



Commercial Availability of Electric-Powered Loaders

Requested by
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Executive Summary

Background

More than one-half of California's greenhouse gas emissions are produced by the transportation sector, which includes off-road vehicles used by California Department of Transportation (Caltrans). These and other pollutants endanger the state's environment, economy and public health. Executive Order N-79-20 sets a goal of 100% zero-emission off-road vehicles and equipment operations by 2035. In response to this order and to contribute to the safety, equity and livability in the state, Caltrans is looking to expand its use of electric-powered vehicles in its construction and maintenance equipment fleets.

In earlier attempts to transition to a more climate-friendly fleet, Caltrans purchased hydrogen fuel cell-powered sweepers and experienced both equipment and refueling infrastructure challenges. Caltrans' goal is to purchase electric-powered sweepers and other electric-powered construction and maintenance equipment. A potential first step toward this goal is to purchase or rent an electric-powered loader to test and evaluate the usefulness of electric-powered equipment and determine the infrastructure needs.

This Preliminary Investigation presents information about 100% zero-emission electric-powered loaders that are commercially available. It also includes information about a limited number of other electric-powered and hybrid construction equipment. The search focused on equipment from approximately 15 vendors and manufacturers identified in preliminary research and from Caltrans' current list of off-road equipment suppliers. Equipment from manufacturers reporting the availability of electric-powered loaders, other electric-powered construction equipment or prototype systems is presented in this report.

Summary of Findings

Equipment information and product descriptions were sourced primarily through a literature search of online resources and limited follow-up with manufacturer representatives. Information is presented in the following categories:

- Electric-powered loaders.
- Other electric-powered construction equipment.
- Hybrid vehicles.

Specifications vary by product, depending upon publicly available information. Additional information about each loader is available at the product web site and in the product brochure.

Each product, including its manufacturer, is summarized below. Additional information about the equipment, including the product web site and the product brochure, is presented in the **Detailed Findings** section of this Preliminary Investigation.

Electric-Powered Loaders

580 EV Electric Backhoe Loader

(See page 8)

CASE Construction Equipment

Availability: Available to prebook

The 580 EV is powered by a 90-kWh lithium-ion battery pack. Runtime is approximately eight hours.

GEL-1800 Electric Wheeled Front Loader

(See page 9)

Greenland Machinery

Availability: Available to prebook.

This loader has a 1.8-ton-rated operating load with a nine-hour operating time.

GEL-5000 Electric Wheeled Front Loader

(See page 10)

Greenland Machinery

Availability: Available to prebook.

The GEL-5000 has a 5-ton load capability with an eight-hour operating time.

24e Electric Wheel Loader

(See page 11)

Schäffer Lader

Availability: Available for purchase.

This loader can be equipped with two battery packs for a runtime of approximately five hours.

L25 Electric Compact Wheel Loader

(See page 13)

Volvo Construction Equipment

Availability: Available to prebook.

The L25 has a compact design that makes it suitable for numerous construction applications. Runtime is up to eight hours.

WL20e Electric Wheel Loader

(See page 16)

Wacker Neuson SE

Availability: Available to purchase.

The WL20e Electric Wheel Loader has an articulated pendulum joint that ensures maneuverability. Runtime is up to five hours.

Kramer 5055e Electric Wheel Loader

(See page 17)

Kramer-Werke/Wacker Neuson SE

Availability: Unknown.

The compact design of this loader and all-wheel steering ensure superior maneuverability. Runtime is up to five hours.

Kramer KL25.5e Electric Wheel Loader

(See page 17)

Kramer-Werke/Wacker Neuson SE

Availability: Unknown.

This full-value wheel loader features new drive technology. Runtime is up to four hours.

Future Plans

Volvo Construction Equipment plans to introduce the 4.5-ton L20 Electric Compact Wheel Loader in late 2022. Two battery sizes will be available—a 33-kWh or 40-kWh system. Runtime will be up to six hours.

In early 2022, John Deere & Company plans to announce an aggressive Scope 3 goal for carbon dioxide equivalent (CO₂e) reduction as part of its 2030 environmental, social and governance goals. To support the goal, the company is actively working on multiple machine forms, including wheel loaders, that will be battery electric, diesel-electric and diesel-electric-battery plug-in. (The U.S. Environmental Protection Agency describes Scope 3 greenhouse gas emissions as “the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly impacts in its value chain.”)

Other Electric-Powered Construction Equipment

Backhoes

John Deere & Company is actively testing a prototype electric battery backhoe, the 310 X-Tier backhoe with E-Power. The company is working with National Grid, an electricity, natural gas and clean energy delivery company, to test the electric backhoe concept. Details about the model are limited at this time.

Excavators

GEX-8000 Electric Wheeled Excavator

(See page 20)

Greenland Machinery

Availability: Available to prebook.

The GEX-8000 has a battery capacity of 140.95 kWh. Runtime is approximately 13 hours.

19C-IE Electric Mini Excavator

(See page 21)

J C Bamford Excavators Ltd. (JCB)

Availability: Unknown.

The three-battery pack creates 15 kWh of capacity. Runtime is four hours. An optional four-battery pack increases capacity to 20 kWh and provides an additional two hours of continuous use.

ECR25 Electric Excavator

(See page 22)

Volvo Construction Equipment

Availability: Available to prebook.

The excavator features a zero-tail swing radius design for maneuverability. Runtime is up to four hours.

Future Plans

In late 2022, Volvo Construction Equipment plans to introduce two new models: the 1.8-ton EC18 electric compact excavator (battery capacity of 20 kWh and runtime of three to five hours) and the 1.8-ton ECR18 electric compact excavator (battery capacity of 16 kWh and runtime of up to four hours).

Forklifts

GEF Series Electric Forklift Truck

(See page 24)

Greenland Machinery

This series features three models:

- GEF 1800, with a load capacity of 3,968 pounds.
- GEF 2500, with a load capacity of 5,512 pounds.
- GEF 3500, with a load capacity of 7,717 pounds.

Availability: All models available to prebook.

Prototype Systems

Manufacturer web sites and other resources reported on prototypes for the following equipment:

- *Bobcat Company* (see page 25):
 - E10e and E17e electric/hydraulic excavators
Availability: Unknown.
 - S70e electric/hydraulic loader
Availability: Unknown.
- *Doosan Infracore North America*: DX17Z-5 electric prototype mini excavator (see page 26). Availability: Anticipated 2022.
- *Hyundai Construction Equipment Americas* (see page 27):
 - R18E 2-ton compact excavator
Availability: Anticipated 2022.
 - 3.5-ton electric excavator
Developed in partnership with Cummins Inc.
Availability: Unknown.
- *Komatsu LTD*: Partnering with Proterra Inc. to develop electric-powered excavators (see page 28). Availability: Anticipated 2023-2024.

Hybrid Vehicles

Loaders

644 X-Tier Wheel Loader

(See page 29)

John Deere & Company

Availability: Available to purchase.

The loader's diesel-electric powertrain (E-Drive) provides fuel economy and performance characteristics that greatly improve upon traditional powertrains. The manufacturer indicated that "[a]ctual fuel-consumption rates and savings will vary with machine application, utilization, operator and model of competitive unit."

944K Hybrid Wheel Loader

(See page 29)

John Deere & Company

Availability: Available to purchase.

The hybrid-electric drive system increases engine life and reduces fuel consumption. The manufacturer indicated that "[a]ctual fuel-consumption rates and savings will vary with machine application, utilization, operator and model of competitive unit."

Excavators

HB365LC-3 Hybrid Hydraulic Excavator

(See page 30)

Komatsu LTD

Availability: Available to purchase.

The hybrid energy conservation system combined with Tier 4 Final technology provides a fuel savings of up to 20%.

Related Research and Resources

When available, product announcements and reporting from trade journals are presented with each equipment model. In addition, articles from two trade publications address the state of electric heavy construction equipment, including summaries of current and anticipated electric-powered equipment from several vendors.

National publications also examine electric-powered heavy construction equipment, including an April 2021 feasibility assessment of battery electric construction equipment and a 2017 Oak Ridge National Laboratory report assessing the technology and market for off-road electric-powered vehicles. A 2016 report from the Electric Vehicle Transportation Center analyzes the implications of electric vehicle fleets, and a 2017 U.S. Department of Transportation report examines the impact of hybrid and electric off-road equipment in reducing greenhouse gas emissions.

Additional publications include a 2020 article on advancements in heavy equipment battery systems and a 2021 conference paper on issues related to hybrid and electric vehicle technologies in off-road applications. Emissions reduction is discussed in a 2019 journal article that reviews methods for monitoring construction vehicle emissions, a 2017 journal article that presents a framework for estimating the energy and environmental effects of heavy-duty diesel equipment, and other articles about quantifying emissions.

Gaps in Findings

Information for this Preliminary Investigation was obtained primarily through an online search of vendor web sites. Commercial availability of electric-powered construction vehicles is limited, although reporting from trade publications indicates availability will increase in the next few years as technologies improve and demand increases.

Next Steps

Moving forward, Caltrans could consider:

- Reviewing the product summaries presented in this report to identify equipment offerings that would be feasible for Caltrans' construction vehicle fleet.
- Reaching out to the manufacturers that did not respond to the request for information to potentially capture details about equipment, prototype systems or future plans for electric-powered construction and maintenance equipment.
- Monitoring products and prototypes presented in this Preliminary Investigation for commercial availability.
- Reviewing the findings of the literature search for additional product and vendor information as well as advances in battery systems and other technologies.

Detailed Findings

Background

More than one-half of California's greenhouse gas emissions are produced by the transportation sector, which includes off-road vehicles used by California Department of Transportation (Caltrans). These and other pollutants endanger the state's environment, economy and public health. Executive Order N-79-20 sets a goal of 100% zero-emission off-road vehicles and equipment operations by 2035. In response to this order and to contribute to the safety, equity and livability in the state, Caltrans is looking to expand its use of electric-powered vehicles in construction and maintenance equipment fleets.

Caltrans has purchased hydrogen fuel cell-powered sweepers, which met with both equipment and refueling infrastructure challenges. The agency's long-term goal is to purchase electric-powered sweepers and other electric-powered construction and maintenance equipment. A potential first step toward this goal is to purchase or rent an electric-powered loader to test and evaluate the usefulness of electric-powered equipment and determine the infrastructure needs.

This project gathered information about 100% zero-emission electric-powered loaders that are commercially available and other electric-powered construction equipment. The search focused on equipment vendors and manufacturers identified in preliminary research and from Caltrans' current list of off-road equipment suppliers, and included:

- Bobcat Company.
- CASE Construction Equipment.
- Caterpillar Inc.
- Daimler Trucks North America.
- Doosan Infracore North America.
- Greenland Machinery.
- Hyundai Construction Equipment Americas.
- J C Bamford Excavators Ltd. (JCB).
- John Deere & Company.
- Komatsu LTD.
- Navistar Inc.
- SANY America.
- Schäffer Lader.
- Volvo Construction Equipment.
- Wacker Neuson SE.

Only some of these manufacturers have announced the availability of electric-powered loaders, other electric-powered construction equipment or prototype systems.

Equipment information and product descriptions were sourced primarily through a literature search of online resources and limited follow-up with manufacturer representatives. Information is presented in the following categories:

- Electric-powered loaders.
- Other electric-powered construction equipment.
- Hybrid vehicles.

Supplementing the product information are resources identified in a literature search of publicly available domestic resources and in-progress research.

Electric-Powered Loaders

Below are product descriptions of electric-powered loaders from the following manufacturers:

- CASE Construction Equipment.
- Greenland Machinery.
- Schäffer Lader.
- Volvo Construction Equipment.
- Wacker Neuson SE.

Specifications vary by product, depending upon publicly available information. Additional information about each loader is available at the product web site and in the product brochure.

CASE Construction Equipment

580 EV Electric Backhoe Loader

From the web site:

- **Zero emissions:** Lower your carbon footprint and achieve incentives/greater consideration for new projects with electrified additions to your fleet.
- **All the performance:** The battery separately powers the drivetrain and hydraulic motors, resulting in hydraulic breakout forces equal to diesel-powered machines and improved performance during simultaneous loader and drivetrain operation.
- **Long-lasting power:** The machine's lithium-ion battery provides enough power for the typical 8-hour workday.
- **Lower operating costs:** Save as much as 90[%] in annual vehicle, fuel and maintenance costs.
- **Classic CASE performance:** The 580 EV retains the precision and efficiency of diesel-powered CASE backhoes with features such as ProControl, which allows for extremely precise boom movement and placement, as well as Comfort Steer, which significantly improves steering while working in tight quarters or in truck loading operations.



Specifications

<u>Topic</u>	<u>Description</u>
Battery pack	480 V, 90 kWh
Charging capability	220 V/three-phase connection
Runtime	Approximately 8 hours
Cost	N/A
Availability	Available to prebook

N/A Not available.

Product Information

Product web site: <https://www.casece.com/northamerica/en-us/products/backhoe-loaders/580ev-project-zeus>

Related Resources:

CASE Unveils “Project Zeus”—The All-New 580 EV—The Industry’s First Fully Electric Backhoe Loader, News Release, CASE Construction Equipment, undated.
<https://www.casece.com/northamerica/en-us/resources/articles/media-case-unveils-project-zeus-580ev-first-fully-electric-backhoe-loader>

From the news release: CASE Construction Equipment introduces “Project Zeus”—the 580 EV (Electric Vehicle), the construction industry’s first fully electric backhoe loader. The power and performance of the 580 EV [are] equivalent to other diesel-powered backhoes in the CASE product line and provide considerably lower daily operating costs while also producing zero emissions—a motivating factor for utility and government contractors incentivized to work with equipment that leverages alternative fuels and lowers emissions.

....

The 580 EV is powered by a 480-volt, 90-kilowatt-hour lithium-ion battery pack that can be charged by any 220-volt/three-phase connection. While applications will vary, each charge will support most common eight-hour workdays. The battery separately powers the drivetrain and hydraulic motors, resulting in hydraulic breakout forces equal to diesel-powered machines and improved performance during simultaneous loader and drivetrain operation.

“CASE Introduces World’s First Fully Electric Backhoe Loader,” Mark Kane, *Inside EVs*, March 11, 2020.

<https://insideevs.com/news/403585/case-fully-electric-backhoe-loader/>

From the article: CASE Construction Equipment unveiled “Project Zeus”—the all-new, all-electric CASE 580 EV backhoe loader, which turns out to be the first in the industry. ... It’s equipped with a 90 kWh lithium-ion battery and should be able to support an eight-hour workday in most applications, offering:

- [P]ower and performance equivalent to other diesel-powered backhoes.
- [Z]ero emission.
- [Q]uieter operation.
- Expected lower daily operating costs.
- [R]educe[d] maintenance demands.
- [P]ayback in around five years (the upfront cost is higher than diesel).

Greenland Machinery

GEL-1800 Electric Wheeled Front Loader

From the product description:

- A 1.8-ton-rated operating load with a nine-hour operation time.
- Low maintenance costs.
- Suitable for outdoor and indoor applications.



Specifications

<u>Topic</u>	<u>Description</u>
Electric drive motor	75 kW/102 hp
Electric working motor	30 kW/40.8 hp
Loading capacity	3,968 lb
Operating weight	11,464 lb
Maximum travel speed	16 mph
Battery voltage	618.24 V
Battery capacity	140.95 kWh
Charging time:	
• 90 kW input	1.5 hours
• 60 kW input	2.5 hours
• 12 kW input	13 hours
Indicative runtime (maximum)	13 hours
Cost	N/A
Availability	Available to prebook

N/A Not available

Product Information

Product web site: <https://www.greenlandmachinery.com/gel-1800-electric-front-loader>

Product brochure: https://www.greenlandmachinery.com/wp-content/uploads/2021/04/Greenland_GEL-1800.pdf

GEL-5000 Electric Wheeled Front Loader

From the product description:

- A 5-ton load capability with an eight-hour operation time.
- Battery capacity of 282 kWh.
- Suitable for outdoor and indoor applications.



Specifications

<u>Topic</u>	<u>Description</u>
Electric drive motor	120 kW/160.9 hp
Electric working motor	90 kW/120.6 hp
Loading capacity	11,023 lb
Operating weight	39,683 lb
Maximum travel speed	22.37 mph

Battery voltage	618.24 V
Battery capacity	282 kWh
Charging time:	
• 90 kW input	3 hours
• 60 kW input	5 hours
Indicative runtime (maximum)	9 hours
Cost	N/A
Availability	Available to prebook

N/A Not available

Product Information

Product web site: <https://www.greenlandmachinery.com/gel-5000-electric-front-loader>

Additional Information

“Greenland Technologies to Transition to Electric Loader Production Models in Second Half 2021,” Becky Schultz, *Equipment Today*, April 2021.

<https://www.forconstructionpros.com/equipment/earthmoving/loaders/news/21389796/greenland-technologies-holding-corporation-greenland-technologies-to-transition-to-electric-loader-production-models-in-second-half-2021>

From the article: The development of electric power in construction equipment is gaining ground, with Greenland Technologies Holding Corporation, a technology developer and manufacturer of electric industrial vehicles and drivetrain systems for material-handling machineries and vehicles, claiming its place in the sector. In late March, it announced completion of full beta versions of its GEL-1800 Electric Loader, its first electric industry vehicle, along with the intent to transition to construction of pilot production representative versions in the second half of 2021.

....

Designed to be used in a range of industries including construction, mining, agricultural and industrial applications, the 11,464-[pound] GEL-1800 has a loading capacity of approximately 3,969 [pounds] and a maximum dump height of 8 [feet]. It comes equipped with a 193-hp (144 kWh) lithium battery that is capable of providing up to nine hours of operation and can be charged in as little as two hours. The electric drive motor has a rated power of 102 hp.

Schäffer Lader

24e Electric Wheel Loader

From the product description:

- Compact dimensions, maneuverability and convincing lifting and traction forces.
- Standard or power battery pack (can be equipped with two battery packs).



- Two charging options: on-board system (230 V/16 A) or external system (400 V/32 A).

Specifications

<u>Topic</u>	<u>Description</u>
Engine power	42 hp
Lifting capacity	4,189 lb
Tipping load	3,726 lb
Operating weight	4,883 lb
Maximum travel speed	12.4 mph
On-board charging time 230 VAC 16A	Approximately 2 hours to charge each battery pack to 80%
Off-board charging time 400 VAC 32A	Approximately 15 minutes to charge each battery pack to 80%
Indicative runtime (with second battery pack)	Up to 5 hours
Cost	N/A
Availability	Available for purchase

N/A Not available.

Product Information

Product web site: <https://www.schaeffer-lader.de/en/loaders/construction-sector/wheel-loaders/24e/>

Product brochure: https://www.schaeffer-lader.de/files/41116/1797/2083/24e_2104_EN.pdf

Related Resource:

“DFD Loaders Announces Exclusive U.S. Distribution of Schäffer Construction Wheel Loaders,” ConstructionEquipmentGuide.com, October 2018.

<https://www.constructionequipmentguide.com/dfd-loaders-announces-exclusive-us-distribution-of-schffer-construction-wheel-loaders/42524>

From the article: Schäffer, a German brand of compact and telescopic articulated loaders, is now available in the United States via Florida-based distributor DFD Loaders. Beginning [Quarter] 4 of 2018, U.S. buyers can choose from 13 models ranging from 25 to 157 hp for different size jobs. Schäffer’s machines are widely recognized for their German engineering and unique approach to loader design challenges, particularly that of lifting heavy loads despite relatively low operating weight. Another product expected to draw a high level of interest is Schäffer’s model 24e—the world’s first electric wheel loader with lithium-ion technology that can reach 12.4 mph. It promises emission-free operations and significant savings in maintenance and operating costs, as well as the potential to deliver operation for an entire day of work with only a short charge, achievable for example, during a regular lunch break.

Volvo Construction Equipment

Contact: Ray Gallant, Vice President, Product Management and Productivity, Volvo Construction Equipment, 717-385-8023, ray.gallant@volvo.com.

L25 Electric Compact Wheel Loader

From the product description:

- Compact design with a machine height of 2.5 m.
- Easy to maintain. All lubrication and maintenance points are easily accessible.
- Suitable for numerous construction applications.



Specifications

Topic	Description
Electric motor driveline (peak)	48 hp
Electric motor working hydraulics (peak)	43 hp
Standard bucket capacity	1.2 yd ³
Operating weight	11,023 lb
Maximum travel speed	10 mph
Battery voltage	48 V
Battery capacity	39 kWh
On-board charging time 230 VAC 16A	Approximately 12 hours
Off-board charging time 400 VAC 32A	Approximately 2 hours
Indicative runtime (depending on application)	Up to 8 hours
Cost*	\$135,000
Availability	Available to prebook

* Recommended retail price based on the above machine specifications.

Product Information

Product web site: <https://www.volvoce.com/united-states/en-us/products/electric-machines/l25-electric/#features>

Product brochure: https://www.volvoce.com/-/media/volvoce/emob/brochures/brochure_l25_electric_en_22_voe2220009505.pdf?v=DEVWP

Future Plans

Later next year, Volvo Construction Equipment plans to introduce the 4.5-ton L20 Electric Compact Wheel Loader, which will be available in two battery sizes—a 33 kWh or 40 kWh system—and can be charged in up to five hours. Runtime is up to six hours.

The company is also working with other models using a variety of technical solutions, including hydrogen fuel cell technology, battery systems and other alternatives for heavy equipment applications.

Related Resource:

“Volvo Construction Equipment Launches Three New Electric Powered Machines,”

Sara Jensen, *OEM Off-Highway*, October 7, 2021.

<https://www.oemoffhighway.com/trends/equipment-launches/construction/article/21759721/volvo-construction-equipment-launches-three-new-electric-powered-machines>

From the article: Volvo Construction Equipment (Volvo CE) announces it plans to introduce three new electric powered compact machines. These will include:

- L20 Electric compact wheel loader.
- EC18 Electric compact excavator.
- ECR18 Electric compact excavator.

....

The L20 Electric features a parallel-type linkage for improved visibility over the attachment being used as well as 100% parallel movements to suit use in fork applications. Also included on the machine is a new intuitive HMI (human machine interface) system designed for the company’s electric compact machines to help ensure optimized operation and comfort.

Two battery size options are available for the L20 Electric, a 33 kWh or 40 kWh battery pack. This allows customers to configure their machine based on their needed net operating time and planned charging schedule said [Paolo Mannesi, global product manager for compact wheel loaders at Volvo Construction Equipment]. The L20 Electric can be charged from 0[% to]100% in up to 5 hours on public charging stations or using the charging cable provided with the wheel loader. Customers can expect to get up to [six] hours of active working time on a single charge with this new wheel loader.

A new parking brake concept with hill-hold functionality will be introduced with the L20 Electric, as well, said Mannesi, to help further improve operator comfort.

Related Resources

Electromobility: The Power of Change, Volvo Construction Equipment, undated.

<https://www.volvoce.com/global/en/our-offer/emobility/>

(Scroll to “Explore Our Electric Range”)

From the web page: At Volvo we recognize that a sustainable business is a successful business, and we are delighted to introduce the Volvo L25 Electric, the first in a new range of electric compact wheel loaders. The Volvo L25 Electric combines the proven Volvo compact wheel loader platform with battery power, providing all the performance you need along with zero-tailpipe emissions and an incredibly low noise level.

Related Resources:

“Volvo’s Electric Excavator and Loader Make Great Diesel Alternatives,” Dan

Mihalascu, *InsideEVs*, September 24, 2021.

<https://insideevs.com/news/535840/volvo-ecr25-l25-california-pilot/>

From the article: Volvo Construction Equipment (Volvo CE) has announced the results of a pilot project in Southern California with the ECR25 Electric compact excavator and L25 Electric compact wheel loader.

For nearly a year, Volvo CE has been testing these battery-powered machines with multiple customers on job sites. The goal was to demonstrate they're viable alternatives to diesel equipment for fleets to reduce carbon footprints and accelerate the deployment of zero-emission solutions in this segment.

The results are encouraging and come just as Volvo CE is getting ready for a full North American rollout of the ECR25 Electric (January 2022) and L25 Electric (early 2022). Conclusions from the pilot project confirmed that Volvo electric construction equipment matches the performance and has significant benefits when compared to diesel machines in the same compact size range.

First Volvo CE Electric Machines Give an Extra Boost to Switzerland's Greenest City, News Release, Volvo Construction Equipment, June 2021.

<https://www.volvoce.com/global/en/news-and-events/press-releases/2021/first-volvo-ce-electric-machines-give-an-extra-boost-to-switzerlands-greenest-city/>

From the news release: Small but mighty electric compact machines from Volvo Construction Equipment (Volvo CE) are being put through their paces by Swiss customers for the first time in one of the most sustainable cities on earth—and the results are proving “quietly” satisfying.

....

“The L25 Electric is being used at one of our landfill sites as well as for road clearing, small-scale material handling and as a forklift. With the batteries acting as a counterweight, it can really lift a lot for a compact machine. Its biggest advantage, though, is that it's low emission, silent and has minimal vibration. Our operators enjoy working with it. In future, we plan to use the L25 Electric on our construction sites in downtown Zurich and other cities where requests for low emissions and silence [are] high.”

Electromobility is Heading Off Road With Electric Construction Equipment, News Release, Volvo Construction Equipment, May 2021.

<https://www.volvoce.com/global/en/news-and-events/news-and-stories/2021/copy-of-six-ways-the-electric-revolution-is-transforming-the-way-we-work/>

From the news release: Bringing electromobility to the construction industry is not without its challenges. Perhaps chief among them is building out the charging infrastructure, which is an issue for on-road EVs [electric vehicles] too, but construction equipment has the added challenge of being the machines tasked with building or maintaining infrastructure.

The Volvo ECR25 Electric excavator and L25 Electric wheel loader, which are already available to buy in select markets and will be commercially available in the U.S. this year, run on lithium-ion batteries and can be charged using a 220/240-volt electrical socket, which is the type of outlet many larger home appliances use. They also come with fast-charge options that can get them close to peak charge within a couple of hours. Research and development are moving fast in this area, and in the near future options like mobile power banks could be available for charging in remote locations.

Wacker Neuson SE

Below are electric-powered wheel loaders from Wacker Neuson SE and Kramer-Werke, a company of Wacker Neuson SE.

WL20e Electric Wheel Loader

From the product description:

- Performance comparable to traditional wheel loader. (The loader has two electric engines: one for the drive system and one for the work hydraulics.)
- Up to 41% savings in operating costs as well as cost advantages in maintenance and service intervals.
- Articulated pendulum joint ensures maneuverability into the smallest angles and good traction, even in uneven ground conditions.



Specifications

Topic	Description
Travel drive motor	8.7 hp
Lifting motor	12 hp
Standard bucket capacity	0.26 yd ³
Operating weight	5,181 lb
Maximum travel speed	9.3 mph
Battery voltage	48 V
Charging time (230 V)	6-8 hours
Runtime (depending on application)	Up to 5 hours
Cost	N/A
Availability	Available for purchase

N/A Not available

Product Information

Product web site: <https://www.wackerneuson.com/en/au/products/wheel-loaders/articulated-wheel-loaders/model/wl20e-1/>

Product specifications: <https://www.wackerneuson.com/en/au/products/wheel-loaders/articulated-wheel-loaders/model/wl20e-1/type/TechnicalData/unit/imperial/>

Kramer 5055e Electric Wheel Loader

From the product description:

- Compact design and all-wheel steering for superior maneuverability.
- Electric motor built into the drive system for great performance and tractive force. (A second electric motor controls the work hydraulics.)
- Performance comparable to a diesel-powered vehicle.
- Reduced operating and maintenance costs compared to a diesel-operated vehicle.



Specifications

Topic	Description
Standard bucket capacity	0.85 yd ³
Operating weight	9,105 lb
Maximum travel speed	9.9 mph
Battery voltage	48 V
Charging time	5-8 hours
Runtime (depending on application)	Up to 5 hours
Cost	N/A
Availability	Unknown

N/A Not available

Product Information

Product web site: <https://www.kramer-online.com/en/discover-kramer/zero-emission/the-kramer-5055e/>

Product brochure: https://www.kramer-online.com/fileadmin/user_upload/KC_EN_bro_5055e_KC.EMEA.10246.V03.EN_preview.pdf

Kramer KL25.5e Electric Wheel Loader

From the product description:

- Full-value wheel loader with new drive technology.
- High performance and efficiency for maximum effectiveness.
- Electric motor built into the drive system for great performance and tractive force. (A second electric motor controls the work hydraulics.)
- Reduced operating and maintenance costs compared to a diesel-operated vehicle.



Specifications

<u>Topic</u>	<u>Description</u>
Standard bucket capacity	0.85 yd ³
Operating weight	9,149 lb
Maximum travel speed	9.9 mph
Battery voltage	48 V
Charging time	5-8 hours
Runtime (depending on application)	Up to 4 hours
Cost	N/A
Availability	Unknown

N/A Not available

Product Information

Product web site: <https://www.kramer-online.com/en/discover-kramer/zero-emission/the-kramer-kl255e/>

Product brochure: https://www.kramer-online.com/fileadmin/user_upload/KA_EN_bro_KL25.5e_KA.EMEA.10253.V03.EN_preview.pdf

Related Resources:

“Eliminating Emissions Increases Application Opportunities,” Sara Jensen, *OEM Off-Highway*, September 11, 2018.

<https://www.oemoffhighway.com/trends/electrification/article/21016949/electric-wheel-loaders>

From the article: During this year’s INTERMAT, Wacker Neuson exhibited two electric wheel loaders, the Kramer 5055e and the Wacker Neuson WL20e. Both machines are part of the company’s range of emissions-free equipment and are capable of working up to 8 hours on a single charge, depending on the application. ... Reducing noise and emissions were major factors for Wacker Neuson’s development of its electric wheel loaders—which [Stefanie Wieland, head of Group Brand, Marketing and Communication at Wacker Neuson SE] says will soon be available in the U.S.—as well as its entire range of zero-emission electric machinery.

“Wacker Neuson Group Exhibits Zero Emission Machine Lineup at INTERMAT 2018,” *OEM Off-Highway*, May 1, 2018.

<https://www.oemoffhighway.com/trends/electrification/press-release/21003220/wacker-neuson-wacker-neuson-group-exhibits-zero-emission-machine-lineup-at-intermat-2018>

From the article: At the only indoor product demonstration at INTERMAT 2018, visitors were able to experience the full range of the zero emission line of the Wacker Neuson Group. Two battery rammers, the dual power excavator, two electric wheel loaders and an electrically operated track dumper were available in the test area, ready to use for visitors. One of the INTERMAT highlights was the brand new electric vibratory plate AP1850e and the first all-electric Zero Tail excavator EZ17e—both also part of the zero emissions line of Wacker Neuson, and both have been presented for the first time to the public. ... Thanks to the intelligent loading management, the EZ17e can be used battery-driven or plugged to the grid and can be charged simultaneously. It is, therefore, especially suitable for environments

in which exhaust fumes and noise should be avoided, for example[,] in inner-cities, inside buildings and tunnels or near schools and hospitals. ... Two reliable electric wheel loaders are long since part of the time-proven emissions-free range and were able to prove themselves in the test area. The WL20e by Wacker Neuson and the 5055e by Kramer demonstrated their abilities, fitting to the application, in the trade fair building on the demo area. Both can be employed for applications of up to eight hours, and with their integrated, practical battery charger they are recharged very quickly.

Electric Construction Machines: Our Zero Emission Solutions, Wacker Neuson, undated.

<https://www.wackerneuson.de/en/products/zero-emission/>

From the web page: In many construction site situations, the application of electric construction machines and construction equipment is worthwhile. For example, if you work in an urban environment. Wacker Neuson makes the “switch” to the electric machine easy: [O]ur zero emission portfolio ranges from the battery-powered rammers to the electric wheel loaders. With this, we are making a completely emission-free construction site possible even today—without compromises in performance!

Other Electric-Powered Construction Equipment

Below are product descriptions of electric-powered backhoes, excavators and forklifts that are currently available or in prototype testing from the following manufacturers:

- John Deere & Company.
- Greenland Machinery.
- J C Bamford Excavators Ltd. (JCB).
- Volvo Construction Equipment.

Following these descriptions are prototype systems from Bobcat Company, Doosan Infracore North America, Hyundai Construction Equipment Americas and Komatsu LTD.

Backhoes

John Deere & Company

Contact: Jon Gilbeck, Manager, Production Systems, Site Development and Underground, John Deere & Company, 563-949-9162, gilbeckjonc@johndeere.com.

Currently, John Deere & Company is actively testing a prototype electric battery backhoe, the 310 X-Tier backhoe with E-Power, with customers. (See *Related Resource* below.) Details about the model are limited at this time.

In early 2022, the company will be announcing an aggressive Scope 3 goal for carbon dioxide equivalent (CO₂e) reduction as part of its 2030 environmental, social and governance goals. To support the goal, the company is actively working on multiple machine forms that will be battery electric, diesel-electric and diesel-electric-battery plug-in, including wheel loaders. More information about these models will be available this year. (The U.S. Environmental Protection Agency describes Scope 3 greenhouse gas emissions as “the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly impacts in its value chain.”)

Related Resource:

John Deere Joint Tests Its First Electric-Powered Backhoe With National Grid, News Release, John Deere & Company, January 6, 2021.

<https://www.deere.com/en/our-company/news-and-announcements/news-releases/2021/construction/2021jan06-electric-powered-backhoe/>

From the news release:

- John Deere is working with National Grid, an electricity, natural gas and clean energy delivery company, to joint test its electric backhoe concept.
- The John Deere-developed backhoe will be used on National Grid job sites, proving out the concept to help further enhance and improve the electric vehicle design.

John Deere, a leading manufacturer of construction equipment, and National Grid, an electricity, natural gas and clean energy delivery company serving more than 20 million people throughout the Northeast, will joint test an electric backhoe concept. The John Deere developed, battery-powered, electric vehicle design—referred to as E-Power—will target the ease of operation and performance level of the diesel-powered, 100 HP 310L Backhoe. The design is intended to provide substantially lower daily operating costs, lower job site noise, enhanced machine reliability, and zero tailpipe emissions.

Excavators

Greenland Machinery

GEX-8000 Electric Wheeled Excavator

From the product description:

- Battery capacity of 140.95 kWh.
- Low maintenance costs.
- Suitable for numerous applications.



Specifications

<u>Topic</u>	<u>Description</u>
Electric drive motor	63.2 hp
Operating weight	18,739 lb
Maximum digging force	50 kN
Minimum ground clearance	14.96 in.
Maximum gradability	≥70% (35°)
System working pressure	28 MPa
Battery voltage	618.24 V
Battery capacity	140.95 kWh

Charging time

- | | |
|---------------|-----------|
| • 90 kW input | 1.5 hours |
| • 60 kW input | 2.5 hours |
| • 12 kW input | 13 hours |

Indicative runtime (maximum) 13 hours

Cost N/A

Availability Available to prebook

N/A Not available

Product Information

Product web site: <https://www.greenlandmachinery.com/gex-8000-electric-wheeled-excavator>

Product brochure: https://www.greenlandmachinery.com/wp-content/uploads/2021/04/Greenland_GEX-8000.pdf

J C Bamford Excavators Ltd. (JCB)

19C-IE Electric Mini Excavator

From the product description:

- Performance comparable to diesel-fueled machine.
- On-board charger with standard, domestic 110V input for 12-hour recharging. Available 230V charging option for eight-hour recharge or fast charge option for two-hour recharge.
- Three lithium-ion batteries creating 15 kWh of capacity, enough to power through a typical workday on a single charge. An optional four-battery pack increases capacity to 20 kWh and delivers an additional two hours of continuous use.
- 500-hour greasing intervals.

Specifications

<u>Topic</u>	<u>Description</u>
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Electric drive motor	27 hp
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Operating weight	4,193 lb
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Maximum digging depth	9'3"
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Charging time

- | | |
|-------------|----------|
| • 110 V | 12 hours |
| • 230 V | 8 hours |
| • 380-420 V | 2 hours |

Indicative runtime (maximum)	4 hours
-------------------------------------	---------

Availability	Unknown
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Product Information

Product web site: <https://www.jcb.com/en-us/products/compact-excavators/19c-1e>

Related Resources:

JCB E-TECH, J C Bamford Excavators Ltd., undated.

<https://www.jcb.com/en-gb/campaigns/etech-range>

From the web page: 100% electric. Zero compromise: Get the same high performance as conventional machines with powerful lithium-ion technology.

- Lithium-ion batteries power a full typical day on a single charge.
- 110V, 230V [and] 415V charging capability.
- Fast [c]harge ready.

JCB E-TECH Electric Range Livestream Launch, Video, J C Bamford Excavators Ltd., November 19, 2020.

<https://www.youtube.com/watch?v=QpO8Ynt1Kyg>

From the introduction: Join the leaders in electric innovation as we work toward a more sustainable future. JCB’s pioneering range of machines [is] 100% electric with zero emissions, zero compromise on performance and a lot less noise. No other construction equipment manufacturer has more expertise in building electric machines today.

Constructing the Road to Zero, J C Bamford Excavators Ltd., October 15, 2019.

<https://www.jcb.com/en-gb/news/2019/10/constructing-the-road-to-zero>

From the web page: In the last year, JCB has unveiled three new models that have marked a new dawn in our proud history of construction equipment innovation:

- The 19C-1E—JCB’s first fully electric mini excavator.
- The 30-19E—JCB’s first fully electric Teletruk.
- The new range of [e]lectric scissor lifts powered by lithium-ion batteries.

Their introduction signals the launch of the JCB E-TECH range—a new generation of fully electric machines with zero emissions at point of use and no compromise on performance.

Volvo Construction Equipment

Contact: Ray Gallant, Vice President, Product Management and Productivity, Volvo Construction Equipment, 717-385-8023, ray.gallant@volvo.com.

ECR25 Electric Excavator

From the product description:

- Zero-tail swing radius design for maneuverability in confined spaces.
- Performance comparable to a diesel-powered vehicle.
- Greasing required monthly.



Specifications

<u>Topic</u>	<u>Description</u>
Operating weight	5,908-6,129 lb
Maximum digging depth (short/long arm)	8'1"-9'1"

Maximum dump height (short/long arm)	9'2"-9'8"
Breakout force	5,020 lbf
Travel speed (minimum/maximum)	1.49 mph/2.8 mph
Overall width	5'1"
Overall length (short/long arm)	12'9"-13'2"
Electric motor (peak)	24 hp
Battery voltage	48 V
Battery capacity (full package)	20 kWh
On-board charging time 230 VAC 16A	Approximately 5 hours
Off-board charging time 400 VAC 32A	Approximately 50 minutes for 80% charge
Indicative runtime (depending on application)	Up to 4 hours
Cost	\$92,900*
Availability	Available to prebook

* Recommended retail price based on the above machine specifications.

Product Information

Product web site: <https://www.volvoce.com/united-states/en-us/products/electric-machines/ecr25-electric/#attachments>

Product brochure: https://www.volvoce.com/-/media/volvoce/emob/brochures/brochure_ecr25_electric_en_22_voe2220009506.pdf?v=C0VWPw

Future Plans

In late 2022, Volvo Construction Equipment plans to introduce two new models: the 1.8-ton EC18 electric compact excavator, which has a battery capacity of 20 kWh and runtime of 3 to 5 hours; and the 1.8-ton ECR18 electric compact excavator, which is a short-radius model of the EC18 excavator with a battery capacity of 16 kWh and runtime of 2.5 to 4 hours.

The company is also working with other models using a variety of technical solutions, including hydrogen fuel cell technology, battery systems and other alternatives for heavy equipment applications.

Related Resource:

“Volvo Construction Equipment Launches Three New Electric Powered Machines,”

Sara Jensen, *OEM Off-Highway*, October 7, 2021.

<https://www.oemoffhighway.com/trends/equipment-launches/construction/article/21759721/volvo-construction-equipment-launches-three-new-electric-powered-machines>

From the article: Volvo Construction Equipment (Volvo CE) announces it plans to introduce three new electric-powered compact machines. These will include:

- L20 electric compact wheel loader.
- EC18 electric compact excavator.

- ECR18 electric compact excavator.

....

The new EC18 and ECR18 electric compact excavators have many aspects in common with their diesel equivalent, said Clement Brette, [g]lobal [p]roduct [m]anager for Compact Excavators at Volvo CE, during the virtual launch event. These include use of the same machine structures, a high level of operator comfort, the same hydraulics systems and optimized lifting and digging capabilities. ... The machines are compatible with Volvo's range of fast chargers and can be recharged from 0[% to] 80% in up to 1 hour.

Forklifts

Greenland Machinery

GEF Series Electric Forklift Truck

From the product description:

- Three models, all with compact design and powerful output.
- Regenerative braking.
- Low maintenance costs.
- Suitable for numerous applications.



Specifications

GEF 1800

<u>Topic</u>	<u>Description</u>
Load capacity	3,968 lb
Vehicle weight	7,452 lb
Lift height	10'
Fork spread	3.2'/0.65'
Travel speed with load (maximum)	9.3 mph
Battery voltage/rated capacity	48 V
Cost	\$23,999
Availability	Available to prebook

GEF 2500

<u>Topic</u>	<u>Description</u>
Load capacity	5,512 lb
Vehicle weight	9,039 lb
Lift height	10'
Fork spread	3.28'/0.8'
Travel speed with load (maximum)	9.3 mph

Battery voltage	48 V
Cost	\$28,999
Availability	Available to prebook

GEF 3500

<u>Topic</u>	<u>Description</u>
Load capacity	7,717 lb
Vehicle weight	11,389 lb
Lift height	10'
Fork spread	3.28'/0.8'
Travel speed with load (maximum)	9.3 mph
Battery voltage	80 V
Cost	\$34,999
Availability	Available to prebook

Product Information

Product web site: <https://www.greenlandmachinery.com/gef-series-electric-forklifts>

Product specifications: <https://www.greenlandmachinery.com/forklift-expanded-spec-sheet>

Prototype Systems

Bobcat Company

On its web site, Bobcat Company explains that it is “engineering fully electric-powered machines that eliminate all hydraulics, as well as machines with electric motors.” Other resources describe the E10e and E17e electric/hydraulic excavators and the S70e electric/hydraulic loader. See *Related Resources* below for product information.

Related Resources:

Electric Prototype Machines, Bobcat, undated.

<https://www.bobcat.com/company-info/next-is-now>

(Scroll to “New Electric Equipment”)

From the web page: Bobcat is engineering fully electric-powered machines that eliminate all hydraulics, as well as machines with electric motors. The fully electric concept machine has the potential to completely revolutionize the compact equipment industry. The smaller electric machines offer zero emissions and a durable lithium-ion battery.

....

Bobcat is proving that battery-powered electric solutions can deliver the performance, uptime and versatility needed for heavy-duty work. With electronically controlled travel and zero emissions, the E10e and E17e excavators and S70e skid-steer loader bring the world's leading compact equipment brand to indoor demolition and urban construction projects. State-of-the-art lithium-ion battery technology provides a full day's runtime, while zero emissions open up more possibilities for working indoors or in spaces with limited

ventilation. All that, and these machines require minimal maintenance to reduce operating costs.

ConExpo: Bobcat Introduces Electric Concept Compact Equipment, *Roads & Bridges*, March 13, 2020.

<https://www.roadsbridges.com/conexpo-bobcat-introduces-electric-concept-compact-equipment>

From the web site: The new electric prototype machines from Bobcat—including the S70e electric/hydraulic loader and the E10e and E17e electric/hydraulic excavators—are designed to help equipment owners achieve zero emissions, lower noise levels and, most importantly, comparable and sometimes better performance to the diesel machines virtually anywhere, including indoor demolition or urban construction job sites. With a ruggedized lithium-ion battery, operators can get a longer runtime between daily charge cycles, supplying steady power before recharge is needed. According to Bobcat, these new machines are designed [to] work just as hard as diesel models with fewer maintenance needs.

Bobcat also introduced the first all-electric compact loader—the T76e. This concept loader is designed to provide a solution for emissions-free, fully electronic operation so customers can be ready for tomorrow’s job site demands. A major innovation in the T76e is controllability of horsepower and performance through electronic mechanics instead of the traditional hydraulic and diesel system. According to Bobcat, this loader will be foundational for innovations that will change compact equipment in a number of ways, from improved productivity and enhanced precision to more intelligent machines that bring new capabilities to the job site.

Bobcat E10e Mini-Excavator, Bobcat Company, undated.

<https://www.bobcat.com/eu/company-info/news-media/e10-electric>

The E10e has a state-of-the-art [l]ithium-[i]on, maintenance-free battery pack with an advanced management system, designed to fit within the standard machine envelope to maintain the machine’s ZTS profile.

Following the daily working routine, the E10e can operate throughout a full [eight]-hour day, using operator breaks to recharge the batteries. Using an external super-charger functionality, the batteries can be recharged to 80% of battery capacity in around [one] hour. The battery can also be recharged overnight by using the on-board charger from a standard 230V grid. Plus, the new machine is easy to maintain and safe to operate—thanks to the exclusive use of low voltages, there is no need for operators to have special authorization to work with the E10e.

Doosan Infracore North America

Doosan Infracore North America has developed the DX17Z-5 electric prototype mini excavator, which could be commercially available in 2022.

Related Resources:

“Doosan DX17Z-5: The New Electric Mini Excavator,” *HeavyQuip Magazine*, March 2020.

<https://www.heavyquipmag.com/2020/03/16/doosan-dx17z-5-the-new-electric-mini-excavator/>

From the article: The Doosan DX17Z-5 electric prototype mini excavator is being shown for the first time in North America during CONEXPO-CON/AGG 2020, March 10-14. The

DX17Z-5 zero tail swing, electric mini excavator could be available for customers in North America as early as 2022.

Why Electric Construction Equipment is on the Rise, Doosan Infracore North America, September 2021.

<https://na.doosanequipment.com/en/news-stories/the-cutting-edge/why-electric-construction-equipment-is-on-the-rise>

From the web page: Several equipment manufacturers displayed prototypes or first-generation electric-powered machines during CONEXPO-CON/AGG 2020. Doosan was one of those manufacturers, showing a prototype of an electric DX17Z-5 mini excavator, though this machine is not currently available in North America. When considering a machine's components, hybrid or electric technology is a better fit for smaller equipment. The larger the machine, the larger the components where electrical storage capacity can be a barrier. This early in the process, it's logical for manufacturers to begin making the electric transition with smaller equipment first.

Hyundai Construction Equipment Americas

Hyundai Construction Equipment Americas has developed two electric-powered excavators: the 2-ton R18E compact excavator prototype that is expected to launch in 2022 and a 3.5-ton electric excavator developed in partnership with Cummins Inc.

Related Resources:

“Hyundai CE Develops 2-Ton Electric Excavator Prototype,” *Equipment Journal*, July 18, 2020.

<https://www.equipmentjournal.com/construction-news/hyundai-electric-excavator-prototype/>

From the article: The Hyundai R18E is a two-ton-class machine designed for use both indoors and in urban settings. Offering power and productivity equivalent to the Hyundai's diesel-powered R17Z-9A compact excavator, the R18E is 60[%]t more energy-efficient. ... With an operating weight of 1,725 [kilograms], digging depth of 2.4 meters and dump height of 268 [centimeters], the R18E is powered by an induction-type motor with a one-hour current rating of 225 amps. Digital control of the electric excavator is provided through a microcontroller. The machine can operate up to eight hours on a full charge and can be fully recharged in five hours. The Hyundai-developed excavator uses a LFP type [lithium]-ion battery, generating a power capacity of 19.6 hp. Its battery charger is rated at 4 hp, with a free voltage range of 100-230 volts AC.

....

Hyundai has also partnered with Cummins to create a 3.5-ton electric excavator. “Through our collaboration with Cummins, we have produced an excavator in the highly popular 3.5-ton size class,” [Stan Park, vice president of distribution and marketing, Hyundai Construction Equipment Americas] said. “We expect this machine to be well received not only in the rental market, but in municipalities focused on green initiatives, in urban construction where machine noise can be an issue and in applications that are exposed to fire hazards.”

Powered by Cummins BM4.4E flexible battery modules, which generates 5.9 hp each, the Hyundai R35E excavator prototype is designed to support a full work shift and charge in less than three hours.

Hyundai Construction Equipment and Cummins Develop Electric Powered Mini Excavator Prototype, News Release, Cummins Inc., October 29, 2018.

<https://www.cummins.com/news/releases/2018/10/29/hyundai-construction-equipment-and-cummins-develop-electric-powered-mini>

From the news release: Based on the long-term productive partnership of the companies, HCE [Hyundai Construction Equipment] and Cummins agreed to collaborate on the design and development of electric powered mini excavators for this market. Powered by Cummins BM4.4E flexible battery modules (4.4 kWh each), the 3.5-ton excavator is designed to operate for a full eight-hour shift and charge in under three hours.

Komatsu LTD

Komatsu LTD is partnering with Proterra Inc. to develop electric-powered excavators. Commercial production is anticipated in 2023 or 2024.

Related Resources:

Komatsu is Developing All-Electric Excavators, Craig Cole, Road/Show by CNET, January 26, 2021.

<https://www.cnet.com/roadshow/news/komatsu-is-developing-all-electric-excavators/>

From the article: Bloomberg reported that Komatsu Ltd., Asia's leading manufacturer of construction equipment[,] has partnered with Proterra Inc., a company that manufactures electric buses and battery packs, to build electrically powered excavators.

Proterra will supply Komatsu with various components including batteries and peripherals. Later this year, the Japanese firm plans to begin testing small and midsize excavators fitted with electric powertrains. Assuming everything goes to plan, commercial production could begin in 2023 or [20]24.

The Proterra Powered Electric Excavator From Komatsu, Proterra Inc., undated.

<https://www.proterra.com/vehicles/proterra-powered-vehicles/komatsu-electric-excavator/>

Proterra and Komatsu are partnering to develop a battery-electric middle-class hydraulic excavator, the first vehicle of its kind for both companies. The Komatsu electric excavator will be powered by Proterra's proven battery technology to provide cleaner, quieter construction equipment without compromising on performance.

Hybrid Vehicles

Below are product descriptions of hybrid construction equipment from John Deere & Company and Komatsu LTD.

Wheel Loaders

John Deere & Company

644 X-Tier Wheel Loader

From the product description:

- Diesel-electric powertrain (E-Drive), providing fuel economy and performance characteristics that greatly improve upon traditional powertrains. (*Note: Actual fuel consumption rates and savings will vary with machine application, utilization, operator and model.*)
- State-of-the-art technology and innovative features.



Specifications

<u>Topic</u>	<u>Description</u>
Net power	172 kW (231 hp) at 1,500 rpm
Standard bucket capacity	4-4.75 yd ³
Operating weight	41,571-41,649 lb
Cost	N/A
Availability	Available to purchase

N/A Not available.

Product Information

Product web site: <https://www.deere.com/en/loaders/wheel-loaders/mid-size-wheel-loaders/644-x-wheel-loader/>

Product brochure: <https://www.deere.com/assets/pdfs/common/products/wheel-loaders/wheel-loader-644-x-mf644xaen.pdf>

944K Hybrid Wheel Loader

From the product description:

- Hybrid-electric drive system designed to increase engine life and reduce fuel consumption. (*Note: Actual fuel consumption rates and savings will vary with machine application, utilization, operator and model.*)



- Control of automatic traction to help eliminate wheel spin and tire wear, further reducing daily operating costs.
- Easy greasing and maintenance.

Specifications

Topic	Description
Net power	400 kW (536 hp) at 1,600 rpm
Standard bucket capacity	8.5-10 yd ³
Operating weight	19,607-124,614 lb
Cost	N/A
Availability	Available to purchase
N/A	Not available.

Product Information

Product web site: <https://www.deere.com/en/loaders/wheel-loaders/large-wheel-loaders/944k-wheel-loader/>

Product brochure: <https://www.deere.com/assets/pdfs/common/products/wheel-loaders/944k-wheel-loader-dka944.pdf>

Excavators

Komatsu LTD

HB365LC-3 Hybrid Hydraulic Excavator

From the product description:

- High production with low fuel consumption. Hybrid energy conservation system combined with Tier 4 Final technology provides up to 20% fuel savings compared to the nonhybrid excavator design.
- Six working modes to match engine speed, pump delivery and system pressure to a wide variety of applications.
- Easy access for maintenance and service.



Specifications

Topic	Description
Net power	201 kW (269 hp) at 1,950 rpm
Standard bucket capacity	0.89-2.56 yd ³
Operating weight	81,791-85,495 lb
Cost	N/A

Availability

Available to purchase

N/A Not available.

Product Information

Product web site: <https://www.komatsu.com/en/products/excavators/large-excavators/hb365lc-3/>

Product brochure: https://mc-1b532e28-a559-47ec-b3e4-499989-cdn-endpoint.azureedge.net/-/media/brochures/excavators/hb365lc_3_aess905_02_ev2.ashx?rev=4f2193efc027450bb9e6d79ac443d122

Related Research and Resources

A literature search of recent publicly available resources identified publications that are organized into the following topic areas:

- Vendor equipment and resources.
- National research and resources.
- Related research and resources.

Vendor Equipment and Resources

Multiple Vendors

“Current State of Electric Equipment,” Frank Raczon, *Construction Equipment*, July 2020.
<https://www.constructionequipment.com/current>

From the article:

So far when it comes to all-electric equipment, the industry has indeed been treated to mostly prototypes, and the gap between prototype and actual sales can be wide. It was the same with hybrids eight to 10 years ago. With all-electrics, OEMs [original equipment manufacturers] have been restricted by the limits of battery technology, and demand is limited compared to diesel, but some companies don't mind gaining public relations points while treating end-users to visions of the technology to come.

All-electric construction vehicles from several manufacturers are featured in this article, including Doosen, Case Construction Equipment and Volvo Construction Equipment.

“Electric Dreams: Will Heavy Construction Equipment Go All-Electric?,” Kendall Jones, ConstructConnect, February 2019.

<https://www.constructconnect.com/blog/electric-dreams-will-heavy-construction-equipment-go-electric>

From the article:

Globally, the construction industry is responsible for 11% of energy-related carbon emissions so it's not unreasonable to think that countries will at some point ban the sale of heavy equipment with diesel engines much like they are doing now [with] cars and trucks. Benefits of all-electric heavy equipment include reduced noise, zero emissions, reduced service times and a lower total cost of ownership.

Until that time comes, we're likely to see a lot more hybrid, as well as some all-electric, models of current equipment lineups from manufacturers in the coming years. Here's a look at a few of the current and upcoming all-electric offerings from some of the major players in the industry.

The article provides summaries of current and anticipated equipment from Bobcat, Caterpillar, Hyundai Construction Equipment Americas, JCB, Volvo Construction Equipment and Wacker Neuson.

National Research and Resources

“Operational Feasibility Assessment of Battery Electric Construction Equipment Based on In-Use Activity Data,” Fuad Un-Noor, George Scora, Guoyuan Wu, Kanok

Boriboonsomsin, Harikishan Perugu, Sonya Collier and Seungju Yoon, *Transportation Research Record*, April 2021 (online).

Citation at <https://journals.sagepub.com/doi/10.1177/03611981211004581>

From the abstract: This paper [analyzes] real-world second-by-second activity data from 17 off-road vehicles across six equipment types to investigate their electrification potential. The collected data are used to determine real-world power and torque demands—which are then used to select currently available electric motors suited for electrification of these types of equipment. Required battery sizes for battery electric operation are also calculated considering recorded energy demands, and battery sizes are standardized across equipment types for realistic implementation. The resulting battery electric systems are simulated to determine their effectiveness in fulfilling real-world activity demands. The results show that four of the six types can be electrified to a significant extent using battery electric powertrains with a single-motor set-up, while the remaining two types are more suitable for hybridization because of their high energy needs.

Transportation Electrification Beyond Light Duty: Technology and Market Assessment,

Alicia Birky, Michael Laughlin, Katie Tartaglia, Rebecca Price and Zhenhong Lin, Oak Ridge National Laboratory, September 2017.

<https://info.ornl.gov/sites/publications/Files/Pub72938.pdf>

From the executive summary:

This document focuses on electrification of government, commercial and industrial fleets. These fleets have been divided into three market segments based on equipment use: service fleets, goods movement and people movement. In particular, it addresses highway vehicles not used for personal transport; non-highway modes, including air, rail and water; and non-road equipment used directly or in support of these uses.

Electrification in the construction industry is discussed in Section 3.2, beginning on page 24 of the report (page 42 of the PDF).

Analyzing the Potential of Hybrid and Electric Off-Road Equipment in Reducing Carbon Emissions From Construction Industries, Matthew Holian and Jae-Ho Pyeon, U.S.

Department of Transportation, September 2017.

<https://transweb.sjsu.edu/sites/default/files/1533-analyzing-the-potential-of-hybrid-and-electric-off-road-equipment-in-reducing-carbon-emissions-from-construction-industries.pdf>

From the abstract: This report quantifies the likely impact recent improvements in emissions technology in the heavy construction equipment fleet will have on national- and state-level carbon emissions from construction industries. Specific technologies examined in this report include hybrid and electric-powered off-road equipment. Innovation in the equipment manufacturing industry, and adoption of innovative technology by construction firms, is driven by a wide range of factors, some of which can be influenced by public policy. Therefore, this paper describes policies available to public decision-makers at the local, state and national levels that impact equipment use and development decisions, including those that encourage the use of green equipment in government procurement, local level job site emissions regulations, and state and nationally mandated emissions standards, fuel taxes and direct research subsidies.

Electric Vehicle Fleet Implications and Analysis, Doug Kettles, Electric Vehicle Transportation Center, November 2016.

<https://rosap.ntl.bts.gov/view/dot/31876/comingFromSearch>

From the abstract: The objective of this project was to evaluate the implementation and effectiveness of electric vehicles (EVs) used in fleet operations. The study focuses on [b]attery-[e]lectric [v]ehicles (BEVs) and [p]lug-[i]n [h]ybrid [e]lectric [v]ehicles (PHEVs); collectively known as [p]lug-[i]n [e]lectric [v]ehicles (PEVs). The report reviews regulatory, operational and expense considerations and provides a review of current use and applications. Many classes of vehicles are included, from Class 1 motorcycles to Class 8 semi-trucks; in total, [12] different classes and applications are reviewed. The results reveal a broad spectrum of current usage, with case studies that include the use of electric motorcycles by police departments, [EV] use for ride-sharing and as taxis, and the use of mass transit electric buses. The report also identifies the programs, incentives and legislative mandates that encourage the expansion of EV fleet use, and how these programs may increase overall rates of market penetration and encourage new applications. Some applications can have a large impact, some much smaller; collectively, they work to make a positive significant difference in fleet operational efficiency and environmental and health impacts. These results can be used to evaluate other fleet vehicle applications by appropriate users.

Related Research and Resources

Electric Equipment

“Electrified Construction Equipment Gaining Momentum,” Sara Jensen, *Pavement Maintenance and Reconstruction*, page 42, March/April 2020.

<https://issuu.com/forconstructionpros.com/docs/pvm0320>

From the abstract: This article discusses the rise in electric-powered construction equipment among manufacturers seeking to meet emissions regulations and improve efficiency. The author explores the potential that electrification offers to reduce emissions, reduce noise levels, and increase operator safety and comfort. Also discussed are challenges associated with machine recharging and the increased pursuit of electric powertrains.

Battery Technologies

“Advancements in Battery Systems for Heavy Equipment are Increasing,” Sara Jensen, *ConstructionPros.com*, pages 42-43, December 2020.

<https://www.forconstructionpros.com/construction-technology/article/21206640/advancements-in-battery-systems-for-heavy-equipment-are-increasing>

From the article: As electrification continues to advance in the heavy equipment and vehicle industries, so do the battery technologies available to power them. With these new battery technologies have come increases in power output as well as new applications in which they are employed.

Hybrid Construction Equipment and Technologies

“Hybrid and Electric Vehicle (HEV/EV) Technologies for Off-Road Applications,” M. Abul Masrur, *Proceedings of the Institute of Electrical and Electronics Engineers (IEEE)*, Vol. 109, Issue 6, pages 1077-1093, June 2021.

<https://ieeexplore.ieee.org/abstract/document/9311805/authors#authors>

From the abstract: Hybrid and electric vehicle (HEV/EV) technology is reasonably mature at this time, with a few million vehicles around in the world, and there is a significant amount of

literature in the public domain on this subject. However, there is not enough literature on the application of this technology for off-road vehicles, including construction equipment, other industrial utility vehicles, and nonautomotive applications, such as a locomotive, ships or airborne vehicles. With this in mind, the author presents here the topic and its current status. In addition, the author discusses the issue related to the decision-making process before the above technology is introduced for any HEV/EV application so that one is assured that the technology will bring benefit if applied for a particular purpose.

“A Comprehensive Overview of Hybrid Construction Machinery,” Jixin Wang, Zhiyu Yang, Shaokang Liu, Qingyang Zhang and Yunwu Han, *Advances in Mechanical Engineering*, Vol. 8, Issue 3, March 2016.

Citation at <https://journals.sagepub.com/doi/10.1177/1687814016636809>

From the abstract: With the increasing attention of energy saving and emission reduction technology, the recent application of hybrid powertrain technology affects the development of construction machinery industry. This article reviews these publications and provides comprehensive references. This article reviews the state-of-art for the hybrid wheel loader and excavator, which focuses on powertrain configuration, energy storage devices and energy management strategies. The basis of classification and characteristic of each powertrain configuration are described. Advantages and disadvantages of batteries, supercapacitors, hydraulic accumulators and flywheel used in hybrid construction machinery are summarized. The existing energy management strategies for hybrid construction machinery are also elaborated. The technological challenges and developing trends in the near future for hybrid construction machinery are discussed.

Emissions Reduction

“Methods for Monitoring Construction Off-Road Vehicle Emissions: A Critical Review for Identifying Deficiencies and Directions,” Samad M. E. Sepasgozar, Heng Li, Sara Shirowzhan and Vivian W. Y. Tam, *Environmental Science and Pollution Research*, Vol. 26, pages 15779-15794, 2019.

Citation at <https://link.springer.com/article/10.1007%2Fs11356-019-05003-6>

From the abstract: The paper reviews the existing applications of sensing technologies for measuring construction off-road vehicle emissions (COVE) such as earthmoving equipment. The current literature presented different measurement methods and reported the results of utilization of new technologies for measuring COVE. However, previous papers used different technology applications covering only a part of the monitoring process with its own limitations. Since technologies are advancing and offering novel solutions, there is an urgent need to identify the gaps, re-evaluate the current methods, and develop a critical agenda for automating the entire process of collecting emissions data from construction sites, and monitoring the emission contributors across cities.

“Fuel Use and Pollutant Emissions Taxonomy for Heavy Duty Diesel Construction Equipment,” Phil Lewis and William Rasdorf, *Journal of Management in Engineering*, Vol. 33, No. 2, March 2017.

Citation at <https://trid.trb.org/view/1420070>

From the abstract: The purpose of this paper is to present a taxonomy of fuel use and pollutant emissions rates for heavy duty diesel (HDD) equipment to assist equipment managers in estimating the energy and environmental effects of their fleets. ... The taxonomy was based on real-world fuel consumption and emissions data collected from in-use equipment. An engine modal analysis was conducted on the data to categorize it by engine load. Weighted average fuel use and pollutant emissions rates were calculated based on the results of the engine modal analysis. The taxonomy presents weighted average fuel use and emissions rates according to

equipment type; Environmental Protection Agency (EPA) engine-tier technology type; and pollutants, including nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO₂) and particulate matter (PM). The taxonomy provides an accurate and easy-to-use guide to assist equipment managers in estimating fuel consumption and consequential pollutant emissions.

Developing a Model to Quantify Emissions From Heavy-Duty Construction Equipment,

Robert Russell, Kent Johnson and Thomas Durbin, California Department of Transportation, June 2014.

<https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0016793-final-report-task-2330-a11y.pdf>

From the abstract: Off-road equipment is one of the most significant sources of nitrogen oxides (NO_x) and particulate matter (PM), both nationally and within California. Within California, in-use off-road diesel equipment is estimated to be the [sixth] largest source of PM emissions and the [eighth] largest source of NO_x emissions, representing 7% and 4% of PM and NO_x emissions, respectively (CARB 2010). Although increasingly more stringent engine standards are being implemented for off-road engines, there is a still some lag between the implementation of the standards compared to similar standards for on-road vehicles. Off-road engines also have relatively long life spans, due to their inherent durability, and can sometimes remain in use for several decades. It is anticipated that the relative contribution of these sources will continue to increase as on-road emissions continue to be reduced. These factors make the control of emissions from off-road equipment one of the more critical areas in terms of reducing emissions inventories and protecting public health.

Measuring and Modeling PM Emissions From Heavy-Duty Construction Equipment,

Matthew Barth, Thomas Durbin, J. Wayne Miller, R.L. Russell and G. Scora, California Department of Transportation, January 2012.

<https://rosap.nrl.bts.gov/view/dot/27671>

From the abstract: Gaseous and particle emissions from construction engines are an important fraction of the total air pollutants and are gaining increasing regulatory attention. Quantification of NO_x and PM is necessary to inventory the contribution of the construction equipment, such as used by Caltrans, to atmospheric loadings, particularly for those projects in nonattainment or maintenance areas. At present, however, there is no model mutually accepted by Caltrans and regulatory agencies that can be used for the estimation of construction emissions or the development of appropriate regulations. This is due in part to a lack of emissions data from construction equipment under in-use operating conditions. The lack of a sound scientific basis for regulation has resulted in legal cases and other obstacles that could potentially delay or inhibit important transportation projects.