



The State of Terminal Electrification: 10 lessons learned for container terminal operators

Why the challenge is shifting from buying electric equipment to designing an energy-aware terminal operation

Whitepaper

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1. Executive summary

Electrification has moved from a long-term sustainability ambition to a practical investment question for container terminals around the world. Electric quay and yard equipment is increasingly established, battery-electric horizontal transport is developing rapidly, shore power requirements are becoming more concrete, and terminal operators are being asked to make infrastructure decisions that will affect their operations for decades.

Decarbonisation remains an important driver. The International Maritime Organization's 2023 greenhouse gas strategy sets an ambition to reach net-zero greenhouse gas emissions from international shipping by or around 2050, with intermediate checkpoints for 2030 and 2040. In Europe, regulation is creating additional momentum. From 2030, certain container and passenger ships calling at covered EU ports will have to use on-shore power supply or an alternative zero-emission technology while at berth.

But another consideration has become increasingly difficult to ignore: energy resilience.

Recent disruptions to global energy markets demonstrate how exposed diesel-dependent operations remain to events far beyond the terminal gate. The Strait of Hormuz alone accounted for more than a quarter of global seaborne oil trade in 2024 and the first quarter of 2025, equivalent to around one fifth of global petroleum liquids consumption. During 2026, disruption to flows from the Gulf and through other strategic maritime routes again affected oil availability and prices. The International Energy Agency reported exceptionally high prices for middle distillates during the severe market disruption earlier in 2026.

This does not mean that electricity is inherently secure, inexpensive or immune to price volatility. An electrified terminal becomes dependent on grid availability, electrical infrastructure, power contracts and, increasingly, sophisticated energy management. The nature of the dependency changes.

For terminal operators, that matters. Electrification can reduce exposure to globally traded diesel and create opportunities to combine grid power with renewable generation, storage and more active energy management. At the same time, it introduces a completely new set of operational constraints.

This is the central lesson from Portwise's work on terminal electrification: **Terminal electrification is no longer primarily a technology question. It is an operational design question.**

Battery size affects charging. Charging affects equipment availability. Equipment availability affects fleet size. Fleet size affects capital expenditure and traffic. Charging power affects peak electrical demand. Peak demand affects grid infrastructure. Shore power competes for the same electrical capacity. And every one of these decisions ultimately affects terminal productivity and service levels.

Based on our work in terminal design, simulation, operational improvement and electrification, this paper presents ten lessons for operators considering the next stage of their energy transition.

2. Why electrification is becoming a strategic question

The conventional case for terminal electrification starts with emissions. Replacing diesel-powered equipment with electric alternatives eliminates local exhaust emissions from that equipment and can reduce overall greenhouse gas emissions, particularly where electricity is generated from lower-carbon sources. It can also reduce noise and change maintenance requirements. Those benefits remain important. But the strategic case is becoming broader.

Terminals are making investment decisions in an environment in which energy supply, energy cost and regulatory requirements are less predictable than they once appeared. Oil and refined fuels are internationally traded commodities. Their availability and price can be influenced by production decisions, refinery capacity, geopolitical conflicts and disruptions at maritime chokepoints thousands of kilometres from a terminal.

The Strait of Hormuz illustrates the scale of this exposure. In 2024 and the first quarter of 2025, more than one quarter of global seaborne oil trade passed through the strait. Around one fifth of global LNG trade also passed through Hormuz in 2024. The events of 2026 have provided a particularly visible energy vulnerability. The IEA's September 2026 Oil Market Report described continuing disruptions to normal oil flows associated with instability around the Gulf and Red Sea routes, and projected substantially lower global oil supply for 2026 than a year earlier.

Electrification cannot isolate a terminal from global energy markets. Electricity prices may themselves be influenced by natural gas prices, generation availability, transmission constraints and regulation. Grid congestion can become a significant operational limitation. A terminal that replaces diesel dependency with an inadequately designed electrical dependency has not solved its resilience problem. The opportunity is different.

Electricity gives terminals more options for how energy is sourced, stored, distributed and managed. Depending on the local situation, a terminal may combine grid supply with renewable generation, stationary battery storage, intelligent load management and equipment batteries. Energy therefore becomes something that can increasingly be designed alongside the operation.

That changes the terminal planning question from:

Which diesel equipment should we replace with electric equipment?

to:

How should we design an operational and energy system that can deliver the required terminal performance at an acceptable cost and risk?

That is a considerably more complex question.

2.1 Lesson 1. Start with efficiency, not electrification

The cleanest unit of energy is the unit that the terminal does not need to consume. This sounds straightforward, yet electrification programmes can easily begin with equipment procurement. A terminal identifies a diesel fleet, selects an electric alternative and then calculates the infrastructure required to operate that fleet. That may mean electrifying an inefficient operation.

Every unnecessary container move still requires energy when performed by an electric vehicle. Every avoidable travel distance still consumes battery capacity. Poor equipment dispatching still creates idle time and congestion. Inefficient yard planning still increases horizontal transport distances. Operational optimisation should therefore form part of the electrification baseline.

A Portwise review of terminal improvement studies carried out between 2007 and 2020 found that operational improvement measures could reduce estimated energy consumption by an average of approximately 12 to 16 per cent without investment in new technology. The measures included improved planning, better equipment deployment and reductions in unnecessary movements. This is an internal Portwise finding rather than a universal industry benchmark, but it illustrates the size of the opportunity. The implication is important. If a terminal can first reduce the amount of work its equipment needs to perform, it may subsequently require fewer batteries, fewer charging events, less grid capacity or fewer vehicles. Electrification and operational efficiency should therefore not be treated as separate sustainability programmes. They are part of the same design problem.

The practical question for operators: Before dimensioning the future electrical system, how much energy demand can be removed through better operations?

2.2 Lesson 2. Electrification maturity differs significantly by equipment type

There is no single technology maturity level for an electrified terminal. Electrification of fixed and semi-fixed equipment has been developing for many years. Quay cranes are already electrically powered at many terminals, while electrification solutions for yard cranes such as RTGs are well established in various configurations. Horizontal transport creates a different challenge. Terminal tractors, automated guided vehicles, straddle carriers and other mobile equipment combine high utilisation with variable travel distances, payloads and waiting patterns. They cannot simply remain connected to a fixed electrical supply. Batteries therefore introduce a new constraint: energy must be carried with the equipment.

Portwise has previously identified horizontal transport electrification as an area where the interaction between equipment technology and operations requires considerably more attention than for more established electric crane applications. Battery capacity, charging time, duty cycle and operational peaks all influence whether a particular solution works. The appropriate roadmap will consequently differ from terminal to terminal.

A terminal does not need to electrify everything simultaneously. In many cases, a phased transition aligned with equipment replacement cycles will be more realistic. During that transition, electric and conventional fleets may operate alongside one another. This creates its own planning requirements, but it also provides an opportunity to learn before committing the entire operation to one configuration.

The practical question for operators: Which equipment categories are sufficiently mature for our operation today, and which decisions should remain flexible until technology and operational evidence develop further?

2.3 Lesson 3. Grid capacity can become the new terminal capacity constraint

Container terminal planning traditionally focuses on physical and operational capacity. How many vessels can the quay handle? How much yard capacity is required? How many cranes, transport vehicles and gate lanes are needed? Electrification introduces another capacity dimension: electrical power. When equipment that previously carried its own energy in a diesel tank becomes dependent on electricity, the terminal's grid connection and internal distribution network become part of the production system. The issue becomes particularly important when several high-demand activities coincide. Quay cranes may be operating intensively while vehicles are charging, reefers continue consuming electricity and one or more vessels draw shore power. Average annual electricity consumption does not reveal this problem. The grid and electrical infrastructure must be able to respond to the required instantaneous load.

Portwise's work on electrification therefore considers the combined implications of electric equipment, charging infrastructure, shore power, terminal operations and existing grid capacity. Insufficient grid capacity can limit equipment deployment or require charging to be actively managed around terminal operations. For existing terminals, this deserves attention early in the electrification roadmap. Strengthening a regional connection, constructing new substations or changing the internal power distribution system may have considerably longer lead times than ordering new handling equipment. The future bottleneck may therefore sit outside the quay, yard or gate.

The practical question for operators: What is the maximum simultaneous electrical demand under realistic peak operations, and can the existing grid and terminal infrastructure support it?

2.4 Lesson 4. Charging strategy and fleet size are one decision

Battery-electric equipment creates a fundamental trade-off. A terminal can install larger batteries and operate equipment for longer between charging events. It can install higher-power chargers and recharge more quickly. It can introduce opportunity charging during naturally occurring idle periods. It can charge vehicles during longer breaks, or consider solutions such as battery swapping. None of these choices is independent.

If vehicles require long charging periods during operating hours, fewer units are available to perform container moves. Maintaining the required service level may therefore require additional vehicles. Purchasing more vehicles increases capital expenditure and may create additional traffic and parking requirements. Increasing charging power could reduce charging time, but may increase peak electrical demand and infrastructure requirements. Increasing battery capacity could reduce charging frequency, but changes vehicle cost, weight and potentially utilisation.

Portwise therefore models battery state of charge and equipment movements together rather than treating charging as a standalone technical calculation. Different battery sizes, charger quantities, charging powers and fleet sizes can be tested against the same operational requirements. The correct charging strategy is not the one that charges the battery fastest. It is the configuration that delivers the required operation with an acceptable combination of equipment, battery, infrastructure, energy and performance costs.

The practical question for operators: What combination of battery size, charging strategy, charger quantity and fleet size minimises total system cost while protecting terminal performance?

2.5 Lesson 5. Where equipment charges can matter almost as much as how fast it charges

Charging infrastructure occupies physical space. That immediately makes it a terminal design issue. A charger that looks convenient on a technical drawing may be operationally inefficient if vehicles need to deviate significantly from their normal routes to reach it. Repeated across thousands of equipment movements, small charging detours can create substantial dead mileage. Alternatively, placing chargers close to heavily used routes may create congestion or conflicts with other traffic. One of the most useful sources of information for charging design is therefore equipment idle-time behaviour. Terminal equipment does not move continuously. Vehicles wait at transfer points, queue for work, experience operational interruptions and stand idle during parts of a shift. By analysing where and for how long these idle periods occur, terminals can identify opportunities to charge batteries without creating an entirely separate activity.

Portwise uses this type of operational information to assess charger location and charging strategies. The principle is simple: fit charging into the operation where possible, rather than forcing the operation to fit around charging. For brownfield terminals in particular, this can become an

important design challenge because available space, existing traffic routes and electrical infrastructure severely constrain charger placement.

The practical question for operators: Where does equipment already spend sufficient time stationary, and can those locations be used to recharge without introducing new operational losses?

2.6 Lesson 6. The fastest charger is not automatically the best charger

Charging technology is often discussed in terms of power and speed. For an operating terminal, however, charging speed is only one performance variable. Faster charging can reduce vehicle downtime and potentially limit the need for additional fleet capacity. But higher charging power also creates larger instantaneous electrical loads. Multiply this by many vehicles charging simultaneously and the consequences for substations, cables, peak-demand tariffs and the grid connection can be significant. Conversely, lower charging power may reduce the electrical peak but require longer charging periods or additional equipment.

Alternative concepts add further choices. Opportunity charging can distribute charging throughout the operation. Battery swapping separates vehicle availability from battery charging time but introduces additional batteries, handling systems and operational processes. Emerging approaches such as automated or wireless charging may create advantages in particular environments, especially highly automated terminals, but introduce their own infrastructure and maturity considerations.

There is consequently no universally superior charging technology. The right comparison should consider the complete terminal system: equipment availability, battery degradation, charger utilisation, grid demand, infrastructure investment, terminal traffic and operational resilience. Technology should follow the operating concept.

The practical question for operators: Which charging technology produces the best terminal-level outcome rather than simply the shortest technical charging time?

2.7 Lesson 7. Peak power can matter more than total energy consumption

A terminal can consume the same amount of electricity in two scenarios while requiring very different electrical infrastructure. The difference is timing. Suppose a fleet consumes a given number of megawatt-hours during a day. If charging is distributed relatively evenly over 24 hours, the peak power requirement may be manageable. If much of the same energy is drawn during a two-hour window, the terminal may require a substantially larger connection and electrical installation. This distinction is fundamental to electrification planning.

Terminals are naturally variable environments. Vessel schedules create peaks. Large exchanges generate intensive yard activity. Shift patterns affect equipment availability. Shore power demand

depends on which vessels are alongside. Refrigerated containers create a relatively continuous load, while heavy equipment introduces more variable demand. Energy management must therefore become increasingly connected with operational planning.

Portwise has explored how scheduling and load management can redistribute electrical demand. Charging can be staggered, non-critical loads can be shifted, and energy storage may be used to buffer short periods of high demand. This does not mean the terminal should compromise vessel productivity in order to optimise an electricity bill. Operational service requirements remain the primary constraint. The opportunity is to identify where energy demand can move in time without affecting those service requirements.

The practical question for operators: Which electrical peaks are unavoidable consequences of the required operation, and which can be removed through better scheduling, charging control or storage?

2.8 Lesson 8. Shore power and terminal electrification cannot be planned separately

Shore power is sometimes approached as an infrastructure project at the quay. From an energy-system perspective, that boundary is artificial. A vessel using shore power becomes another significant electrical consumer within or adjacent to the terminal system. Its demand may occur precisely when the terminal is also operating at high intensity. The number of shore-power connections required therefore depends on much more than the number of berths. Vessel mix, berth allocation, port stay duration, compatibility, operational schedules and simultaneous calls all influence actual demand.

This is becoming increasingly relevant in Europe. FuelEU Maritime includes requirements for certain container and passenger ships to use on-shore power supply or another zero-emission technology at berth from 1 January 2030 in ports covered by the relevant Alternative Fuels Infrastructure Regulation requirements, with broader provisions following later. For terminal operators, the important question is what happens when shore power is combined with electric handling equipment. If both are dimensioned independently using conservative peak assumptions, a terminal may overinvest in infrastructure. If their combined demand is underestimated, the electrical system may become a constraint during precisely the busiest periods. Berth planning and energy planning therefore become increasingly interconnected.

The practical question for operators: What does the combined load profile of shore power, terminal equipment, reefers and other consumers look like under realistic vessel schedules?

2.9 Lesson 9. Electrification changes the operating model, not only the equipment

Diesel equipment contains a degree of energy independence. Once fuelled, an individual machine can generally operate without considering the energy needs of other machines. Electric equipment changes this relationship. Multiple machines share electrical infrastructure and frequently compete for charging capacity. The terminal must therefore coordinate two flows simultaneously: containers and energy. Dispatching decisions may need to incorporate battery state of charge. Equipment allocation may need to take charging locations into account. Maintenance teams require new electrical and battery competencies. Mixed fleets require different fuelling and charging processes. Energy management systems may increasingly interact with terminal operating systems. Peak demand may even become a variable in operational decision-making.

Portwise describes electrification as requiring changes in resource allocation, charging management, operational planning and staff capabilities. This shift has organisational consequences. In many terminals, energy procurement, engineering, operations, equipment maintenance and sustainability have historically been separate disciplines. Electrification creates dependencies between them.

A technically sound electrification strategy can therefore still fail if the organisation is not prepared to operate it. The transition plan should address people, processes, control systems and governance alongside physical infrastructure.

The practical question for operators: Who will be responsible for balancing operational performance, equipment availability and electrical demand once energy becomes part of daily terminal control?

2.10 Lesson 10. Test electrification dynamically before committing major CAPEX

The previous nine lessons all point towards the same conclusion. Terminal electrification consists of interacting variables. Battery size influences charging frequency. Charging frequency interacts with equipment utilisation. Charging time affects fleet availability. Fleet size affects capital expenditure. Charger position affects travelling distance. Charging power influences electrical peaks. Shore power creates additional demand. Vessel schedules determine operational peaks. Grid capacity constrains what can happen simultaneously. Changing one assumption can create effects elsewhere in the system. This is why static averages alone are insufficient for many electrification decisions.

A spreadsheet may calculate annual energy consumption. It can estimate how many hours an average vehicle operates and how much energy an average move requires. These calculations are useful during early-stage assessment. But terminals do not operate at averages. They operate through peaks, queues, vessel delays, equipment conflicts, changing travel distances, variable workloads and periods of intense activity followed by quieter intervals.

Dynamic simulation can reproduce these interactions over time. Portwise uses simulation to test equipment types, fleet quantities, battery sizes, charging strategies, charger locations, shore-power configurations and infrastructure alternatives under realistic operational scenarios.

The purpose is not to produce a perfect forecast. The purpose is to expose failure modes before investments are fixed. What happens if a vessel arrives late? Can the fleet recover its battery state after an unusually intensive period? What happens if several chargers are unavailable? Can shore power and equipment charging coexist during peak operations? How sensitive is the business case to electricity and diesel prices? These are scenario questions. They require a system view.

The practical question for operators: Which assumptions could materially change the business case or terminal performance, and have those assumptions been stress-tested dynamically before investment?

3. What is the state of terminal electrification today?

Taken together, these lessons suggest that the industry is moving into a new stage. The first stage was largely about possibility: can terminal equipment be electrified? For increasing categories of terminal equipment, the answer is now yes.

The second stage is about integration: how should electric equipment, batteries, charging, grid infrastructure, shore power and terminal operations work together? That challenge is much less standardised.

The broad direction is becoming clearer. Electrification will play an important role in terminal decarbonisation. International shipping is under increasing pressure to reduce emissions, regional regulation is accelerating shore-power deployment, and equipment manufacturers continue to develop electric alternatives.

At the same time, the events affecting energy markets in recent years add another dimension. Diesel dependence exposes terminal operations to a global supply chain that includes oil production, refining, international shipping and strategic chokepoints. Electrification can reduce part of that exposure, but only by creating a robust alternative. That means sufficient grid capacity, appropriate redundancy, sensible charging strategies and an understanding of local electricity markets. Where conditions allow, renewable generation and energy storage can add further options. In other locations, limited grid capacity or carbon-intensive electricity may weaken parts of the case.

The relevant question is therefore not whether an electric terminal is universally better than a diesel terminal. The question is: **What electrification configuration makes operational, economic and environmental sense for this terminal, in this location, over its investment horizon?**

4. A decision framework for terminal operators

Before making major electrification investments, a terminal should be able to answer six connected questions.

1. What operation are we actually trying to electrify?

Establish the expected throughput, vessel patterns, equipment movements, service levels, operational peaks and future growth scenarios.

2. How much energy can we avoid using first?

Identify operational improvements that reduce unnecessary moves, travelling distance, waiting and equipment hours before dimensioning new infrastructure.

3. Which equipment should be electrified, and when?

Consider technology maturity, replacement cycles, operational requirements and the implications of operating mixed fleets during the transition.

4. How will equipment obtain energy without reducing performance?

Test battery sizes, charging powers, charging locations, charging strategies and fleet quantities as one integrated problem.

5. Can the electrical system support the resulting operation?

Model total and peak demand across handling equipment, shore power, reefers and other terminal consumers. Assess grid capacity, internal distribution, storage opportunities and resilience.

6. Does the complete business case remain robust under uncertainty?

Test alternative assumptions for throughput, electricity costs, diesel prices, battery performance, equipment prices, grid constraints and regulatory developments.

The sequence matters.

Starting with equipment procurement and solving the remaining questions afterwards risks locking the terminal into an expensive configuration. Starting with the operation creates a different approach. First understand what the terminal needs to accomplish. Then determine the most efficient operational concept. Then calculate the energy required to support that concept. Only then should equipment and infrastructure be dimensioned.

5. From energy consumer to energy-managed terminal

Electrification will not make container terminal operations simpler. In many respects, it does the opposite. Diesel offers a remarkably convenient energy system. Fuel can be stored, transported and transferred quickly, and a fuelled machine can operate independently for many hours.

Electricity introduces more visible constraints. Power must be available at the right location and at the right time. Batteries have finite capacity. Charging takes time. Multiple assets share infrastructure. Grid connections cannot be expanded instantly. But electrification also creates an opportunity that conventional fuel does not offer to the same degree.

Energy can become actively integrated with terminal design and operations. Charging can respond to equipment demand. Storage can reduce electrical peaks. Renewable electricity can be produced locally where conditions permit. Equipment batteries may eventually become part of a wider energy-management system. Operational optimisation can reduce both handling costs and energy demand. Most importantly, electrification encourages terminals to think about energy as part of the operating system rather than simply as a commodity purchased after the operational concept has been designed.

That may be the most important lesson of the transition so far. The terminals that make the strongest electrification decisions will not necessarily be those that adopt electric equipment fastest. They will be those that understand the interaction between operations, equipment and energy best.

For terminal operators, the objective should therefore not be to electrify as much equipment as possible. It should be to design a terminal that remains productive, resilient and economically viable as its energy system changes. That is the real challenge of terminal electrification.

About Portwise

Portwise is a world-leading consultancy firm that combines extensive automation and operational knowledge with proven simulation tools to create a futureproof plan for port, terminal and warehouse operations.

Originally founded in 1996 as TBA, Portwise supports terminal operators and port authorities in making long-term decisions on terminal design, operations, automation and electrification. Dynamic simulation is used to test how equipment, infrastructure and operational strategies interact before major investments are committed.

Selected sources and AI

This paper draws on Portwise experience and published Portwise material concerning terminal electrification, decarbonisation, charging infrastructure, grid capacity, shore power, operational efficiency and simulation, including Portwise's terminal electrification methodology and its earlier research into energy savings through operational improvement.

External context has been checked against publications from the International Energy Agency, US Energy Information Administration, International Maritime Organization and European Commission. Current energy-market references relate specifically to circumstances observed in 2026 and should be updated if this paper is republished materially later.

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