



The future of off-highway electric vehicles is here with electric excavators leading the way

As passenger vehicles increasingly become electric, so too will industrial and off-highway vehicles.

External drivers of off-highway electric vehicles

Led by global emissions standards and local noise ordinances

While there are many drivers pushing for electrification of industrial off-highway equipment, their relevance differs by segment and application. That said, both external and internal drivers are having an immediate impact.

Externally speaking, air and noise pollution are the greatest drivers. Local ordinances of inner-city construction sites demand emissions zoning and noise reduction standards, in addition to increasing importance of operator comfort.

On a national level, global emissions regulations will further drive OEMs to adopt new engine standards, reduce their emissions to near zero in the short-term, and ultimately zero emission solutions such as electrification or H₂ in the long-term.

EXTERNAL DRIVERS OF OFF-HIGHWAY ELECTRIFICATION

Local emission & noise avoidance

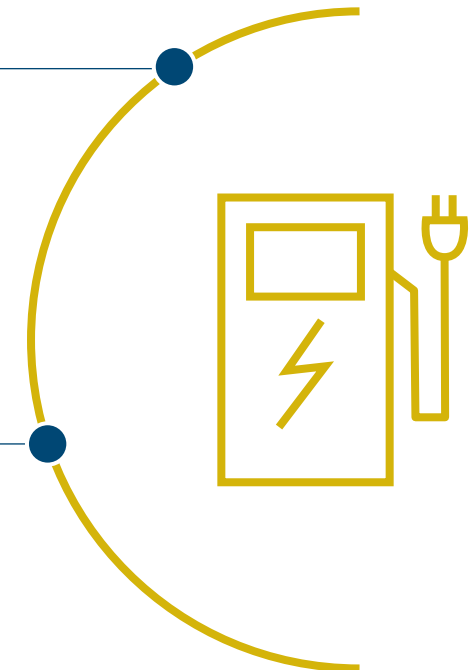


- Emission and noise reduction of inner-city construction sites
- Increasing importance of operator comfort

Emission regulation



- Transition to new engine standards
- Downsizing below regulation limits
- Urban low emission zoning increasingly relevant for off-highway equipment



= Agriculture



= Construction equipment

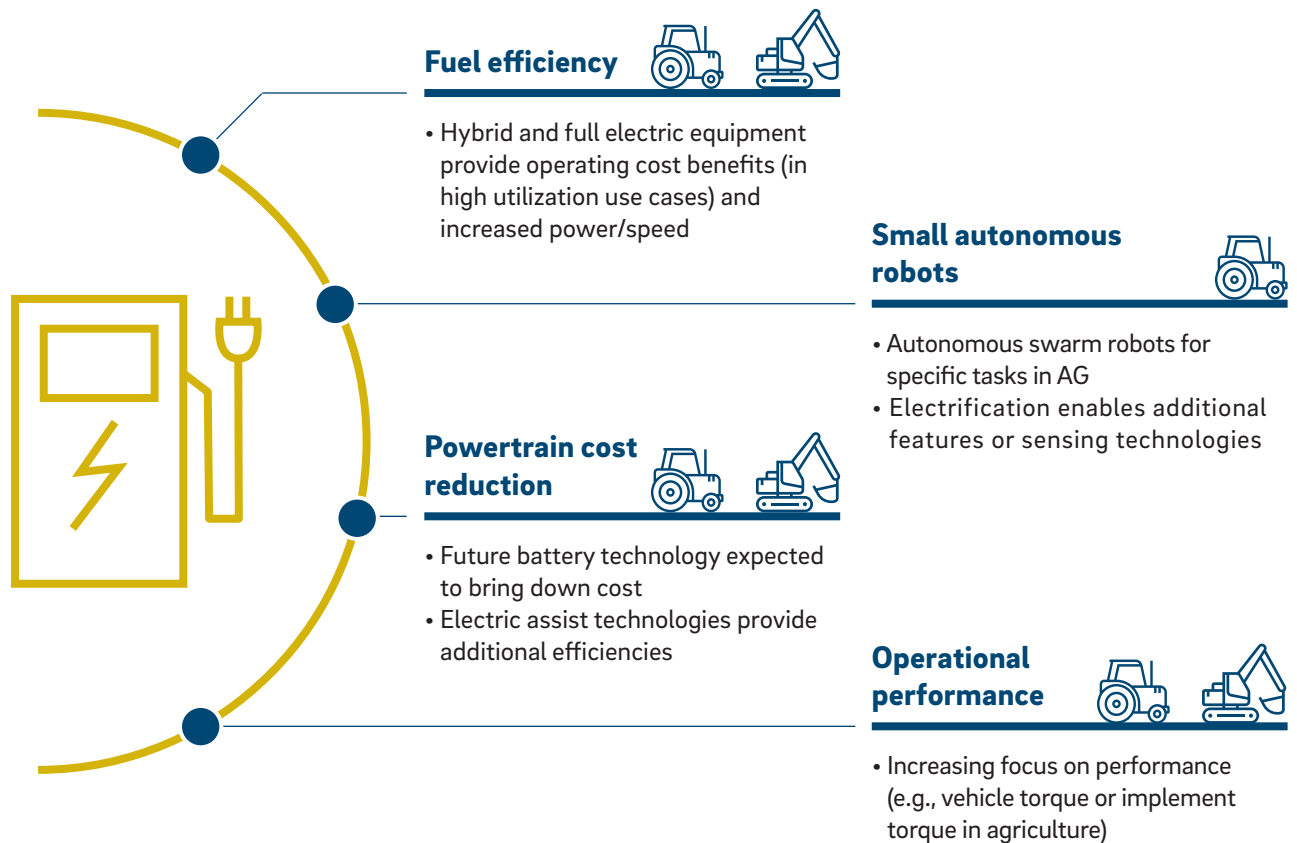
Internal drivers of off-highway electric vehicles

Better performance, cost reductions, and additional efficiencies

As for internal drivers of off-highway electric vehicles, with electric excavators leading the market, manufacturers are focused on increasing vehicle torque and performance in addition to better fuel efficiency through the adoption of hybrid and fully electric vehicles.

In high utilization use cases, both hybrid and fully electric vehicles achieve attractive “fuel” or energy savings. Future battery technology is expected to further reduce costs and electric assist technologies (such as autonomous swarm robots) are expected to provide additional efficiencies.

INTERNAL DRIVERS OF OFF-HIGHWAY ELECTRIFICATION



= Agriculture

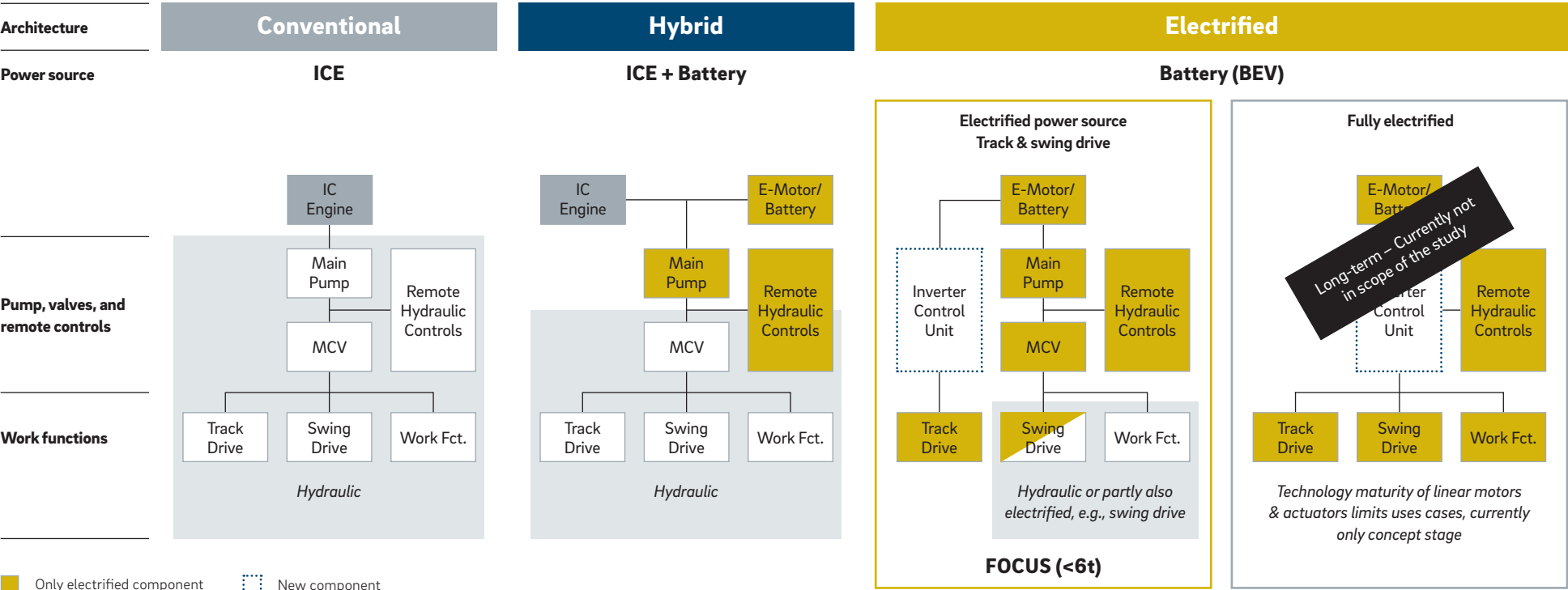


= Construction equipment

Electric drive trains are the immediate priority for small to medium weight equipment
Hybrid solutions less important overall though still a future option

While hybrid solutions could play a part in the eventual adoption of large electric excavators, electric drive trains for small and mini excavators (under 6 tons) are the immediate priority, according to current and planned manufacturing investments. As you can see in the accompanying figure, fully electrified components and vehicles will become more of a factor in the long-term. Although these developments were not in the scope of our current study, the technology must mature further before becoming a viable option.

SYSTEM ARCHITECTURE OVERVIEW – ELECTRIFICATION OF EXCAVATORS



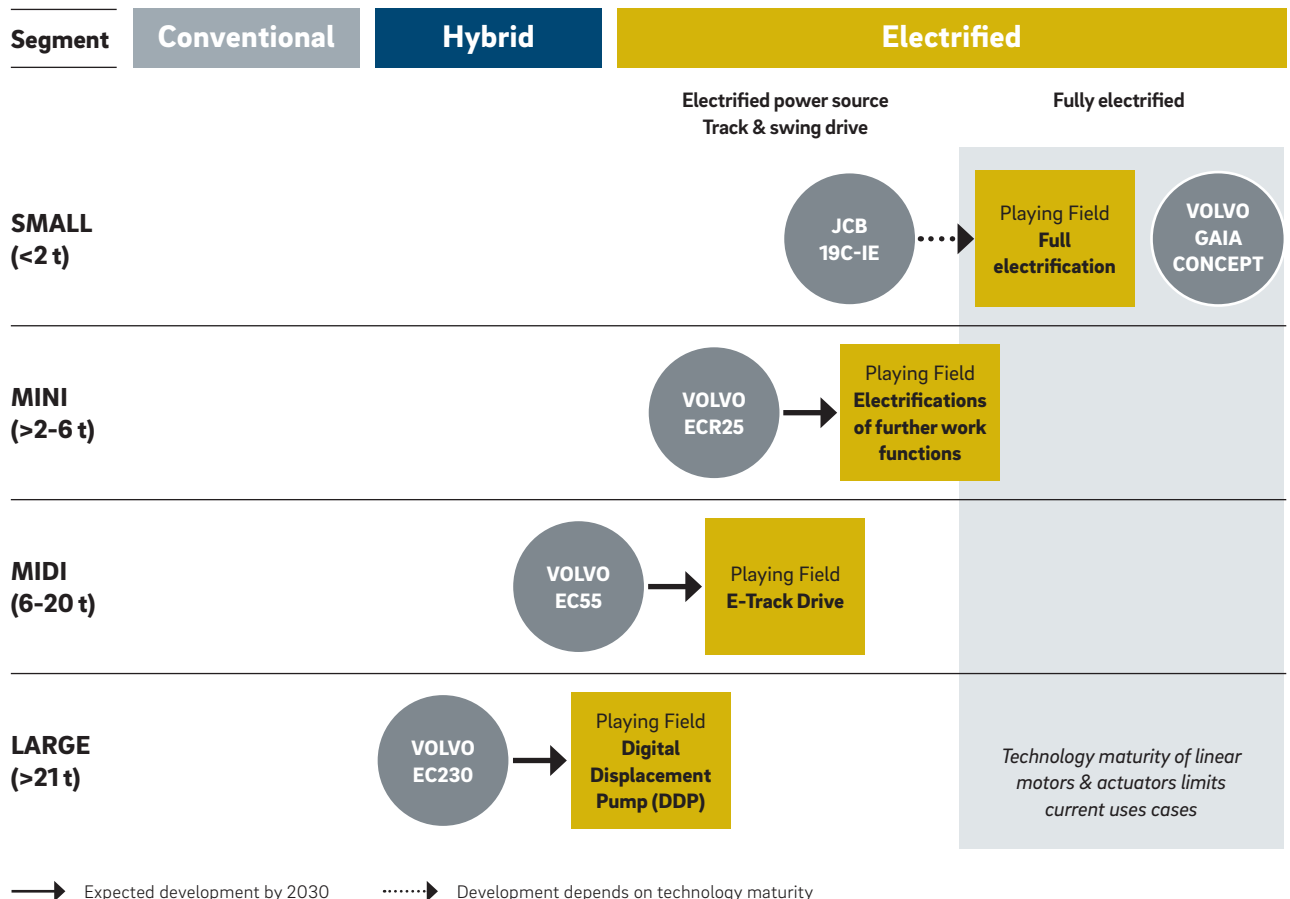
ICE = Internal combustion engine BEV = Battery Electric Vehicle MCV = Main control valve

Small and mini excavators are paving the way for electrification Larger segments will follow in the next 10 years

Although fully electric excavators are still in development, small and mini electric excavators under 6 tons have already arrived in small numbers. What's more, large scale market investments and trending penetration rates clearly show that electric excavators will account for up to 20% of select markets by 2025 (more on that later).

Moving forward, we expect small and mini excavators to be mostly fully electrified (or battery powered) on a wide scale, followed by medium excavators (6-20 tons), and lastly large excavators (over 21 tons) within 10 years time. The latter could involve more hybrid solutions, however, to account for the lack of remote charging options.

PATTERNS OF ELECTRIFICATION ARCHITECTURES ACROSS EXCAVATOR SEGMENTS



Source: Expert interviews, market research, Roland Berger

Electrification of excavators will be use-case-specific

The bigger the excavator, the harder the application becomes

According to current standards, small to mini excavators are good for urban construction sites, trenching, utility work, and landscaping. Although ill-suited for large scale jobs, smaller excavators are primed and quickly emerging as a zero-emission, low noise, and easy charging solution with the help of urban power grids. Alternatively, mid-sized and large excavators (6-20+ tons) are primarily used for digging and demolition, open pit mining, and pipeline work. These will likely go hybrid electric first, as current battery weights and lack of remote charging facilities make large electric excavators unfeasible for now.

ELECTRIFICATION ACCORDING TO SIZE

Equipment size	Usage	Pro's/Con's		
		Diesel	Hybrid	Battery electric
LARGE EXCAVATORS >20 ton	- Digging and demolition on large construction sites - Open pit mining - Pipeline work	+ Established tech + High power density - Additional emission controls needed for tougher standards	+ Operating cost benefits for high utilization applications	- Prohibitive battery weight and cost due to required high energy density - No charging facility at remote sites
MIDI EXCAVATORS 6-20 tons	Digging and demolition on standard size construction sites	+ Established tech - Additional emission controls needed for tougher standards	+ Operating cost benefits for high utilization applications	- Prohibitive battery weight and cost due to required high energy density - No charging facility at remote sites
MINI EXCAVATORS <6 tons	- Urban construction sites - Trenching, utility work - Landscaping	+ Established tech - Additional emission controls needed for tougher standards	- Lower equipment utilization limits operating cost benefits vs. system cost	+ Zero-emission + Low noise + Charging through domestic main supply

Mainstream technology
 Emerging future technology

Electrification is a priority for every major excavator manufacturer

All are investing, some are moving directly to battery electric

Since 2015, every major excavator manufacturer (10 in total) has dramatically increased their investment into electric excavators. These investments include original BEV mini excavators, prototypes, hybrid products, and even one planned medium-sized electric excavator.

Although there's no clear indication on whether mid- to large-size excavators will adopt battery or fuel cell technology, both are clearly in the plans of several manufacturers as they see this as an opportune path to the future. That said, many manufacturers say fully electric will not be the only solution and are considering battery powered components with combustion engine or hybrid drive trains.

ELECTRIFICATION OFFERING ACROSS SUPPLIERS

Electrification of the excavator business

ORIGINAL BEV PRODUCTS
(medium & large segment)

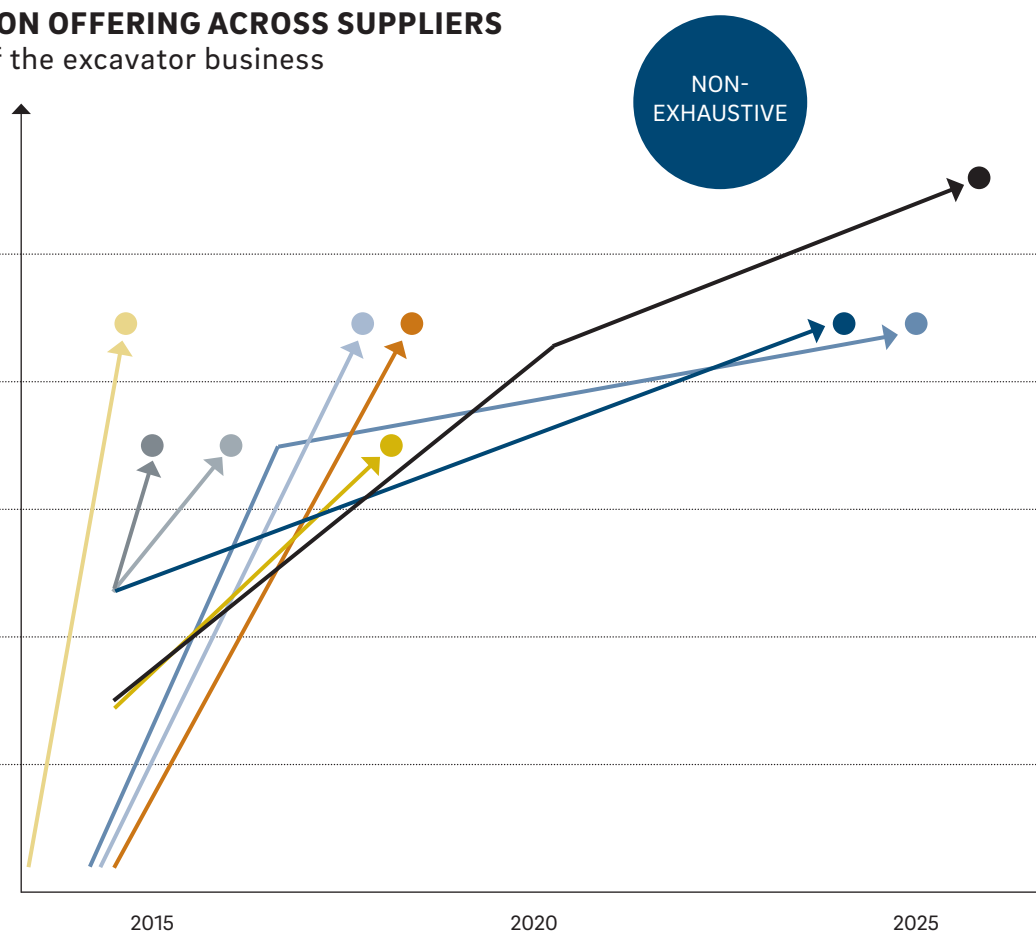
ORIGINAL BEV PRODUCTS
(small segment)

DEALER RETROFIT BEV

BEV PROTOTYPES

BATTERY ELECTRIC HYBRID PRODUCTS

NO BATTERY-ELECTRIC PRODUCTS



ICE = Internal combustion engine BEV = Battery Electric Vehicle

Source: Expert interviews, market research, Roland Berger

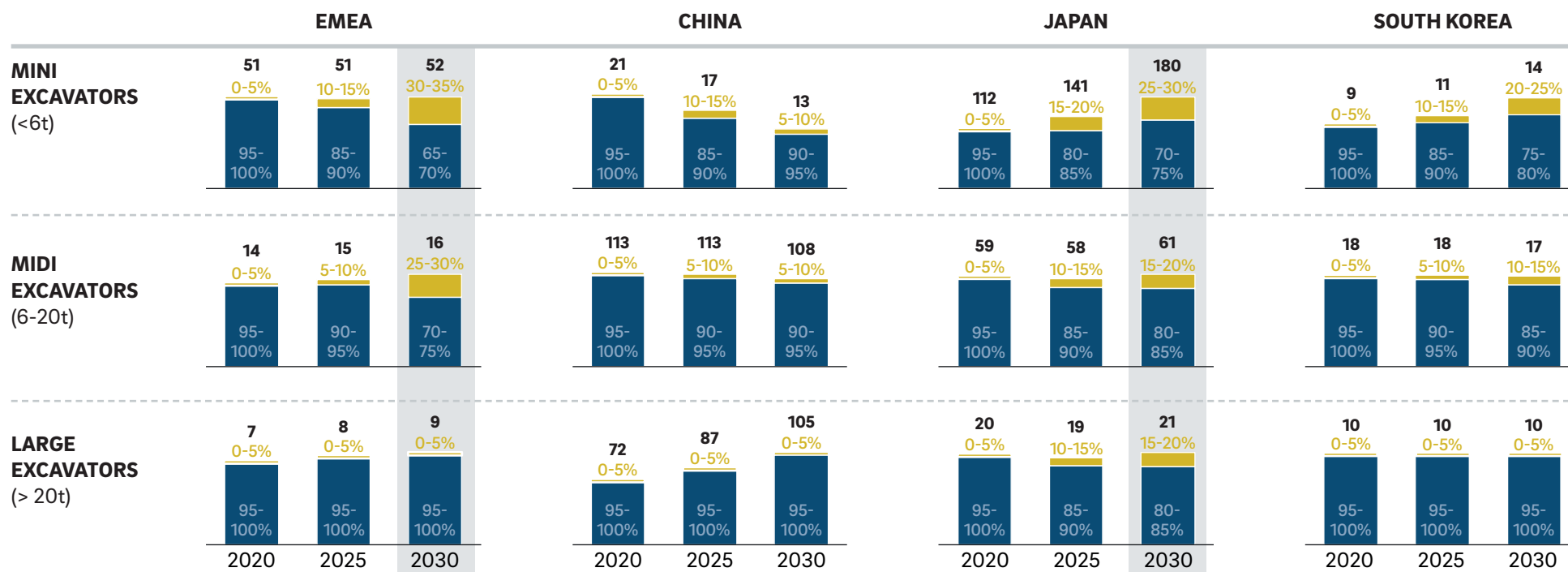
Japan and Europe at the forefront of industrial electrification

Two regions are the most advanced across all segments

While less than 1% of today's mini excavators (less than 6 tons) are currently available as fully electric, that number is expected to increase 20 fold in Japan and 10 fold in Europe by 2025, to 20% and 10% respectively. China and Korea are also expected to electrify up to 10% of their mini excavators by 2025 at the earliest, 2030 at the latest. Meanwhile, medium-sized excavators could reach 10% penetration in Japan by 2025, and 5% penetration in Europe, China, and Korea that same year. As for large excavators, only Japan has plans for significant penetration by 2025, hoping for 10% of total production that same year.

PRODUCTION LEVELS ACROSS MARKETS

Produced excavators - Conventional vs. BEV 2019-2030¹ ['000 units,%]



¹ Production volume within country/region

■ Units conventional

■ Units electrified (BEV)

To stay competitive, industrial equipment manufacturers must act now **All players must position themselves to take part in the future**

Today, most industrial manufacturers and suppliers have already launched first offerings (prototypes, small series, dealer retrofits) for all-electric vehicles, primarily in the small excavator segment. Given the sizable market pressures, all are rightfully considering where to invest in electric propulsion technology to ensure a competitive position once the market takes off.

While there are still unknowns for heavy-duty machines, new technologies or applications (or even old ones such as hybrid or fuel cell powertrains) could quickly change the prohibitive battery weight and remote charging issues affecting fully electric large excavators.

Therefore, industrial manufacturers and suppliers must chart their electric futures today while considering all technology choices, risk exposures, and suitable partners needed to succeed.

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