Appendix C: Technology Applicability Scoring Methodology

This appendix describes the methodology staff used to determine Technology Applicability scores for the application of 3 zero-emission technologies to each of the 25 most common types of CHE found at California's seaports and intermodal railyards.

Staff performed this first-level screening of the 75 equipment-technology combinations to eliminate combinations that are not practical or unlikely to be technologically capable of meeting operational feasibility (duty cycle, power requirements) within 10 years and therefore did not warrant further assessment.

Technology Applicability has two components: Practicality and Technological Potential. These terms are defined in detail below, as is the full process for determining Technology Applicability. Each CHE-technology combination received a score of 0 or 1 for both Practicality and Technological Potential. To obtain a Technology Applicability score, the Practicality score of 0 or 1 was combined with the Technological Potential score of 0 or 1 to achieve a combined score of 0, 1, or 2.

Practicality and Technological Potential do not consider:

- Cost or availability of the equipment
- Cost or availability of the energy source (electricity or hydrogen)
- Cost or availability of the infrastructure to provide the energy source
- Refueling/charging logistics

These factors are considered for CHE-technology combinations that receive a Technology Applicability score of 1 or greater.

Practicality

Practicality is a gauge of whether a CHE-technology combination makes functional sense by meeting at least one of the following three criteria:

1. There is evidence of the zero-emission technology being used[1] for this type of equipment.
2. There is evidence of the zero-emission technology being used for *similar* equipment.[2]
3. The CHE-technology combination is feasible from a logistics or engineering perspective given the state of the zero-emission technology for similar equipment

[1] "Evidence of being used" means that there are articles, reports, or publications of demonstrations, tests, or prototypes between January 2020 and January 2025.

[2] Similar means equipment which is generally the same size with similar lift capacity. For example, forklifts, log stackers, reach stackers, side handlers, and top handlers are similar. RMGs, RTGs, and shuttle/straddle carriers are similar. AGVs, mobile cranes, utility trucks, and yard trucks are similar.

and there are no commercially available models of this CHE that use the other two zero-emission technologies. This addresses CHE-technology combinations in which:

a. The technology is available and *could* be applied to the equipment, but
b. There is no evidence of this happening, and
c. There are already commercially available zero-emission alternatives.

Staff applied the above criteria to each of the 75 CHE-technology combinations. If any of the above criteria applied, staff assigned a Practicality value of 1. Otherwise, a value of 0 was assigned.

For example, from a logistics perspective, it is not practical for a forklift to be continually tethered, or plugged in, to a grid-electric source. The amount of cable management arms, reels, and conduits would make the application impractical. While there are discussions about testing grid-electric technology on similar equipment,[3] there is no evidence of usage. Therefore, staff assigned grid-electric heavy lift forklifts a score of 0 for Practicality.

Alternatively, despite no demonstrations of hydrogen fuel cell log stackers, staff determined that it is feasible to produce a hydrogen fuel cell log stacker given 2025 fuel cell technology. Furthermore, hydrogen fuel cell technology has been demonstrated with similar equipment such as top handlers.[4] Therefore, staff assigned hydrogen fuel cell log stackers a Practicality score of 1.

The third criterion addresses CHE-technology combinations that are impractical in a demand-driven market. A product will not likely be developed if there are already functional and practical commercially available solutions. One example is battery-electric or hydrogen fuel cell RMGs. The technology exists in 2025 to make battery-electric or hydrogen fuel cell RMGs. However, the industry standard RMG is grid-electric, making the development and subsequent adoption of battery-electric or hydrogen fuel cell RMGs unlikely. Therefore, both battery-electric RMGs and hydrogen fuel cell RMGs received a 0 for Practicality. This same reasoning also applies to grid-electric ship-to-shore cranes. Due to the success of this zero-emission option, it has not been practical for industry to invest in the development of alternative zero-emission technologies for ship-to-shore cranes.

In general, battery-electric and hydrogen fuel cell technologies are practical for CHE with unpredictable routing or those that travel long distances. Grid-electric is practical for mostly stationary CHE or those with predictable operating paths. For some operations, highly mobile CHE would deplete batteries before an opportunity to charge is available, making

[3] See the discussion of two grid-electric technologies for on-road vehicles in the *Grid-Electric AGVs and Yard Trucks* section.

[4] For example, fuel cells allow the excavator to operate untethered from an energy source. Fuel cells will allow for quick filling times, like those of its diesel counterpart. Fuel cells are found in similar equipment. This is discussed further in the *Hydrogen Fuel Cell CHE* section.

hydrogen fuel cell technology practical for that application, even if no hydrogen fuel cell models are commercially available for that type of CHE.

Technological Potential

Technological Potential measures the likelihood that industry will continue to develop a zero-emission CHE-technology combination to be commercially available and meet the duty cycle and operational needs of the diesel equipment it is replacing within the next 10 years. Staff reviewed industry and scholarly reports and feasibility studies on technology development assessments of various CHE-technology combinations. Staff used the information in these assessments to determine Technological Potential.

Use of Technology Readiness Levels to Determine Technological Potential

The National Aeronautics and Space Administration originally developed the Technology Readiness Level (TRL) system for space programs. It has been widely adopted and adapted by the U.S. Department of Energy[5] and other organizations,[6] including CHE equipment manufacturers and seaports, to evaluate technology development and readiness. The system assigns a TRL from 1 to 9 depending on how far the technology is in the product development cycle. Table C-1 provides a summary of TRLs.

Table C-1: Technology Readiness Level Descriptions[7]

TRL	Stage of Development	Description
1-3	Early Research/ Proof of Concept	TRLs 1 to 3 represent the *research* part of research and development (commonly called R&D). TRL 1 starts with computer simulations and "paper studies." The development process then progresses towards TRL 3 when prototypes of sub-components are tested in a lab environment.
4-5	Technology Development	At TRLs 4 and 5, working prototypes of the full product are developed and tested in controlled, but relevant environments.

[5] U.S. Department of Energy, "Technology Readiness Assessment Guide: U.S. Department of Energy," October 12, 2009. Accessed May 13, 2025. *https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04/@@images/file*.

[6] Héder, M. (2017). *From NASA to EU: The evolution of the TRL Scale in Public Sector innovation*. The Innovation Journal: The Public Sector Innovation Journal, 2017(22(2)), 3.

[7] Adapted from The U.S. DOE TRL, see ibid. 310, Table 1 of Section 2.0. and TRL descriptions provided in the Australian Department of Defense brochure, "Technology Readiness Levels Definitions and Descriptions" (*www.dst.defence.gov.au/sites/default/files/basic_pages/documents/TRL%20Explanations_1.pdf*)

TRL	Stage of Development	Description
6-7	Technology Demonstration/ Pilot Testing	At TRLs 6 and 7, functional prototypes have been tested successfully in "real-world" conditions.
8	Commissioning	At TRL 8, the technology in its final prototype form has been proven to work in final environments with expected results. TRL 8 represents the end of system development.
9	Fully Operational	At TRL 9, the technology can operate in a full range of conditions and is in final form and is production-ready. The design is finalized, and all components are available and/or manufacturable.

TRLs describe product development, prior to production-level manufacturing. The next step after product development is manufacturing production and commercial availability.[8] When there was no evidence of commercial availability, staff used data from demonstration reports and applied the TRL methodology as described in The U.S. Department of Energy's *Technology Readiness Assessment Guide* to assign a TRL .[9]

When determining Technological Potential, staff assigned a score of 1 if the CHE-technology combination met one of the following criteria by the end of January 2025:

1. Commercially available.
2. A similar type of equipment using the same technology is commercially available.
3. Achieved TRL 4 or greater.
4. A similar type of equipment using the same technology achieved TRL 4 or greater.

TRL 4 represents the development of a functional prototype being tested in controlled, but relevant environments. The cutoff was chosen for two reasons.

1. Lack of public data below TRL 4 - early-stage projects often lack published literature due to industry competitiveness and volatility.
2. Development timeline constraints – Completing the product development testing at seaports and intermodal railyards for equipment below TRL 4 could require more than 10 years, making these technology applications impractical for near-term assessments.

[8] For example, the Australian Government Department of Defense description of TRL 9 uses the phrase, "ready for full commercial deployment" (see *www.dst.defence.gov.au*: *www.dst.defence.gov.au/sites/default/files/basic_pages/documents/TRL%20Explanations_1.pdf*)

[9] U.S. Department of Energy. "Technology Readiness Assessment Guide: U.S. Department of Energy," October 12, 2009. Accessed May 13, 2025. *https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04/@@images/file*.

Staff applied these criteria across the 75 CHE-technology combinations evaluated. If any criteria applied, a Technological Potential value of 1 was given. Otherwise, a value of 0 was assigned.

For example, while there are no commercially available hydrogen fuel cell off-road cranes, a 2023 project converted a Liebherr LR1200 electric crawler crane to run on hydrogen,[10] achieving TRL 8. Based on this, staff assigned a Technological Potential score of 1 for hydrogen fuel cell off-road cranes.

The Practicality and Technological Potential criteria intentionally overlap. Evidence of technology use is factored into both Practicality and Technological Potential. This overlap and potential double-scoring helps ensure that industry-supported CHE-technology combinations are assessed further if there is a close call with either Practicality or Technological Potential evaluation.

Calculating Technology Applicability

Table C-2 through Table C-10 show the Practicality and Technological Potential scoring for battery-electric CHE, grid-electric CHE, and hydrogen fuel cell CHE.

Table C-2: Battery-Electric Technology Applicability Scoring for Bulk Material CHE

CHE	Practicality	Technological Potential	Combined Score
Crane, Material Handling	1	1	2
Crane, Mobile	1	1	2
Crane, Mobile Harbor	0	0	0
Crane, Off-Road	1	1	2
Dozer	1	1	2
Excavator	1	1	2
Forklift, Heavy Lift	1	1	2
Forklift, Telehandler	1	1	2
Haul Truck	1	1	2
Loader or Loader-Excavator	1	1	2
Log Stacker	1	1	2

[10] Geert van der Klugt, "Crawler crane converted to hydrogen by Reedyk and Adrighem," Infrasite.nl, December 21, 2023. Accessed March 27, 2025. *https://www.infrasite.nl/bouwen/2023/12/21/rupskraan-omgebouwd-naar-waterstof-door-adrighem-en-reedyk/*.

Table C-3: Battery-Electric CHE Technology Applicability Scoring for Container CHE

CHE	Practicality	Technological Potential	Combined Score
AGV	1	1	2
Rail-Mounted Gantry Crane	0	1	1
Reach Stacker	1	1	2
Rubber-Tired Gantry Crane	1	1	2
Ship-to-Shore Crane	0	0	0
Shuttle and Straddle Carriers	1	1	2
Side Handler	1	1	2
Top Handler	1	1	2
Yard Truck	1	1	2

Table C-4: Battery-Electric CHE Technology Applicability Scoring for Facility Support CHE

CHE	Practicality	Technological Potential	Combined Score
Aerial Lift	1	1	2
Cone Vehicle	1	1	2
Railcar Mover	1	1	2
Utility Trucks, Other (fuel trucks, water trucks, etc.)	1	1	2
Utility Truck, Sweepers	1	1	2

Table C-5: Grid-Electric CHE Technology Applicability Scoring for Bulk Material CHE

CHE	Practicality	Technological Potential	Combined Score
Crane, Material Handling	1	1	2
Crane, Mobile	0	0	0
Crane, Mobile Harbor	1	1	2
Crane, Off-Road	1	1	2
Dozer	0	0	0
Excavator	1	1	2
Forklift, Heavy Lift	0	0	0
Forklift, Telehandler	0	0	0
Haul Truck	0	0	0
Loader or Loader-Excavator	0	0	0
Log Stacker	0	0	0

Table C-6: Grid-Electric Technology Applicability Scoring for Container CHE

CHE	Practicality	Technological Potential	Combined Score
AGV	0	0	0
Rail-Mounted Gantry Crane	1	1	2
Reach Stacker	0	0	0
Rubber-Tired Gantry Crane	1	1	2
Ship-to-Shore Crane	1	1	2
Shuttle and Straddle Carriers	0	0	0
Side Handler	0	0	0
Top Handler	0	0	0
Yard Truck	1	0	1

Table C-7: Grid-Electric Technology Applicability Scoring for Facility Support CHE

CHE	Practicality	Technological Potential	Combined Score
Aerial Lift	0	0	0
Cone Vehicle	0	0	0
Railcar Mover	0	0	0
Utility Trucks, Other (fuel trucks, water trucks, etc.)	0	0	0
Utility Truck, Sweepers	0	0	0

Table C-8: Hydrogen Fuel Cell Technology Applicability Scoring for Bulk Material CHE

CHE	Practicality	Technological Potential	Combined Score
Crane, Material Handling	1	1	2
Crane, Mobile	0	1	1
Crane, Mobile Harbor	1	1	2
Crane, Off-Road	1	1	2
Dozer	1	1	2
Excavator	1	1	2
Forklift, Heavy Lift	1	1	2
Forklift, Telehandler	1	1	2
Haul Truck	1	1	2
Loader or Loader-Excavator	1	1	2
Log Stacker	1	1	2

Table C-9: Hydrogen Fuel Cell Technology Applicability Scoring for Container CHE

CHE	Practicality	Technological Potential	Combined Score
AGV	1	1	2
Rail-Mounted Gantry Crane	0	1	1
Reach Stacker	1	1	2
Rubber-Tired Gantry Crane	1	1	2
Ship-to-Shore Crane	0	0	0
Shuttle and Straddle Carriers	1	1	2
Side Handler	1	1	2
Top Handler	1	1	2
Yard Truck	1	1	2

Table C-10: Hydrogen Fuel Cell Technology Applicability Scoring for Facility Support CHE

CHE	Practicality	Technological Potential	Combined Score
Aerial Lift	1	1	2
Cone Vehicle	1	1	2
Railcar Mover	1	1	2
Utility Trucks, Other (fuel trucks, water trucks, etc.)	1	1	2
Utility Truck, Sweepers	1	1	2