet of 14 fulltime operational vehicles (2) ~50-minute charging + travel/set-up time estimated, effective battery use of 188 kWh per discharge cycle, charge rate of 250 kW (3) Based on 8-hour shifts including 1-hour breaks

Fast opportunity charging

BE-CHE charges quickly and frequently throughout operations, ideally during random periods of inactivity as well as scheduled breaks. Chargers are positioned at strategic decentralized locations where units of CHE have short breaks, such as loading zones, to maximize efficiency and minimize downtime. Converting idle time to charge time is especially challenging since exact location and duration of idling varies and is hard to predict. This strategy generally leads to a relatively flat electricity demand profile without major peaks.



Battery swapping

BE-CHE units swap batteries when the battery reaches a low state of charge during shifts. Operators maintain the same CHE throughout their shifts, eliminating the need for additional BE-CHE. Each swapping station can charge approximately 6 to 12 batteries simultaneously and serve around 20 to 70 CHE units in continuous operation. Swapping stations are typically located in central areas of the terminal, although there may be multiple locations to enhance accessibility and efficiency. Additional batteries are required to make battery swapping possible.This strategy generally leads to a relatively flat electricity demand profile without major peaks.

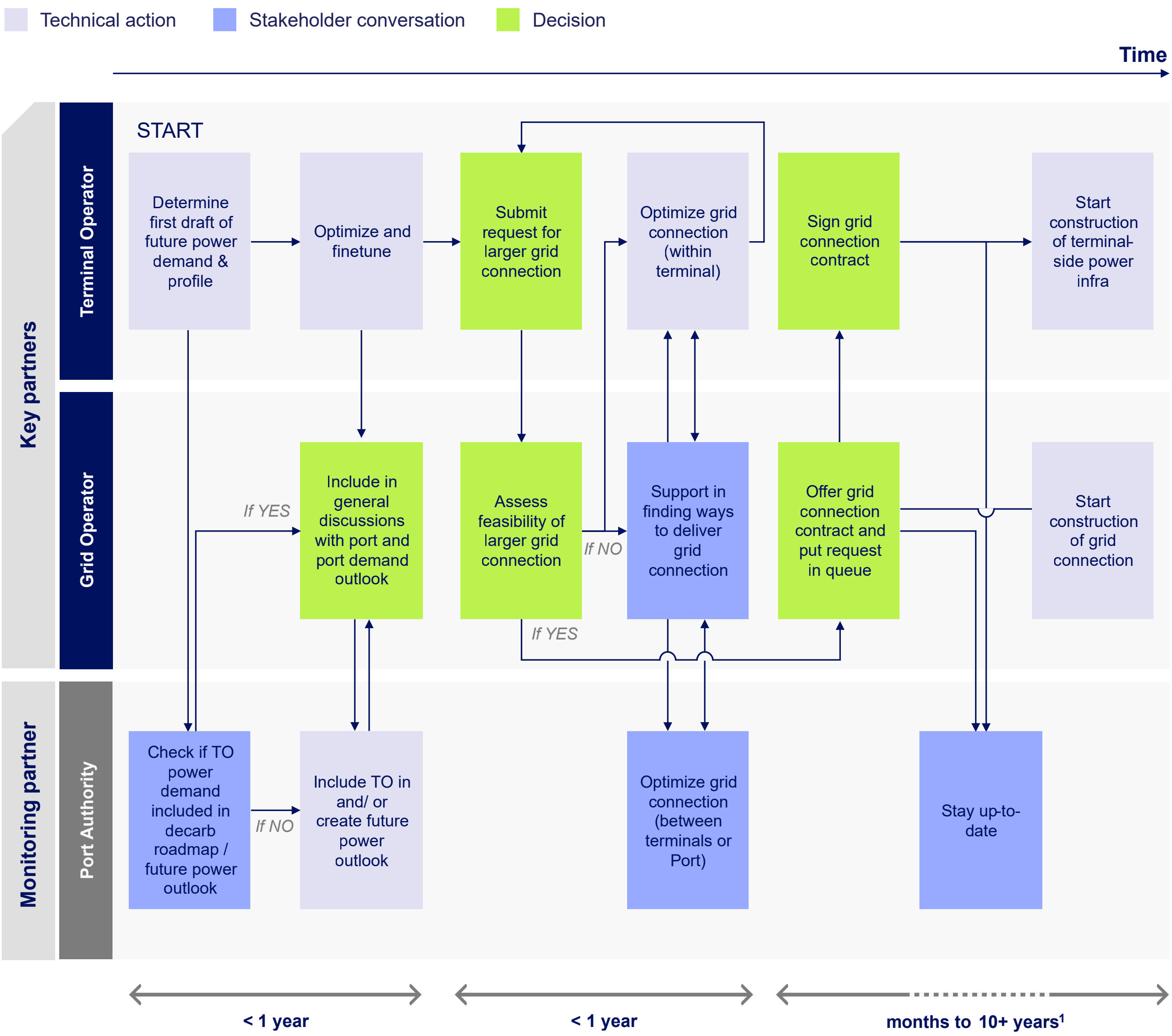
For more information on charging strategies, please check the ZEPA 2024 Voluntary Standards

3 High-level guide to process for securing power infrastructure

Following the steps in the process shown in Exhibit H will help to ensure that port community members undertake the necessary dialogues and data sharing to secure timely grid capacity. The Case Study on page 17 displays how a partnership between electricity network operators and a Port Authority can work in practice.

EXHIBIT H **The right dialogues and data sharing need to happen between stakeholders to ensure the timely availability of grid capacity.**

High-level guide to process for securing timely grid capacity



(1) Duration highly dependent on availability of grid capacity and therefore local conditions, if new transmission grid infrastructure is required, timelines can span 10+ years because of planning and permitting delays, regulatory issues around investment frameworks and supply chain issues, especially for crucial components such as transformers. Timelines for transmission grid infrastructure vary massively per country.
Source: Systemiq analysis based on ZEPA member input

ZEPA

CASE STUDY

Strategic Program Electricity Infrastructure

Working in partnership with electricity network operators TenneT, Stedin, Deltalinqs and the Port of Rotterdam are implementing a program to speed up electrification in the port and meet rising electricity demand from the port and industrial area. The program's main goals are to alleviate grid congestion by matching the area's electricity supply to rising demand as fast as possible and to develop a resilient, future-proof electricity infrastructure that can serve the area through to 2050.

Work for the program falls into three main strands: expediting construction of network infrastructure needed immediately; drawing up a long-term action plan for infrastructure to meet projected demand; and enhancing the flexibility of the existing grid to optimise its capacity to serve both current and anticipated customers.

Central to the program's rapid progress is the Port Authority's support for collaboration between network operators, which is enabling their alignment on common goals and cross-organizational planning. Involving energy experts in discussions on companies' electricity needs and their grid congestion issues has been similarly helpful, investing and generating such practical solutions as Group Transport Agreements, additional local generation, and flexible connections to alternative substations.

Central to the program's rapid progress is the Port Authority's support for collaboration between network operators

Research undertaken by the program's New Energy Taskforce, a joint initiative from TenneT, Stedin and Deltalinqs funded by the Port Authority, emphasizes the importance of collaboration between all partners in port electrification programs. The taskforce gathered information from across the range of the port's diverse energy users.

Key insights for other ports seeking sustainable infrastructure solutions to their complex electrification challenges are:

- **Set up a program management team** that includes representatives from all the interested parties in the port
- **Foster mutual understanding of each partner's interests** and collective alignment on roles, expectations, and responsibilities
- **Maintain regular, in-person meetings** (e.g., once a week) to sustain momentum and strengthen connections
- **Take enough time at the outset to establish a clear, shared vision** and plan for the program
- **Set up robust governance** with clear reporting lines and escalation pathways
- Ask all program partners to commit formally to **transparency and open data-sharing**
- Make sure the program has enough of **the right people to meet its objectives.**

Conclusion

The container terminal industry's expected transition to electricity-powered equipment is a cause for celebration. Achieving this milestone will catapult the whole port industry forward on its journey to zero emissions. But it poses a challenge to members of port communities worldwide: unless they prioritise meeting their surging power needs and collaborate on finding the best solutions, they will struggle to reach electrification targets on time.

Transition to electricity-powered equipment... will catapult the whole port industry forward on its journey to zero emissions.

This report has identified actions that terminal operators and other port tenants, port authorities and grid operators can take now to make sure their port has the grid infrastructure and load management practices it needs to support their rapid energy transition. Most urgently:

- Container terminal operators should quantify their growing power needs and share these projections with grid operators as soon as possible, so grid operators know when and by how much they may need to expand grid capacity
- terminal operators should adopt charging strategies for their expanding electric fleets that make best use of the power available from their individual grid connections
- Port Tenants and port authorities should work together on harmonizing power loads port-wide so collectively they make best use of available port-wide grid capacity.
- Moving these actions to the top of strategy agendas in ports is critical to realising the vision of all-electric container terminals by 2035 and the swift electrification of all other port tenants.

BACKGROUND

General word about ZEPA and its members

The Zero Emissions Port Alliance (ZEPA) is a cross-value-chain port alliance set up by its members to tackle BE-CHE adoption challenges together. Specifically, ZEPA aims to accelerate port decarbonization by making battery-electric container handling equipment affordable and accessible, and therefore implementable, within the next ten years.

Systemiq held the secretariat of ZEPA and provided analytical and organizational support throughout the development of this document.

Affordabitlity

Challenge: BE-CHE is currently more expensive than diesel CHE

Accessibility

Challenge: BE-CHE value chain does not have the scale required for a large roll-out, implementation is often complex

Attractiveness

Immediate benefits: BE-CHE immediately eliminates stailpipe emissions

LEVERS TO IMPROVE COMPETITIVENESS (FOCUS OF ZEPA)

- Technology learning effects
- Reduced charging downtime
- Standardisation & decoupling

- Scaled production capacity
- Standardisation & decoupling
- Power purchase agreements
- Workforce training

BENEFITS

- No scope 1 emissions
- Lower scope 2 emissions
- No air pollutants
- Lower levels of vibration & noise

ZEPA has 12 members whose activities span the container handling sector.

Acknowledgements

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- International Association of Ports and Harbors (IAPH)
- Port of Antwerp-Bruges
- Smart Freight Centre
- Portwise
- IAV
- EUROGATE
- K&L Gates

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Further Reading

This report is part of a three-report series by the Zero Emission Port Alliance, dedicated to making untethered battery-electric container handling equipment affordable and accessible by 2030. Together, these reports tackle key adoption challenges to accelerate port decarbonization and drive industry-wide innovation.

For further reading please see the other publications or see www.zepalliance.com

WORKSTREAM 1

Expected purchases for battery-electric container-handling equipment 2025-2035

WORKSTREAM 2

2024 Voluntary Standards for battery-electric straddle carriers and terminal tractors

WORKSTREAM 3

Strengthening port power infrastructure and electric load management so container terminals and ports electrify efficiently