The Clean Jobsite:

A Decarbonization Guide for California Construction Site Operations

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1.0 Introduction: The Evolution Toward Low-Emission Construction

The California construction industry is at a pivotal turning point. As the state advances its ambitious carbon neutrality goals, the traditional, continuous-run diesel jobsite is undergoing a necessary evolution. Adopting a Battery Energy Storage System (BESS) is the core strategy for achieving immediate emissions reductions today while establishing the infrastructure for a fully zero-emission future. This guide provides a critical roadmap for construction professionals, focusing on the deployment of a safe, centralized BESS Hub to manage zero-emission assets and significantly reduce site-level combustion.

The transition to a Clean Jobsite represents a fundamental shift aligned with California's policy trajectory. This transition offers tangible operational advantages: significant cost reductions, improved community air quality, and enhanced competitiveness in a market increasingly defined by sustainability standards.

1.1 Defining the Clean Jobsite: Scope 1 and Scope 2 Emissions

To effectively decarbonize site operations, it is essential to first classify where the emissions originate, following the Greenhouse Gas (GHG) Protocol:

Emission Scope	Origin	Construction Examples (Emissions Targeted)
Scope 1	Direct Emissions from sources owned or controlled by the company.	Combustion of diesel in excavators, loaders, dozers, and cranes; Fuel consumption in temporary diesel generators.
Scope 2	Indirect Emissions from the generation of purchased energy (electricity, steam, heat, or cooling).	Purchased utility grid power used for trailers, tools, and charging equipment.

The transition framework provided here is designed to be flexible according to the realities of the specific jobsite. Where infrastructure allows, BESS can be utilized to achieve Zero Scope 1 Emissions, and in off-grid scenarios, BESS can dramatically reduce Scope 1 Emissions by pairing with a generator in Hybrid Mode. These site operation reductions combine with minimizing Scope 2 emissions by sourcing clean power to achieve a Clean Jobsite. In all cases, the BESS optimizes Scope 1 and 2 performance in alignment with decarbonization objectives.

1.2 Regulatory Framework: CARB and the 2035 Vision

The primary driver for the Clean Jobsite transition is a robust regulatory framework and the statewide push toward decarbonization led by the California Air Resources Board (CARB). California's objectives are clearly defined: achieving carbon neutrality by 2045 and accelerating strategies to reach 100% zero-emission from off-road vehicles and equipment operations by 2035, where feasible, as established by Executive Order N-79-20.(Executive Order N-79-20).

Financial and Competitive Advantage

- **Access to CORE and Federal Incentives:** State programs, such as the Clean Off-Road Equipment Voucher Incentive Project (CORE), provide critical, high-value subsidies and grants to offset the capital cost of electric assets, making Total Cost of Ownership (TCO) parity immediate. (For the latest eligible equipment list under CORE, see CA CORE Eligible Equipment Catalog). There may be federal or local incentives available as well.
- **Reduced Operational Costs:** Electric equipment typically has lower maintenance costs and lower "fuel" costs when charged with optimized or renewable power. BESS Hybrid Mode delivers immediate fuel savings and engine hour reduction.
- **Improved Worker Health, Safety, and Productivity (HSP) through infrastructure optimization, allowing generators to operate exclusively at their peak performance curve.** Eliminating continuous diesel generator noise and exhaust improves communication (reducing hearing protection demands in certain areas) and drastically lowers workers' exposure to carcinogenic particulate matter (PM2.5) and nitrogen oxides (NOx). A quieter, cleaner site leads directly to reduced fatigue, fewer missed communications, and increased overall productivity.
- **Enhanced Community Relations:** Jobsites utilizing the BESS approach significantly reduce noise pollution and air pollutants for much of the day, which is critical for securing permits and maintaining good standing in dense California municipalities.

1.3 A Step-by-Step Transition Framework for California Contractors and Managers

Decarbonization should be implemented as a staged, measurable process. This guide is structured around four interconnected phases designed to move the jobsite from a diesel-centric operation to a fully optimized Clean Power Hub.

The framework is organized as follows:

1. **Phase I: The Equipment Transition (Chapter 2):** Focusing on the shift from diesel to electric machinery and performing a Total Cost of Ownership (TCO) analysis.
2. **Phase II: The Energy Solution (Chapter 3):** Establishing the foundational power infrastructure by deploying a Safe Mobile BESS Hub and mastering BESS Hybrid and Grid-Optimized modes.
3. **Phase III: Asset and Resource Optimization (Chapter 4):** Applying data-driven management to optimize asset and resource utilization.
4. **Phase IV: Compliance & Incentives (Chapter 5):** Navigating California's regulatory landscape, maximizing federal and state financial incentives where available, and ensuring long-term project viability.

This phased approach ensures that critical infrastructure is established early, supporting the safe and cost-effective rollout of the electric fleet and achieving infrastructure optimization.

2. Phase I: The Equipment Transition: Reducing then Eliminating Scope 1 Emissions

2.0 Transitioning the Fleet: From Diesel to Electric Machinery

The core of a zero-emission jobsite is the replacement of the Internal Combustion Engine (ICE) with the electric motor. This transition is defined by the elimination of Scope 1 emissions from vehicles and equipment and is achievable today across nearly all light and medium-duty classes.

2.1 The Business Case for Electrification: Total Cost of Ownership (TCO)

While the initial sticker price of Zero-Emission Vehicles (ZEVs) and electric construction equipment is typically higher than their diesel counterparts, the long-term economics strongly favor electrification. Financial analysis must shift from initial purchase price to Total Cost of Ownership (TCO) over the asset's life cycle, a calculation immediately favorable in California due to high fuel costs and robust incentives.

A comprehensive TCO analysis compares the full ownership and operating costs of a diesel machine versus an electric machine, typically over a five-to-seven-year period. Many electric original equipment manufacturers (OEMs) have TCO calculators on their websites.

Key Factors in TCO: Electric vs. Diesel

Cost Component	Diesel Equipment (High)	Electric Equipment (Low)	TCO Impact
Fuel / Energy	High and volatile diesel costs (requires refueling logistics).	Lower, more stable electricity costs (especially if charged off-peak or via on-site solar). Immediate fuel savings in BESS Hybrid Mode.	**Significant Savings**
Maintenance	Extensive maintenance schedule (oil/ filter changes, exhaust systems, turbochargers, transmission).	Minimal maintenance (fewer moving parts, no fluids, long-lasting electric motor).	**Major Savings**
Government Incentives	None.	Subsidies, tax credits (e.g. IRA, CORE), and grants may accelerate adoption of zero-emission infrastructure.	**Reduces Initial Cost**
Downtime	Higher due to scheduled maintenance and component failures.	Lower due to fewer components and longer brake life (regenerative braking).	**Increases Uptime/ Revenue**
Engine Performance	Requires warm-up; torque is speed-dependent.	Instant, high torque from zero RPM; works better in high-duty cycles.	**Improved Productivity**

Example Savings: For a 20-ton mid-size excavator operating 1,500 hours per year, maintenance cost savings and energy cost savings can result in a TCO parity point within the first five years, especially when factoring in available incentives.

2.2 Overview of Zero-Emission Equipment Options

The market for electric equipment is rapidly expanding. Contractors should prioritize the electrification of machines that operate in dense urban areas, indoors, or on high-noise projects first, as the immediate benefits (noise reduction, air quality) are highest in these environments.

Immediate Adoption (Compact & Medium Duty)

These classes have achieved performance parity with diesel and are widely available from major OEMs, including Green Machine Equipment, Inc., Volvo, JCB, Cat, Komatsu, Bobcat, and Wacker Neuson.

Equipment Type	Typical Battery Runtime	TCO Readiness
Mini & Mid-Size Excavators (1.5t to 23t)	4–8 hours of work per charge.	High—Ideal for immediate replacement.
Compact Loaders & Skid Steers	4–6 hours of work per charge.	High—Excellent for indoor/ sensitive sites.
Compaction Equipment (Rammers, Vibratory Plates)	Full-day operation with swappable batteries.	Very High—Often uses shared battery platforms.
Telehandlers (e.g., 5- to 6-ton capacity)	Full-shift operation depending on duty cycle.	Medium/High.

Green Machine Electric Excavators

Get powerful performance with zero emissions—perfect for indoor, urban, or environmentally sensitive job sites. Designed with full auxiliary hydraulics, they offer the versatility operators expect while running quietly and cleanly for up to 8 hours on a single charge. Each unit fully recharges in just 8 hours on a standard 220V outlet, making all-day productivity simple and sustainable.

[View Inventory]

Heavy-Duty and Specialty Equipment

For heavy-duty and specialty equipment, the strategy shifts from simple battery replacement to a multi-technology approach that addresses high energy demands and long duty cycles.

- **Zero-Emission Destination Technologies:** For heavy-duty assets (25+ ton excavators, wheel loaders, and large haulers), hydrogen fuel cell technology provides a permanent, zero-emission pathway. By offering energy density and refueling speeds comparable to diesel, hydrogen is a critical long-term partner to the battery-electric fleet, ensuring that even the most energy-intensive operations meet California's long-term environmental objectives.
- **High-Efficiency Hybrid Solutions:** In applications where zero-emission platforms are still scaling, diesel-electric hybrids serve as a high-impact efficiency tool. These machines utilize advanced energy recovery (like regenerative swing and braking) to reduce fuel consumption by up to 40%. While not classified as zero-emission, they provide immediate Scope 1 reductions and represent a proven efficiency standard for heavy earth-moving.
- **The BESS Equipment Infrastructure Backbone:** Regardless of the machine's fuel source, a Safe Mobile BESS Hub is the essential backbone for heavy-duty sites. It provides the high-amperage "burst" power required for DC Fast Charging (DCFC) large electric fleets and handles the massive peak loads of tower cranes (700A+), which would otherwise require oversized, inefficient generators or costly utility grid upgrades.

While BESS are often associated with light-duty charging, they are foundational infrastructure for heavy-duty site operations for three primary reasons:

1. High-Amperage Peak Shaving: Heavy assets like tower cranes (700+) create massive, intermittent electrical spikes. A BESS "shaves" these peaks, allowing the site to operate on a much smaller, more efficient grid connection or generator that handles only the base load.

2. Support for DC Fast Charging (DCFC): Large electric excavators and haulers require high-kilowatt rapid charging to maintain full-shift productivity. A BESS acts as a "power reservoir," delivering the high-intensity energy needed for fast charging without overstressing the site's primary power source.

3. Operational Agility in High-Duty Cycles: In remote or infrastructure-heavy projects (e.g., bridge or highway work), the BESS allows for a mobile, self-sustaining power hub that follows the fleet, ensuring that zero-emission "refueling" is always available exactly where the heavy work is happening.

2.3 On-Site Charging Infrastructure Requirements

The shift to electric equipment necessitates a robust, reliable power strategy. Equipment procurement should consider BESS that support multiple charging standards, including Levels 1, 2 and 3 charging. Level 3 charging, or DC Fast Charging (DCFC), provides the most efficient charging for a jobsite and is best supported by a centralized BESS charging hub that can provide the necessary high-power AC output.

The BESS Hub must serve as a versatile power distributor, featuring multiple connection points to accommodate the entire jobsite's electrical needs:

- **High-Power Three-Phase (e.g., 208V, 480V, 400V Cam-Locks):** Used to power large temporary loads, such as external DCFC units, tower cranes, and high-demand welding equipment.
- **Medium-Power Single-Phase (e.g., NEMA 14-50R, CS Twist Locks):** Used for standard Level 2 charging of lighter-duty vehicles, site trailers, and temporary power distribution panels.
- **Utility Single-Phase (e.g., NEMA 5-20R):** Used for standard 120V site tools, lighting, and small power demands.

3. Phase II: The Energy Solution: Adopting the Safe Mobile BESS Hub

3.1 Why BESS are Essential: The Foundational Energy Backbone

The greatest operational challenge in zero-emission asset adoption is providing sufficient, reliable, and clean electrical power to charge it. Traditional diesel generators are defined by continuous operation and low efficiency, creating a mismatch for the intermittent power needs of a modern site. The BESS solution addresses this by immediately moving the site from continuous, high-emission power to managed, clean power sourced from any input.

BESS units provide a modern, flexible solution, acting as a smart, quiet power buffer and central charging station. They are capable of accepting charge from utility grid connections, high-efficiency generators, or on-site renewable sources, including solar. Additionally, multiple BESS can be connected to form a microgrid, maximizing the availability of clean power and providing the permanent, smart infrastructure required for operational resilience.

The BESS enables sophisticated power models—including Hybrid Mode—to achieve comprehensive Infrastructure Optimization:

Power Model	Technical Role	Strategic Benefit
Optimized Hybrid Operations	Utilizing the BESS Hybrid Mode allows a generator to run only at its peak efficiency to recharge the system.	Immediate Efficiency: Minimizes fuel consumption and engine hours by up to 80% on off-grid sites.
Grid-Integrated Storage	The BESS charges from the grid during off-peak hours and discharges during expensive peak windows.	Load Management: Stabilizes the local grid and eliminates "Demand Charge" cost spikes.
Clean Power Hub	The BESS is charged solely by clean, onsite sources (e.g., solar) or green-tariff grid power.	Zero-Emission Objective: Achieves a fully decarbonized, self-sufficient jobsite.

- **Infrastructure Optimization via Hybrid Mode:** For remote or off-grid operations, the BESS Hybrid Mode provides an immediate, practical solution for reducing fuel consumption, noise, and maintenance. By restricting generator use to short intervals of optimal, full-load run-time, the system ensures combustion assets operate at peak efficiency while the BESS handles the primary site demand.
- **Strategic Grid Integration:** For urban sites with utility access, and sites with temporary power poles, the BESS manages the grid connection to maximize cost-efficiency. By absorbing power during off-peak hours and discharging it during peak demand windows (leveraging Time-of-Use rates where feasible), the system acts as a financial buffer against utility price spikes. This model also facilitates the use of green-tariff electricity, effectively reducing or eliminating Scope 2 emissions.
- **Solar Integration:** Deploying solar canopies or mobile arrays allows the BESS to be charged with locally generated, clean power, further minimizing reliance on external power sources and achieving near-zero Scope 2 emissions, thus completing the transition to the Clean Power Hub. Multiple BESS can be connected to form a microgrid powered by clean energy.

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Viridi's RPS1200 containerized Battery Energy Storage System is the latest and largest unit in the Fail-Safe family.

3.2 Mobile BESS: Functionality and Safety Imperatives

The charging infrastructure required for a clean jobsite is distinct from standard EV charging and often involves mobile, high-voltage solutions. When selecting a BESS, functionality must be paired with proven safety protocols to protect workers and assets.

3.2.1 Key Infrastructure: BESS as the Smart Power Hub

Versatile AC Output: High-quality BESS units provide flexible, integrated AC power distribution capable of supporting the entire jobsite load. The BESS functions as a central switchboard, offering multiple connection types simultaneously to eliminate the need for complex temporary distribution.

Power Optimization: Advanced telemetry systems monitor the BESS charge level, input source (Grid, Generator, Solar), and equipment charging needs in real-time. This dynamic management prevents equipment downtime, minimizes reliance on external power during critical phases, and optimizes charging during off-peak utility hours to minimize costs. Intelligent controls ensure the generator is only activated when necessary and runs at peak efficiency.

3.2.2 Prioritizing Safety: The Clean Jobsite Standard

As BESS contain substantial energy, safety is non-negotiable. Contractors must select units built to the highest safety and certification standards, as robust engineering directly mitigates operational risk.

Key safety features to look for in a BESS solution:

1. **UL Certification (UL 9540):** Mandatory for fire safety. Ensures the BESS enclosure, battery management system (BMS), and thermal runaway mitigation features meet stringent safety standards.
2. **Advanced Thermal Management:** A comprehensive liquid or air-cooling system designed to maintain optimal battery temperature and prevent thermal runaway within the cell arrays.
3. **Fire Suppression Systems:** High-quality BESS units with 1+ MWh of capacity should include multi-stage fire suppression (e.g., aerosol or gaseous systems) engineered for fast activation in the event of an internal fault.
4. **Robust Enclosure and Monitoring:** BESS should have durable, tamper-resistant enclosures with continuous remote monitoring of voltage, current, temperature, and ventilation to detect anomalies before they become critical.

Choosing a certified, intelligently managed BESS manufactured by a company that prioritizes testing and safety ensures operational efficiency while mitigating the risks associated with high-density power storage on the jobsite.

3.3 Sizing the Clean Power System: A Practical Methodology

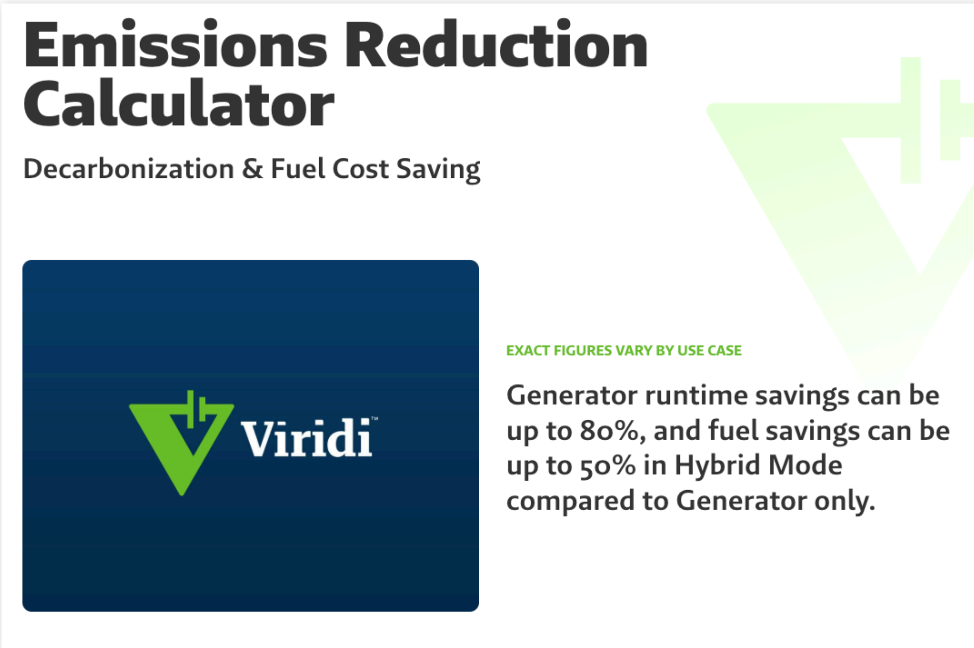
Successfully deploying BESS on the jobsite requires precise capacity planning. The goal is to select a BESS size (measured in kWh for capacity and kW for output) that can handle the full site load and charging demand for the desired duration while minimizing generator run-time in off-grid applications. Depending on the power requirements of the jobsite, multiple BESS may be needed. In such cases, the BESS selected should be capable of forming a microgrid and operating effectively as a single BESS.

See Appendix I for a step-by-step methodology for determining the size of the BESS needed to power the jobsite.

3.3.3 Emissions Reduction Calculator

Understanding the emissions reductions and fuel cost savings of utilizing a BESS in Hybrid Mode is a critical part of the energy transition. While exact figures vary by use case, in general terms, generator runtime savings can be up to 80%, and fuel savings can be up to 50% in Hybrid Mode compared to the Generator-Only scenario. The reduction in CO2 emissions directly corresponds to the reduction in fuel consumption.

To estimate CO2 emissions reductions, the amount of fuel saved in Hybrid Mode is multiplied by the appropriate coefficient for the given fuel type, as found on the [EIA Carbon Dioxide Emissions Coefficients list]. As shown on the list, each gallon of diesel fuel consumed produces 22.5 pounds of CO2. A 56-kW generator consumes 3.5 gallons of fuel per hour at 75% load. Operating over a 4-hour period, this generator produces 315 pounds of CO2. Switching to Hybrid Mode and reducing the fuel consumption by 50% saves 157.5 pounds of CO2 from being emitted.



[Visit: Viridi Emissions Reduction Calculator](https://viridiparente.com/emissions-reduction-calculator/)

(https://viridiparente.com/emissions-reduction-calculator/)

Appendix II provides a detailed mathematical model for calculating run-time, fuel and emissions reductions in Hybrid Mode.

Decarbonization & Fuel Cost Saving Scenarios

Scenario 1: A 5-kW load must be supported for 120 hours.

In the Generator-Only scenario, a 36-kW generator operates continuously between idle and 25% load for the duration of the time period, burning approximately 0.81 gallons of fuel every hour. The total fuel consumption for this scenario is about 97 gallons, producing approximately 2,183 pounds of CO_2.

In Hybrid Mode, a 150-kWh, 30-kW BESS is paired with a 56-kW generator. The BESS is able to support the load for more than 85% of the time. For the remaining 15% of the time, the generator must support the load while charging the BESS, leading to an estimated load between 50% - 75% and a fuel consumption rate of 3.05 gallons per hour for approximately 17 hours. The total fuel consumed in this scenario is just over 52 gallons, producing 1,188 pounds of CO_2.

The total savings for this scenario are:

- 103 hours of runtime (85.8% reduction)
- 44.79 gallons of fuel (46.14% reduction)
- 1,005.5 pounds of CO_2 (46.14% reduction)

Scenario 2: A 20-kW load must be supported for 120 hours.

In the Generator-Only scenario, a 100-kW generator operates continuously at 25% load for the duration of the time period, burning approximately 2.34 gallons of fuel every hour. The total fuel consumption for this scenario is 300 gallons, producing 6,322.5 pounds of CO2.

In Hybrid Mode, five 150-kWh, 30-kW BESS are connected in a microgrid capable of discharging 150-kW. These BESS are paired with a 250-kW generator. The BESS microgrid is able to support the load for more than 88% of the time. For the remaining 12% of the time, the generator must support the load while charging the BESS, leading to an estimated load between 50% - 75% and a fuel consumption rate of 11.5 gallons per hour for approximately 14 hours. The total fuel consumed in this scenario is approximately 162 gallons, producing 3,645 pounds of CO2.

The total savings for this scenario are:

- 106 hours of runtime (88.2% reduction)
- 118.56 gallon (42.22% reduction)
- 2,661.67 (42.22% reduction)

4. Phase III: Asset and Resource Optimization

4.0 Intelligent Dashboards for Fleet and Asset Management

The transition to electric fleets with a central BESS hub generates a massive amount of real-time data on battery health, charge status, and utilization patterns. Leveraging this telematics data is essential for maintaining productivity.

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Utilization Tracking: Digital platforms track the utilization hours of electric assets vs. remaining battery capacity, preventing unexpected downtime and optimizing charging schedules. BESS telemetry systems can integrate here to provide a holistic view of energy availability across the site.

Jobsite Flow Optimization: Data analytics can identify inefficiencies in equipment movement (e.g., long travel distances for loaders, unnecessary machine idling). Optimizing the placement of charging hubs and the staging of materials can significantly reduce travel time and maximize payload efficiency, leading to less energy consumption overall.

5. Phase IV: Compliance & Incentives

5.0 Strategic Alignment: Policy Frameworks, Incentives, and Investment Readiness

The successful adoption of a clean jobsite requires a clear understanding of the California regulatory timeline, available subsidies, and modern financing mechanisms.

5.1 The Regulatory Landscape: Local and State Frameworks

The CARB 2035 off-road equipment goals represent a major pillar of California's environmental policy. Beyond state-level objectives, local jurisdictions are increasingly adopting standards that prioritize quiet, emission-free operations. For contractors, staying ahead of this regulatory outlook is key to maintaining a competitive edge and ensuring seamless project approvals.

5.1.1 On-Site Requirements and Standards

Noise and Air Quality Standards: Strict ordinances in major California metropolitan areas (e.g., Los Angeles County, San Francisco Bay Area) create a natural advantage for electric equipment and the near-silent operation of a BESS hub. As local standards tighten, traditional permits for continuous diesel generation are becoming increasingly complex to secure.

Client and Project Criteria: Public and private developers are now integrating decarbonization targets directly into their procurement processes. Bidding successfully often requires a detailed Site Decarbonization Plan that demonstrates how the project will minimize its carbon footprint.

5.1.2 Connecting the Clean Jobsite to the Clean Building: Title 24 Solar Standards

California's Title 24, Part 6 (Energy Code) represents the state's commitment to high-efficiency, electrified buildings. By requiring new residential and commercial construction to integrate renewable energy and storage, these standards reinforce the long-term shift toward electrification. Mastering on-site BESS deployment during construction is a direct precursor to the permanent energy systems that define modern California infrastructure.

5.1.3 Verifying Local Codes for BESS Placement and Use

The deployment of a high-energy BESS unit on a temporary jobsite is regulated not only by state environmental agencies but also by local fire departments, building, and planning departments. Failure to secure the proper permits can result in costly work stoppages and fines. Prior to placing BESS at a jobsite, consult with the appropriate advisors to ensure compliance with local codes.

5.2 Strategic Investment: Maximizing Incentives for Equipment and Infrastructure

In some circumstances, there may be financial incentives at the federal, state, and local levels to accelerate the adoption of electric equipment and BESS infrastructure. These incentives may come in the form of credits, rebates, vouchers or other incentives, with varying eligibility rules and compliance requirements. As of the time of this guide's publication, BESS may qualify for federal tax credits through the Inflation Reduction Act (IRA), including additional bonuses for domestic content and geographic deployment. Adherence to domestic sourcing and Foreign Entity of Concern (FEOC) guidelines ensures that the jobsite's energy infrastructure contributes to national supply chain resilience while maximizing available federal investment credits. Consult with advisors to understand what incentives may be available based on the jobsite's specifics.

In addition to potential federal incentives, the State of California provides robust, direct financial support for equipment purchase and infrastructure development through multiple, often stacked, programs:

1. Equipment Purchase Grants (CORE)

The Clean Off-Road Equipment Voucher Incentive Project (CORE) provides direct grants that cover a significant portion (sometimes up to 50%) of the incremental cost of electric machinery over the diesel equivalent. CORE is the primary funding mechanism for equipment acquisition and prioritizes specific equipment categories (like compact loaders and excavators) with rolling application windows. Check CORE's website for eligibility rules and voucher availability.

2. Infrastructure Vouchers

CORE Infrastructure Add-on Vouchers: CORE is not just for equipment; it offers supplemental vouchers specifically for the charging or refueling infrastructure (the charger or BESS unit) needed to support the new zero-emission asset purchased simultaneously. This bundling streamlines financing and ensures contractors acquire an operable system immediately.

5.3 Capitalizing on Modernization

Traditional equipment financing models may not adequately address the higher upfront cost of electric fleets. Some modern financial strategies include:

Leasing and Service Models: Utilize operating leases that shift the risk of battery degradation or obsolescence away from the contractor. Newer "Equipment-as-a-Service" (EaaS) models bundles the machine, charging infrastructure, and maintenance into a predictable monthly fee. Major equipment rental houses offer electric equipment for both short- and long-term rental.

Sustainability-Linked Loans (SLLs): These specialized loans offer lower interest rates to contractors who meet pre-defined Environmental, Social, and Governance (ESG) targets, such as achieving a specific percentage of electric fleet utilization or documented Scope 1 reduction.

Green Bonds: Large contractors may issue green bonds to raise capital specifically for financing fleet electrification and clean power assets.

6. Conclusion and Resources

6.1 Conclusion: Securing the Future Jobsite

The transition to a clean jobsite, centered on the Battery Energy Storage System (BESS), is a strategic imperative for long-term viability and alignment with California's evolving energy standards. The BESS serves as the intelligent heart of the site, providing the high-power AC distribution necessary to support a modern electric fleet while significantly reducing fuel costs and emissions. By leveraging state and federal incentives today, construction firms can lead the industry toward a quieter, cleaner, and more efficient future. As the state moves toward its 2035 and 2045 objectives, the most resilient contractors will be those who have already established a BESS-centric power strategy.

6.2 Glossary of Key Terms

Term	Definition
BESS	**Battery Energy Storage System.** Mobile, large-capacity battery units that replace diesel generators for site power and charging. **Must be UL 9540 certified for safety.**
CARB	**California Air Resources Board.** The state agency responsible for setting and enforcing air pollution and climate mandates.
CORE	**Clean Off-Road Equipment Voucher Incentive Project (California).** A key state grant program providing significant discounts on the purchase of zero-emission construction equipment.
HVO	**Hydrotreated Vegetable Oil.** A renewable diesel fuel alternative that significantly reduces life-cycle emissions in conventional diesel engines.

IRA	**Inflation Reduction Act of 2022.** This act may provide significant tax credits for Battery Energy Storage Systems (BESS) through the Investment Tax Credit (ITC), with a base credit up to 30% and additional credits potentially available.
Scope 1	Direct greenhouse gas emissions from sources owned or controlled by the company (e.g., burning diesel in an excavator).
Scope 2	Indirect emissions from the generation of purchased energy (e.g., the electricity used to charge equipment).
TCO	**Total Cost of Ownership.** A comprehensive financial analysis that includes purchase price, fuel/energy, maintenance, downtime, and resale value over the asset's life.

6.3 Directory of Resources

CARB Off-Road Regulation Information: (Source: **CARB Website**)

CORE Program: (Source: California **CORE Website**)

EIA Carbon Dioxide Emissions Coefficients : (Source: **EIA Website**)

Inflation Reduction Act of 2022: (Source: **IRS Website**)

Viridi Total Solution (**https://viridiparente.com/products/**)

Emissions Reduction Calculator (**https://viridiparente.com/emissionsreduction-calculator/**)

Appendix I: Determining BESS Size for Powering the Jobsite

Information Needed for BESS Sizing

1. Aggregate Power Demand (kW) - including all constant loads
2. Shift Duration (hrs.) including equipment break times
3. Battery Energy Storage System (BESS) capacity, voltages, and charge/discharge rates

Once these are established, calculate:

- Energy required per shift (kWh)
- Energy required for constant loads (kWh)
- Charging windows and power rating (kW)

Key Takeaways

- Match BESS charge power to available charging windows.
- Ensure overnight charging can restore full SOC before next shift.
- Factor in all electrical loads (e.g. electric equipment and appliances) for aggregate demand.
- Factor in start-up load versus operating load when using the BESS to power appliances such as air conditioners or refrigerators:

  Surge current needed to start motors is significantly higher than operating load.

  Check appliance manuals for temporary start-up load.
- Utilize BESS intelligent dashboards to plan recharging operations.
- Group equipment by charging voltage to determine quantity of BESS needed:

  A single BESS can charge multiple pieces of equipment at a single charging voltage up to its Max Discharge Power Rating (see Example Scenario 2 below).

Example Scenario 1:

On Day 1, a construction site requires charging for one 25 kWh excavator (6 hours of operation), with charging during lunch and overnight.

Step 1: Gather Key Data

- Excavator Battery Capacity: . . . . .25 kWh (from datasheet)
- Excavator Input Voltages: 120/240/480V

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- Excavator Max Power Output Rating: . . . . . . .7 kW (from datasheet)
- Excavator Max Power Input Rating:. . . . . .15 kW (from datasheet)
- Excavator Operating Schedule:
  - *Morning Shift: . . . . .3 hours (DISCHARGE)*
  - *Lunch break:. . . . . .1.5 hour (CHARGE)*
  - *Afternoon Shift: . . . . .3 hours (DISCHARGE)*
  - *Overnight: .12 hours (CHARGE)*
- BESS Voltage: . . . . .480 V (from datasheet)
- BESS Max Discharge Power: . . . . .30 kW (from datasheet)
- BESS Capacity: . . . . .150 kWh (from datasheet)

Step 2: Calculate Energy Consumption

Excavator Max Power Output (kW) X Discharge Time (hrs) = Energy Consumed (kWh)

- Morning Use: . . . .*7" kW"×3" hrs"=21" kWh"*
- Afternoon Use: . . . .*7" kW"×3" hrs"=21" kWh"*
- Total Daily Consumption: . . . .*21 kWh+21 kWh=42" kWh"*

Step 3: Charging Strategy

- Lunch Break Charging (1.5 hrs):
  - *BESS Output Voltage = 208/480V*
  - *BESS Discharge Power = 30 kW (@ 480V)*
  - *Excavator Max Input Power = 15kW*
  - *CHARGE: 1.5 hrs x 15kW = 21 kWh added*
  - *Excavator energy after lunch = Starting excavator battery capacity (kWh) – Morning Consumption (kWh) + Lunch Break Charging (kWh) 25 kWh-21 kWh+21 kWh=25" kWh" (Maximum capacity reached)*
- Excavator Energy at End of Day = Starting Capacity After Lunch – Afternoon Consumption
  - *25 kWh-21 kWh=4" kWh" remaining*
- Overnight Charging:
  - *12 hours available*
  - *At 15 kW, full recharge in 1-2 hours*

Step 4: Calculating Remaining BESS Energy

Starting BESS Energy Capacity (kWh) – Total Energy Discharged During Charging (kWh) [Lunchtime Charging + Overnight Charging] = Remaining BESS Energy (kWh)

150 kWh – (21 kWh + 21 kWh) = 108 kWh remaining after charging one excavator for one 6-hr workday

Example Scenario 2:

On Day 2, add a second, identical 25 kWh excavator to the operation, with the same 3-hr morning shift, 1.5-hr lunchtime charging, 3-hr afternoon shift, and overnight charging. Refer to Step 1 above for Excavator Key Data.

To determine whether two pieces of equipment can be simultaneously charged, check the following:

- Charging voltage: Must be the same for all equipment

  Scenario 2: both have 480 V charging.
- Aggregate Power Demand (kW): Must be less than or equal to BESS Discharge Power.

  Scenario 2: 15 kW + 15 kW = 30 kW Combined max input power
- BESS Discharge Power: Must be greater than or equal to Aggregate Power Demand.

  Scenario 2: 30 kW = 30 kW

To determine when the BESS will need to be recharged, calculate:

- Day 2 BESS Starting Capacity (from Step 4 above): 108 kWh
- Day 2 Lunchtime Charging Discharge: 21 kWh x 2 Excavators = 42 kWh
- Day 2 Overnight Charging Discharge: 21 kWh x 2 Excavators = 42 kWh
- Remaining BESS Energy After Day 2: 108 kWh – (42 kWh + 42 kWh) = 24 kWh

Assuming the BESS has not been used to charge anything else, there is enough capacity to charge one excavator after a 3-hr shift, or two excavators after a 1.5-hr shift. After that time, the BESS will need 3-4 hours to fully recharge.

Appendix II: Mathematical Model for Hybrid BESS/Generator System

1 Variable Definitions

Symbol	Description	Unit
L	Average Load	kW
P_{gen}	Generator Capacity	kW
C_{limit}	Max Battery Charge/Discharge Rate	kW
H	Total Operation Time	hr
$F(x)$	Fuel Rate at Load x (see Appendix)	gal/hr

2 Feasibility Checks

2.1 Primary Capacity Check

The generator must be capable of supporting the average load continuously.

- **Condition:** If $L > P_{gen}$
- **Result:** System failure.

2.2 Hybrid Mode Check

If the average load exceeds the max discharge rating of the BESS, the generator can never turn off.

- **Condition:** If $L > C_{limit}$
- **Result:** The generator must run 100% of the time ($Runtime = H$).
- **Savings:** None.

3 Calculation Algorithm

3.1 Step 1: Determine Effective Charge Rate (P_{charge})

The actual rate at which the battery charges is limited by either the battery's maximum charge rate (C_{limit}) or the generator's spare capacity (after covering the load).

$$P_{charge} = \min(C_{limit},\ P_{gen} - L)$$

3.2 Step 2: Calculate Duty Cycle (D_{cycle})

The Duty Cycle is the fraction of time the generator needs to be ON. Based on steady-state assumption (see assumptions section), the formula is:

$$D_{cycle} = \frac{L}{L + P_{charge}}$$

3.3 Step 3: Calculate Runtime & Fuel

3.3.1 Generator Only (Baseline)

$$\text{Runtime}_{base} = H$$
$$\text{Fuel}_{base} = F(L) \times H$$

3.3.2 Hybrid System

When the generator runs, it must power the load *plus* charge the battery. Therefore, the generator runs at load $L + P_{charge}$.

$$\text{Runtime}_{hybrid} = D_{cycle} \times H$$
$$\text{Fuel}_{hybrid} = F(L + P_{charge}) \times \text{Runtime}_{hybrid}$$

3.4 Step 3: Runtime/Fuel Savings Analysis

The runtime and fuel savings are simply the difference between the hybrid and generator only scenarios from Step 3.

$$\text{Runtime}_{saved} = \text{Runtime}_{base} - \text{Runtime}_{hybrid}$$
$$\text{Fuel}_{saved} = \text{Fuel}_{base} - \text{Fuel}_{hybrid}$$

An important consideration is that, in a hybrid system, a larger generator would likely be used than in a generator only system. Moreover, the generator in a hybrid system needs to have sufficient capacity to charge the battery AND cover the load. Therefore, when estimating fuel savings, it would make sense to use the appropriate generator size for each scenario.

Also, it is important to note that, because the generator needs to charge the battery and cover the load, the fuel rate is significantly higher in a hybrid system. The ratios of runtime savings and fuel savings are thus NOT one-to-one, i.e. the runtime reduction can greatly exceed fuel reduction.

To estimate the reduction in CO_2 emissions for a scenario, multiply the Fuel_{saved} by the appropriate coeffecient for the given fuel type (EIA Carbon Dioxide Emissions Coefficients).

4 Example Calculations

4.1 Example 1

Inputs:

- Load (L) = 5 kW
- Generator Size = 56 kW (hybrid), 36 kW (generator only)
- Battery Max Charge/Discharge (C_{limit}) = 30 kW
- Duration (H) = 120 Hours

1. Effective Charge Rate:

$$P_{charge} = \min(30,\ 56 - 5) = 30 \text{ kW}$$

2. Duty Cycle:

$$D_{cycle} = \frac{5}{5 + 30} = \frac{5}{35} \approx 14.29\%$$

3. Fuel Rate Calculation (Interpolated):

- **Gen Only (36 kW @ 5 kW Load):** The load is 13.9% of capacity. Using the interpolation logic for loads < 25%:

$$\text{Rate} \approx 0.81 \text{ gal/hr}$$

- **Hybrid (56 kW @ 35 kW Load):** The load is 62.5% of capacity. Interpolating linearly between 50% and 75% rates:

$$\text{Rate} \approx 3.05 \text{ gal/hr}$$

4. Totals:

- **Gen Only Fuel**: $0.81 \times 120 = 97.07$ gal
- **Hybrid Runtime**: $0.1429 \times 120 = 17.14$ hr
- **Hybrid Fuel**: $3.05 \times 17.14 = 52.28$ gal

5. Savings:

- $\textbf{Runtime}_{saved}$: $120 - 17.14 = \mathbf{102.86}$ hr (85.71%)
- $\textbf{Fuel}_{saved}$: $97.07 - 52.28 = \mathbf{44.79}$ gal (46.14%)
- $\mathbf{CO_2}$ **reduction**: $44.79 \times 22.45 \approx \mathbf{1005.54}$ lbs

4.2 Example 2

Inputs:

- Load (L) = 20 kW
- Generator Size = 250 kW (hybrid), 100 kW (generator only)

- Battery Max Charge/Discharge (C_{limit}) = 150 kW
- Duration (H) = 120 Hours

1. **Effective Charge Rate:**

$$P_{charge} = \min(150,\ 250 - 20) = 150 \text{ kW}$$

2. **Duty Cycle:**

$$D_{cycle} = \frac{20}{20 + 150} = \frac{20}{170} \approx 11.76\%$$

3. **Fuel Rate Calculation (Interpolated):**

   - **Gen Only (100 kW @ 20 kW Load):** The load is 20% of capacity. Using the interpolation logic for loads $< 25\%$:

$$\text{Rate} \approx 2.34 \text{ gal/hr}$$

   - **Hybrid (250 kW @ 170 kW Load):** The load is 68% of capacity. Interpolating linearly between 50% and 75% rates:

$$\text{Rate} \approx 11.49 \text{ gal/hr}$$

4. **Totals:**

   - **Gen Only Fuel**: $2.34 \times 120 = 280.80$ gal
   - **Hybrid Runtime**: $0.1176 \times 120 = 14.12$ hr
   - **Hybrid Fuel**: $11.49 \times 14.12 = 162.24$ gal

5. **Savings:**

   - $\textbf{Runtime}_{saved}$: $120 - 14.12 = \mathbf{105.88}$ hr (88.23%)
   - $\textbf{Fuel}_{saved}$: $280.80 - 162.24 = \mathbf{118.56}$ gal (42.22%)
   - **CO_2 reduction**: $118.56 \times 22.45 \approx \mathbf{2661.67}$ lbs

5 Assumptions and Limitations

This model relies on the following assumptions regarding fuel curve interpolation and system behavior:

1. **Fuel Curve Interpolation:**
   - For loads between defined data points (25%, 50%, 75%, 100%), the model uses linear interpolation.
   - For loads **below 25%**, the model assumes a theoretical "0% Load" fuel rate equal to half of the 25% rate. It then interpolates linearly between this 0% point and the 25% point. This accounts for the significant efficiency loss (wet stacking risk and fixed overhead) of running generators at very light loads.
2. **Steady-State Operation:** The model assumes the system operates over a duration sufficient to negate initial transient conditions.
3. **Round-Trip Efficiency:** The calculation assumes 100% round-trip efficiency of the battery system.

A Supplement: Generator Fuel Rates

6 Assumptions and Limitations

This simplified model relies on the following assumptions:

1. **Steady-State Operation:** The model assumes the system operates over a duration sufficient to negate initial transient conditions. It treats the load as a constant average, ignoring fluctuations or peak demands that might momentarily exceed the discharge limit, etc.
2. **Round-Trip Efficiency:** The calculation assumes 100% round-trip efficiency of the battery system (AC-DC-AC).
3. **Charge/Discharge Profile:** This model assumes the max charge and discharge rates are identical and that the battery accepts the maximum charge rate continuously.
4. **Instantaneous Response:** The model ignores generator warm-up times and synchronization delays, etc.

While the battery energy capacity (kWh) does not affect the *ratio* of generator runtime according to this model, maximizing capacity has practical benefits:

- **Generator Health:** A larger battery increases the duration of both the ON and OFF intervals, reducing the frequency of generator start/stop events.
- **Battery Health:** A larger capacity relative to the load results in a lower C-rate (discharge current relative to capacity), which extends battery life.
- **Buffer for Load Spikes:** A larger energy capacity provides a safety margin for momentary spikes in load.

A Appendix: Generator Fuel Rates

The following table provides reference fuel consumption rates (gal/hr) for various generator sizes at specific load percentages.

Gen Size (kW)	25% Load	50% Load	75% Load	100% Load
20	0.67	0.94	1.26	1.62
36	1.04	1.60	2.20	2.93
56	1.70	2.60	3.50	4.40
100	2.60	4.10	5.60	7.10
150	3.94	5.42	7.21	8.90
250	5.80	8.90	12.5	16.7
320	7.70	12.2	17.3	22.5
500	10.9	19.4	28.0	37.3
1000	19.0	36.0	52.6	69.3

Table 1: Fuel Consumption Rates (gal/hr)