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SIX Sustainable Industry X | MOBILE WORK MACHINES

BUSINESS FINLAND

pspa We drive e-mobility!

Off-road and special purpose electromobility

Polish-Finnish recommendations for implementing zero-emission non-road machinery

Cooperation:

F5A New Mobility Research & Consulting

Introduction – Poland

Photo © Kramer

Introduction – Poland
by Aleksander Rajch, PSPA

Dear Readers,

According to the World Health Organization, more than 13% of EU residents are regularly forced to breathe air that contains more PM_{10} particulate matter than permitted by the relevant standards. For $PM_{2.5}$ – which is much more dangerous to health and safety – the rate mentioned above exceeds 6%. This dangerous trend has been progressing and is already shortening the life of an average EU resident by 6 to 12 months.

This situation is due to many different causes, but the main culprit is engines that – despite the use of better materials – still emit many harmful toxic compounds into the atmosphere during their operation. Such compounds include carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), and particulate matter (PM), also expressed as the particulate number (PN). The last two compounds are particularly problematic in compression ignition engines, which are the dominant engine type used in non-road machinery.

Regarding average air pollution with PM_{10} and $PM_{2.5}$ particulate matter (particulate matter with a particle size equal to or smaller than 10 and 2.5 micrometers, respectively), Poland is ranked second to last among EU countries.

Introduction – Poland
by Aleksander Rajch, PSPA

To reverse this negative trend and improve Poland's position in the EU air pollution ranking, decisive measures are required. The most significant step is to change the type of drive for special-purpose vehicles. The use of such vehicles, particularly in cities, during road works, renovation, construction, cleanup, and other operations significantly increases the emissions of harmful substances, including particulate matter.

This report discusses all the essential needs, guidelines, and recommendations for the industry and the legislation necessary to implement the required changes in the sector of special-purpose machinery as soon as possible and adapt it to the concept of zero-emission cities. These changes aim to make a tangible contribution towards improving air quality and the quality of life for residents.

The global construction industry is responsible for 23% of global pollution emissions. Machines driven by internal combustion engines generate 1.84 billion tons of CO_2, which accounts for 6% of global emissions. The industry also emits equally significant amounts of toxic substances, including nitrogen oxides (NO_x) and particulate matter (PM_{10} and $PM_{2.5}$).

The negative impact of non-road mobile machinery (NRMM) is a significant problem that can be solved by electrification, and this solution should be implemented as quickly as possible.

Aleksander Rajch
Board Member, External Affairs Director, PSPA

Introduction – Finland

Photo: Opa Latvala, Business Tampere

Introduction – Finland
by Harri Nieminen, VTT

Dear Readers,

The production of non-road mobile work machines is Finland's fourth largest export industry, with 50–80% of its turnover coming from export. That is why the country is spearheading efforts to electrify mobile machinery, with the decarbonization of complete industries and value chains.

Finland is home to a wide range of mobile machinery manufacturers, and in some cases, the top two competitors are in the same segment. More than 20 Finnish OEMs are active in the agriculture, construction, forestry, materials handling and mining machinery sectors.

To spur advancement in these sectors, the Finnish NRMM companies have joined forces in the SIX Mobile Work Machines cluster – in which SIX stands for Sustainable Industry X. Working together, these companies are leading the largest transition in history – digitalization and going green. The cluster's joint objectives are to build a cutting-edge research network, develop competence and future talent as well as increase the visibility and impact of mobile work machine builders globally through thought leadership.

Introduction – Finland
by Harri Nieminen, VTT

The members see their role not only in electrifying machines to reach zero emissions, but also in discovering totally new and unforeseen business opportunities throughout the entire value chain in which the machines operate. This calls for active member participation and requires Finland to cooperate with other countries that excel in new technology areas.

Finnish companies really "walk the talk" with a growing list of firsts in the electrification and decarbonization of heavy-duty mobile machines. Today, Sandvik is the market leader in electrification, automation and digitalization of underground mining machinery. Ponsse and Epec are introducing the first-of-its-kind electric forest machine technology. Kalmar terminal tractors are going electric. Many other projects focusing on the green transition are also in the pipeline.

By adding new and unseen value enabled by electrification, autonomous operation and digitalization, Finnish mobile work machine manufacturers seek to further increase their international competitiveness and decarbonize the environment. Now, these pioneering Finnish experts are ready to share their experience and knowledge with others aiming for climate neutrality in their own mobile machinery markets.

Reaching carbon neutrality also in non-road mobile machinery (NRMM) requires eliminating greenhouse gas emissions from fossil fuels. But above that - as we see it - the future mobile machine is not just sustainable as such. It is enabling totally new, unseen value and sustainability over the value chain the machine is operating in. Finland has taken a proactive role in this development to help build a better and more sustainable world of tomorrow.

Harri Nieminen
Co-Creation Manager, Head of SIX Mobile Work Machines Cluster, VTT Technical Research Center of Finland

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Executive summary

Achieving carbon neutrality requires a significant transformation, and many parties, including the European Union, have already set specific and ambitious targets. Greenhouse gas emissions from vehicles, including work vehicles, caused by the use of fossil fuels, are a key contributor to climate change. This dependence has not gone unnoticed by the Finnish authorities, which emphasize the need to decarbonize road transport, including all sectors and value chains. Due to the difficult conditions in the north of Europe and Finland's fondness for innovation, Finland has become a global leader in the development of heavy mobile machinery. Finnish experts want to share their transformation experience with partners who are aiming for climate neutrality in the mobile machinery market.

Carbon-neutral by 2035

Finland has achieved results that attract the attention of the whole world thanks to the electrification of mobile machinery and the decarbonization of industrial clusters. As a small country with a population of 5.5 million people, Finland is pursuing an ambitious goal of becoming climate-neutral by replacing fossil fuels with zero-emission electricity in the industrial, transport, and heating sectors. The Finnish authorities also plan to achieve negative carbon dioxide emissions. The production of mobile machinery is an important export sector in Finland, and the innovative features that have been introduced, such as electrification and digitization, improve the international competitive potential of the manufacturers.

Increasing demand for electricity

A study by Sitra (the Finnish Innovation Fund and an independent public foundation supervised by the Finnish parliament) indicates that Finland is well on its way to achieving its climate targets. It is estimated that extensive electrification of the Finnish economy will increase electricity demand by more than 20% by 2035. To handle this challenge, the Finnish electricity generation capacity must increase more than threefold from the current 20 GW to more than 70 GW by 2050, but Finland is prepared for that.

In recent years, the share of electric vehicles in Finland has been growing rapidly, and the country has become one of the European leaders in the development of electromobility. According to a survey by the European Environmental Agency (EEA) from 2021, Finland ranked fifth in terms of the percentage of newly registered electric vehicles in Europe, after Norway, Iceland, Sweden, and Denmark.

Electrification of non-road mobile machinery (NRMM)

The electrification of non-road mobile machinery (NRMM) is becoming more and more significant in preventing greenhouse gas emissions. Diesel- and gasoline-fueled internal combustion engines used by the machinery generate CO, CO_2, HC, NO_X, and PM emissions, contributing to climate change and adverse health effects.

Studies published in 2022 indicate that CO or HC emissions in the NRMM sector are 2.5–6 times higher than those from road vehicles, and PM emissions are 5.8 times higher, which is why Finland, Sweden, and Germany have introduced a system for recording NRMM emissions. Construction, agricultural, and forestry machines are the main sources of NO_X and PM emissions. The manufacturers want to accelerate electrification, which is why they offer training for employees, technicians, and customers to promote the environmental benefits of electric drives.

It is estimated that the manufacturers of mobile machinery will expand R&D activities concerning alternative powertrain technologies, focusing on electrification, in the next 2–4 years. Hybrid powertrains are a technology used as transitional technologies to stimulate the use of hydrogen and electricity as the main source of energy in NRMM.

How can other countries benefit from the experience of Finland?

The urgent need for decarbonization has a major impact on the strategies of the manufacturers of machinery, including heavy non-road machinery. Finnish companies and research institutions lead the way in the development of electrification and digitization technologies for the decarbonization of mobile machinery, paving the way for cooperation with global partners.

Thanks to the tradition of knowledge sharing, an excellent education system, and broad-based clusters, such as SIX Mobile Work Machines, companies from other countries can build their own capacity in research and innovation. Influential companies, e.g., Mitsubishi Logisnext, bring their R&D operations to Finland to take advantage of local skills.

Finnish policies to promote decarbonization, such as carbon pricing, inspire other countries to accelerate their anti-emission efforts. Companies that drive decarbonization can gain a competitive advantage over the competition and create innovative and profitable business opportunities.

The Polish potential of the NRMM sector

The Polish government introduced the Electromobility and Alternative Fuels Act, which mandates the use of a specific share of low- and zero-emission vehicles in public transport fleets of larger communes. However, the availability and prices of vehicles meeting such requirements were a significant problem.

In Poland, approximately 21% of electricity comes from renewable sources, but there are plans for expanding the RES capacities. However, it will not be until around 2030 that greater amounts of “green” energy will be available in the grid.

Electric city buses are popular in Poland thanks to the support from EU and Polish funds and local production of electric buses, e.g.: Solaris and MAN. The number of electric buses in Polish cities has reached one thousand, which helps to electrify other transport vehicles.

In Poland, there are ongoing programs for the co-financing of the purchase of electric cars and delivery vans, but there are no subsidies for the purchase of zero-emission high-capacity trucks or machinery.

Opportunities for the popularization of zero-emission machinery

At the moment, the offering of electric machinery is limited, there is no information about the economic parameters, and charging takes longer than refueling. Important aspects also include the subsidy system, which will be critical to the popularization of such machinery, particularly for rental, where the customers have to bear higher costs. Additional preference during tender procedures may encourage the users to select zero-emission machinery as long as beneficial legislative changes are introduced. Changes in the regulations should translate into a higher share of zero-emission machinery and equipment in municipal works, which, in turn, will result in greater public approval and increase the popularity of such machinery in other areas.

Who is to be responsible for this?

A reasonable increase in the share of zero-emission machinery in the construction industry and municipal services requires cooperation between the state government and the local authorities. On the government level, there is a need for a consistent policy of support and mapping of the introduction of zero-emission machinery. Local authorities, in turn, should give preference to zero-emission solutions, such as the requirement to use machinery consistent with the Stage V standard during the implementation of public works and training operators in efficient fuel use. It is also necessary to define the principles of tender procedures that give preference to lower emissions, with a comprehensive perspective of the job and a preference for electric machinery as the most favorable solution.

Finnish „zero” vision

Photo: Opa Latvala, Business Tampere

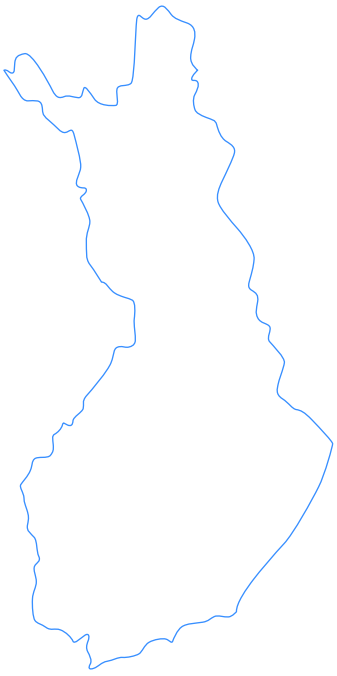
1. Electrification trends in Finland

Achieving carbon neutrality requires a significant transformation. The European Union, along with many countries, cities, and individual companies, has set ambitious mid- and long-term targets for climate neutrality. One of the most significant contributors to climate change is the emissions of greenhouse gases caused by the use of fossil fuels in vehicles. Replacing internal combustion engines in vehicles with electric drives is one of the ways to reduce emissions and achieve our climate targets. This transformation in the transport sector also extends to heavy non-road machinery and the processes in which such machinery is used.

In Finland, the electrification of mobile machinery is not merely a future trend – concrete actions are being taken today.

These actions include the decarbonization of the machines themselves and their operating environments, such as construction sites, mines, ports, farm fields, and forests. The electrification of mobile machinery accelerates the decarbonization of entire sectors and value chains.

Finland's position as a global leader in the development of heavy mobile machinery can be attributed to the challenging environmental conditions in the north of Europe. Additionally, the Finnish culture of innovation and teamwork has been instrumental in achieving breakthroughs in electrification and decarbonization within this industry. As pioneers in this transformation, Finnish experts aim to share their experience and knowledge with all partners who are striving for climate neutrality in the mobile machinery market.

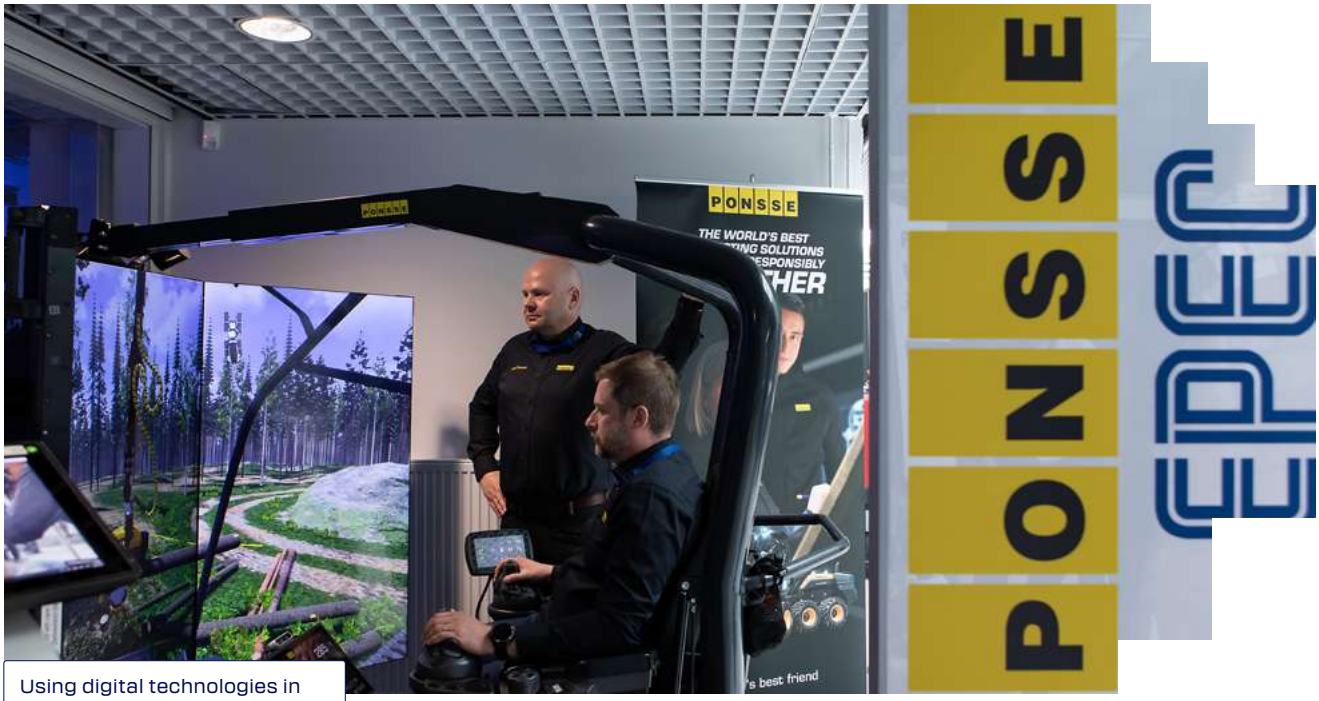


Carbon neutrality by 2035

Finland has taken a pioneering position in electrifying mobile machinery with results that are attracting the world's attention. Thanks to the country's unique combination of natural resources, willingness to invest in innovation and collaborative synergies, the electrification of heavy-duty machinery and decarbonization of complete industrial clusters are already happening today.

Finland is a small Nordic country with only 5.5 million inhabitants. Yet its government has already set out to reach its ambitious climate-neutrality target of 2035. In practice, this means replacing fossil fuels in industry, transport and heating with zero-emission electricity. Soon after that, Finland aims to reach carbon negativity.

The production of non-road mobile work machines is Finland's fourth largest export industry, with 50–80% of its turnover coming from export revenue. By adding new and unseen value enabled by electrification, autonomous operation and digitalization, Finnish mobile work machine manufacturers are seeking to further increase their international competitiveness. Therefore, many manufacturers are adding machines equipped with electrical power lines and new digital functions to their product range, seeing sustainability as a new significant business opportunity.



Using digital technologies in the forestry of the future

Photo: Opa Latvala, Business Tampere

Electricity demand to grow

An extensive study published by **Sitra, the Finnish Innovation Fund** and an independent public foundation supervised by the Finnish Parliament, estimates that Finland is well on its way to achieve its climate targets within the set timeframe.

Sitra estimates that extensive electrification of the Finnish economy will increase electricity demand by more than 20% by 2035. By 2050, Finland's electricity generation capacity must more than triple from the current 20 GW to over 70 GW, but Finland is prepared for that. The main drivers of success will be to ensure that the industry has a stable operating environment, sufficient incentives for electrifying its processes and support for developing new solutions.

Growth in digitalization

Another vast trend is digitalization, which offers significant potential for effective electrification. Digitalization and electrification are both critical components of the ongoing transition toward more sustainable and efficient machines. Finland is quickly becoming recognized as one of the leaders in digitalization, the Internet of Things (IoT), harnessing data and creating value from it with the power of artificial intelligence (AI).

Digitalization and IoT enable mobile work machine manufacturers to generate significant customer value. They form large, global ecosystems to which components, products and processes can be connected. Intelligent objects then become part of larger ecosystems, forming broad value networks of automated production systems and robots.

Digitalization makes it easier to collect, store and process data, which has given rise to big data analytics. In Finland, **developing data analytics and AI capability is a national strategy.** It can be used, for example, to maximize the service life of a machine or equipment and facilitate predictability, effective maintenance measures and remote services. Data also enables new opportunities to create value-adding services to accompany physical products.

Finnish companies not only excel at gathering data, they know how to visualize it and turn it into a form that meets their client's needs. Moreover, they know how to create added-value synergy for machine building, electrification and digitalization.

Using digital technologies in the logistics of the future

Photo: Opa Latvala, Business Tampere

2. How electrification is moving toward new vehicle segments

From cars to new heavy-duty segments

The share of electric cars in Finland has been growing rapidly in recent years. Finland is among the leading countries in Europe to adopt the use of electric cars. According to a study by the European Environmental Agency (EEA), **Finland ranked fifth in Europe in 2021 in the percentage of newly registered electric cars**:

1. Norway
2. Iceland
3. Sweden
4. Denmark
5. Finland

Due to a lack of sufficiently high energy-density storage solutions, electrification in heavy-duty transport, waterborne transport and aviation is happening more slowly than in passenger cars. Still, the advantages of indirect electrification can be used in these sectors since direct electrification is more difficult.

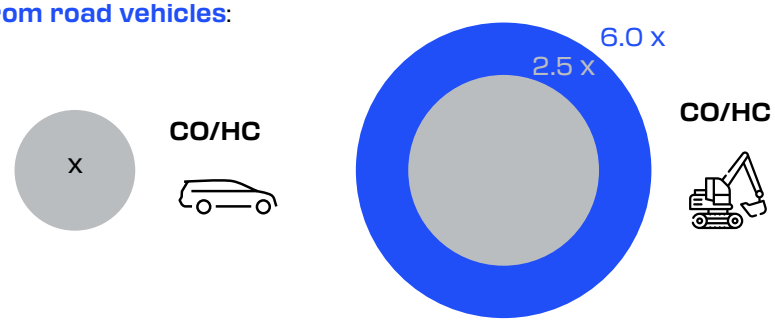
Power-to-X fuels and biofuels allow the decarbonization of harder-to-electrify transportation segments, such as heavy trucks. For example, the use of hydrogen and e-fuels may be future solutions to extend the operation range of electrified heavy-duty transportation. Similarly, hydrogen produced from ammonia or methanol can replace fossil fuels in waterborne transportation.

Electrification of non-road mobile machinery (NRMM)

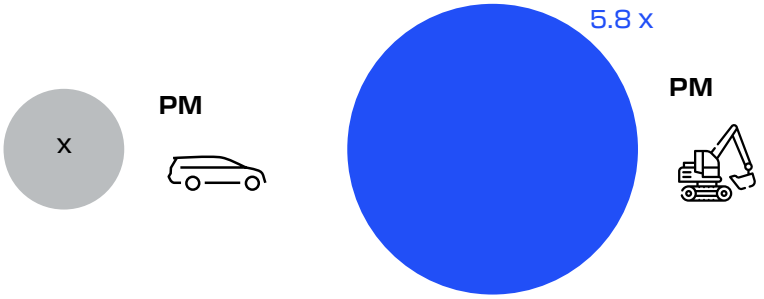
Electrifying the non-road machinery market is becoming ever more critical. Greenhouse gas emissions from combustion engines – diesel or gasoline fueled – installed in non-road machinery significantly contribute to climate change and cause adverse health effects with carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), nitrogen oxides (NO_X) and particulate matter (PM) emissions.

Without substantial technological advances to reduce the use of fossil fuels, NRMM will eventually surpass on-road vehicles as the leading source of greenhouse gas emissions. Due to the large variety of NRMM and difficulty in measuring their operational emissions, there are no exact numbers on emissions or associated fuel consumption. What is known is that the contribution of NRMM to overall emissions is indeed significant.

According to study published in 2022 (DOI:10.3390/su14063471), **CO or HC emissions from the NRMM sector are 2.5 to 6 times higher than those from road vehicles**:



The worst case is with the **PM emissions**, which are **on average 5.8 times higher in the NRMM sector** compared to road vehicles:



According to this same study, Finland is one of only three countries, together with Sweden and Germany, which already have some form of NRMM emission inventory.

Construction, agricultural and forestry machinery are among the most important groups responsible for most NO_x and PM emissions.

In recent years, non-road equipment manufacturers have started creating roadmaps to support sustainability strategies. To accelerate the transition to electric machinery, manufacturers have begun offering training for employees, technicians and customers – including rental companies and contractors – on market value, site productivity and the environmental benefits of electrification.

In the next 2 to 4 years, non-road machinery OEMs are expected to expand their research and development in alternative powertrain technologies, with a focus on electrification. New participants are actively entering the market in the electrification and digital technology space. Already today, hybrid powertrains are being used as transitional technologies to stimulate the use of hydrogen and electricity as the main source of energy in NRMM.

3. What makes Finnish experience unique?

Finland has a long history of producing mobile work machines for harsh operating conditions, resulting in proven manufacturing competence in the mobile machinery industry and cumulated R&D experience that is shared openly among the players.

World-class mobile equipment manufacturers

Finland is home to perhaps the broadest range of mobile machinery manufacturers, and in some cases, the top two competitors are in the same segment, which spurs advancement.

There are **over 20 active Finnish OEMs** in the agriculture, construction, forestry, materials handling and mining machinery sectors alone. Some of the largest ones include:

- **AGCO Power**
- **Avant**
- **Bronto Skylift**
- **Cargotec/ Kalmar**
- **Dinolift**
- **John Deere**
- **Junttan**
- **Konecranes**
- **LMCE Group**
- **Logset**
- **Mantsinen**
- **Metso: Outotec**
- **Normet**
- **Ponsse**
- **Rocla/ Mitsubishi**
- **Logisnext**
- **Sampo**
- **Rosenlew**
- **Sandvik**
- **Tana**
- **Valtra**

The entire mobile machinery manufacturing value chain is represented in Finland by numerous companies operating at each step of the chain to deliver and service reliable, high-quality mobile machinery to customers throughout the world.

Broad base of specialized support firms

The Finnish mobile machinery value chain also consists of a broad base of specialized small- and medium-sized enterprises (SMEs) that support the OEMs in forming a capable and experienced partner network with the competences required for these demanding and high-tech applications.

These SMEs provide advanced technology, system integration and service business know-how with a deep understanding of end-user processes and needs. Some provide advanced niche parts, components and accessories. Others work as contract manufacturers.

All companies in the wider network work to allow Finland to take a leading role in achieving:

- ↗ **Digitalization to create new business opportunities and competitive advantage**
- ↗ **Autonomous and driverless operation for higher ease of use and safety**
- ↗ **Sustainability through resource efficiency and circular economy implementation**
- ↗ **Increased production using real-time monitoring and tracking**

Special collaboration culture

A special culture of collaboration has sprung up in Finland between academia, companies and research institutes that may be more vibrant than anywhere else. Finland's education system, engineering skills and technology know-how rank it high for innovation worldwide. **According to the European Innovation Scoreboard 2022, Finland ranked second**. This collaboration drives the development of new, disruptive solutions, with all parties having a chance to work together, share ideas and build on them in a very encouraging environment.

This unique collaboration comes naturally for the Finns and their business development. It enables Finnish companies and their engineers to understand the whole value chain from R&D through manufacturing and on to successful logistic chains. This enables Finland to take on the role of a leader in this field.

The government of Finland has supported these focused clusters of businesses for decades through funding and international promotion of the results.

Overall, Finland supports highly networked, business-driven research and development programs annually with well over:

EUR 1 billion

to help facilitate the renewal and development of competitiveness in industries.

The aim is to scale up long-term R&D and forward-looking projects that otherwise may never be able to take off. Global companies, such as Mitsubishi Logisnext most recently, have even been drawn to Finland to participate in these appealing programs.

4. Finnish collaboration ecosystem – SIX Mobile Work Machines

Proactively building the future of mobile machines has resulted in the mobile work machine cluster **SIX Mobile Work Machines** in which SIX stands for Sustainable Industry X. The cluster's shared vision is that by 2025 Finland will be known as the world's best place for developing mobile work machines and their key technologies and services.

The cluster is made up of some of the most highly esteemed global brands of mobile machinery manufacturers and their ecosystemic partners, including **Cargotec/ Kalmar, EPEC, Hevtec, Junttan, Nokia, Normet, Ponsse, Sandvik, Tana, Valmet Automotive, Valtra and VTT**. They have all enjoyed long traditions of developing rugged machinery that operates reliably in Finland's harsh conditions as well as in countless other demanding environments around the world. Their international success comes from unmatched performance, long-term durability and low operational costs over their lifetime.

These heavy-duty mobile machine companies have joined forces to embrace the largest transition in history that is taking place now – a twin transition of digitalization and going green.

The members of SIX Mobile Work Machines see this as a unique business opportunity. It is not only a question of electrifying the machine itself to reach zero emissions, it is about discovering totally new and unforeseen value throughout the entire value chain in which the machine operates. This addresses sustainability in a much wider context.

SIX Sustainable Industry X | MOBILE WORK MACHINES

In addition to sharing a common vision, the companies in SIX Mobile Work Machines share three joint objectives:

1. **To create efficient and effective joint innovation development,** building a cutting-edge research network. This allows the cluster members to speed up heavy and time-consuming research and development work by being able to tap into a basket of shared research results for further use by any other member for their own purposes.

2. **Development of competence and availability of future talent.** The members aim to raise the attractiveness of working in the industry by identifying the skills and capabilities needed for new tasks and then providing the necessary educational programs.Ensuring future talent for the industry is a challenge being faced not only in Finland but throughout the world. Skilled talent is needed for both blue- and white-collar roles. Persons with talented research capabilities are also greatly needed for innovative development.

3. **To increase the visibility and impact of mobile work machine builders in Finland and around the world through thought leadership** This will attract investments and the finest experts into the industry. Additionally, it will enable the cluster members to influence the development of global standards and other regulations affecting their areas.

Joint roadmap defines the way

SIX Mobile Work Machines has already crystallized its joint roadmap as a guiding line for the cluster members. The roadmap is filled with a strong portfolio of projects that are all interconnected. It aims to define what is needed to achieve the future smart mobile working machine by 2030.

The interconnected programs within the roadmap cover topics such as: autonomous operations and drive solutions, control systems for intelligence, connectivity and communication, smartly electrified, data-intensive lifecycle services, enabling creation of new and more useful data from raw data and keeping the human in the loop.

Action pays off

The SIX Mobile Work Machines cluster is unique in many ways. It brings together companies that strive toward the same goals. They must all have a high level of commitment to making it work. Each company must bring something to the table – and also be able to get something from it for their own use. Yet most of all, every member must be active.

Collaboration is a key success factor in realizing the vision. This is one core element that Finnish companies do very well. Achieving the cluster's digital-green goals requires cooperation from numerous stakeholders in the private sector, public sector and academia.

Finland has had a deep focus on many small mechanical engineering areas. Now, it has taken a higher system approach with mechatronics. To maintain its leading position in mobile machinery, Finland will need to continue its decade-long cooperation work with other countries that excel in new technology areas.

The SIX Mobile Work Machines cluster opens up new ways of collaborating with other cluster members and also with external partners. It opens multiple doors to new business opportunities.

5. Case studies - Sandvik, Ponsse and Kalmar

Finnish companies have proven that they can really "walk the talk" with a growing list of firsts in electrification and decarbonizing heavy-duty mobile machines.

Normet's electric battery-powered carriers optimize energy consumption and performance in underground mining and tunneling applications. Ponsse and Epec are introducing the first-of-its-kind electric forest machine technology. Konecranes' zero-emission forklifts minimize the carbon footprint and improve the carbon handprint of equipment at terminals and in heavy industrial applications. Kalmar terminal tractors are going electric. And many other projects for green success are in the pipeline at Finnish companies.

Case study

1980s	Sandvik Mining and Rock Solutions' interest in electric solutions began in the with the production of tethered loaders and trucks.
2005-2010	The company began studying the use of battery power for their equipment, producing its first electric machine concept in 2009.
2014	Sandvik developed the first battery underground drill, which was commercialized in 2016.
2019	The company's loading and hauling factory acquired US-based Artisan, now part of Sandvik, which boosted the electrification journey for loading and hauling.

Today, Sandvik is bringing more electric machinery to the market – parallel offerings of both battery and diesel power in the same equipment class. To date, diesel still has the majority share of sales, but the market is demanding electrification for a number of important reasons, especially in underground mining.

Electrification brings greater advantages than just being carbon free. Electrification increases productivity, reliability and safety. Electric underground mine machinery requires less ventilation. Fully autonomous or remote-controlled mining equipment minimizes risks in hazardous environments, like underground mines. The machines are also more accurate to control than conventional equipment and perform jobs faster.

Based on Australia's demand for autonomous machinery in underground mining, Sandvik innovated its **AutoMine solution for loading and hauling**. Today, the range covers full-autonomous and remote-controlled machinery for both surface and underground applications. Advantages include being able to remove operators from hazardous environments and attracting skilled operators to mining. This was followed by Canadian legislation for electrification. But now the global market requires electrification, automation and digitalization.

By 2030–2035, Sandvik aims to offer both electric and diesel options for all its machines and will offer more carbon-free electric solutions for surface mining, as cities will no longer accept diesel-driven machinery. Sandvik concept machines already exist for underground, surface drilling and loading.

Sandvik's Tampere Test Mine is recognized globally as a state-of-the-art environment with 6 km of real tunnel conditions for testing new technologies, demonstrating concepts to customers and verifying the quality of each drilling rig before delivery. It also serves as a center for hands-on equipment training. Additionally, Sandvik is open to having partners from other industries come and test their solutions in these real-mine conditions.

Today, Sandvik is the market leader in electrification, automation and digitalization of underground mining machinery – and aims to maintain that position. Plus, the company is pushing to become the market leader in surface mining. Sandvik is strongly committed to leading the technology transition and staying #1 in its chosen markets.

PONSSE

Case study

Electrification may seem natural also for forestry companies, but this industry actually lags behind many others. Although forestry machines handle and process a great, renewable and sustainable product – timber – the equipment harvesting it normally operates far from any infrastructure or grid, making recharging impossible or difficult – even in the future.

Almost 10 years ago, Ponsse began to tackle the issue of the machinery's high diesel consumption while harvesting and extracting timber with early electrification studies and first concept work. The company first reviewed the harvester application. Since the drive transmission is mostly stationary while the boom and harvester head do most of the work, overall carbon emissions were not significantly reduced.

With the rapid transformation in the automotive business, Ponsse decided about 4 years ago that electrifying its forwarder's drive transmission could be more beneficial and viable. The company considered the business case, starting with feasibility studies

Future Mobile Work Machine Conference in Tampere bringing together global leaders of electrification and digitalization in the machinery sector

Photo: Opa Latvala, Business Tampere

and total cost of ownership, verifying an electrified forward could offer added value. In August **2022, Ponsse launched its EV1 technology concept together with its technology company Epec Oy.**

The full-size machine concept is now working in forest tests, to the awe of customers. Although the forwarder appears the same from the outside, everything under the hood is new. The powertrain is now future-ready for other, more sustainable than fossil-diesel fueled prime movers or energy sources.

Ponsse is also continuing to improve energy efficiency for harvesters. Since the topologies of the forwarder and harvester are completely different, Ponsse is looking into modular solutions that can be applied to both applications.

Switching from hydrostatics and mechanical powertrains to electric ones is highly intriguing for the company's R&D team but poses huge barriers. One of the biggest challenges for Ponsse is that all component and systems engineering for a non-road machine is completely new. It is simply not possible to engineer an electrified machine in an old-school way. Key components for heavy off-road machinery are also not available as off-the-shelf products.

More than 90% of all emissions of a forest machine over its lifetime typically come from diesel consumption during operation. Electrification is clearly one of the key technologies and enablers to drive toward carbon neutrality.

To handle the peak loads needed by heavy non-road machinery – especially forestry machinery – conventional diesel engines are typically over-dimensioned by three times or more compared to their average power needs. Electrification allows the prime mover to be downsized, which alone is a huge benefit.

Ponsse now leads the market in electrifying forestry machinery. The company is the first to come out with a viable full-size hybrid-electric forwarder concept and is pushing to meet its customers' demands for lower emissions, lower fuel consumption and the opportunity to use other sustainable, renewable energy sources in the near future.

KALMAR Case study

Kalmar, **part of Cargotec**, is the global leader in sustainable cargo handling for ports, terminals, distribution centers and heavy industry. The company is a forerunner in electrification, improving its customers' every move.

In the beginning, Kalmar replaced combustion engines with fully electric systems on its material handling trucks in warehouses. Interest in electrification then spread to include the company's many types of cargo and container handling machines.

1980s Kalmar started its electrification journey in the by introducing electric forklift trucks in the light capacity range.

2016 Kalmar was the first in the world to electrify its Kalmar straddle carrier in response to the growing environmental pressure from ports like those in California to minimize CO_2 emissions.

Today, Kalmar has **sold more than 500 hybrid straddle carriers featuring a diesel/electric drive** for which electricity generated by the diesel engine can be stored in batteries. But the transformation is clearly under way, and customers are now testing and buying fully electric machines. Kalmar is also actively investigating the many options for alternative fuel sources, like hydrogen with diesel.

Currently, the company has an electric version available for all its machine models and is further developing them to find new battery solutions. Battery capacity available today poses the greatest challenge to the electrification of large machines operating with heavy loads. How many driving hours are needed before recharging the machine?

Kalmar is also looking into “opportunity charging” to integrate charging into operations and normal working cycles. This means making charging opportunities available for short periods at the spot where a machine is handling a stationary task for a few minutes, such as picking up a container.

Kalmar’s automated machines follow job orders and commands from a central server that manages routing to avoid congestion at seaports or terminals. The company’s first automated straddle carrier, **Kalmar AutoStrad, was delivered to Brisbane, Australia, followed by automated cranes for Hamburg**. Now, these solutions are used at many ports in the world.

Kalmar has trained its personnel to engineer and maintain electrical machines. The company realized that the professionals maintaining electrical vehicles must have different skills than those maintaining combustion engines. Even their global service organization has experts who can help customers with the new electrification and automation technology.

For many years, Kalmar has cooperated closely with European universities in research. This has pushed the company’s development forward, enabling Kalmar to be a forerunner with many of their machines. Investigating electrification for many years has taught the company what to improve throughout the journey.

6. Key benefits of electrifying moving machinery

Electrifying mobile work machinery not only means moving toward net-zero emissions and decarbonization, it also answers the pressing demands from countries, cities and end users today who realize it makes sense for both the environment and business.

In mining, Sandvik has proven that **electrification raises productivity, reliability and safety.** Their use of automation and digitalization have made mining operations more attractive by eliminating risks associated with hazardous working environments.

Ponsse sees electrification as a way to **eliminate power-train losses and gain a radical improvement in system efficiency**. Moreover, electrification is key in tackling the huge fuel consumption during long annual working hours. Their mission and vision is to be the preferred partner for responsible forestry.

Kalmar has recognized that electric-driven machines are **easy for operators to maneuver**, enjoyable to operate and easy to control. Lowering energy consumption and improving sustainability are increasingly important for customers to achieve their own business targets.

For all types of vehicles, electrification has demonstrated that the use of batteries to power operations rather than burning expensive fuel has reduced the cost of ownership over time.

In all, electrification protects the environment, improves air quality, reduces noise and increases the health and well-being of citizens. By leveraging the power of electrification, companies can position themselves for long-term success in a rapidly changing energy landscape.

The Polish potential of the NRMM sector

Photo © Kramer

7. The Polish potential of the NRMM sector

Poland has a population of over 37 million, with 22.5 million residing in cities. Consequently, the urban population accounts for no more than 60%, a figure that has remained relatively stable for several decades, albeit with a slight decline. This indicates a relatively slow pace of urbanization in terms of sheer numbers. Meanwhile, the number of villages being granted city status is increasing annually. According to current criteria, this requires a population of more than two thousand, with at least two-thirds of the population not engaged in agriculture.

There are 37 Polish cities with a population exceeding 100 thousand. These changes can be described as qualitative due to their rapid expansion and comprehensive revitalization of urban infrastructure. Specifically, this applies to public transportation networks, such as underground and tram lines, and more recently, the installation of electric vehicle charging stations. The aging water and sewage systems are being refurbished, and new systems are being constructed. This area witnesses unprecedented urban and industrial projects.

Consequently, Polish cities will experience intensive construction activities in the immediate future, particularly in close proximity to residents.

MECALAC e12

Photo © Mecalac

In order to adhere to the energy transition guidelines set by the European Union and enhance living conditions in densely populated areas, the Polish government introduced the Electromobility and Alternative Fuels Act in January 2018. This legislation mandates the use of a specific proportion of low- and zero-emission vehicles in the municipal fleets of cities, as well as in the fleets of companies responsible for public transport and municipal services in communes with populations exceeding 50,000.

The implementation of these requirements has been repeatedly postponed due to limited market availability of vehicles meeting the act's criteria and their high prices, which often make them an unviable investment. Another crucial consideration is Poland's energy mix. **Currently, approximately 21% of energy production comes from renewable sources, despite having an installed renewable energy capacity of 38%.** The lower efficiency of photovoltaic panels throughout the year and moderately favorable conditions for onshore wind turbines contribute to this disparity. Other renewable sources, such as hydropower, make up a minimal share of the overall energy production.

There are ongoing efforts to expand renewable energy installations and complement them with nuclear reactors. However, the power grid will not be able to handle larger amounts of "green" energy until around 2030. Consequently, the cost and benefit analyses have not justified the purchase of zero-emission vehicles, and the sale of vehicles running on compressed natural gas (CNG) or liquefied natural gas (LNG) has slowed down due to significant increases in natural gas prices. As a result, only a few local initiatives aimed at reducing emissions exist, and they are closely tied to the local availability of high-power charging infrastructure and low electricity costs, often associated with having their own renewable energy sources.

This does not pertain to the topic of electric city buses however, which have received subsidies from various EU and Polish funds. Another important factor supporting zero emission public transport is the **local production of electric buses, with companies like Solaris and MAN playing a significant role.** Solaris, in particular, has extensive experience in zero-emission drivetrains and offers a wide range of electric vehicles across different classes. The company also provides comprehensive services related to route analysis and charging infrastructure, including "turnkey" projects. **The number of electric buses in Polish cities reached 885 units**, and the knowledge gained from this experience, along with the existing charging infrastructure, is facilitating the electrification of other types of transport vehicles.

In Poland, the government has implemented ongoing programs to provide co-financing for the purchase of electric cars and N1 category delivery vans. However, there are currently no subsidies available for the purchase of zero-emission high-capacity trucks or machinery.

8. Machinery - definitions

At this point, it is necessary to establish the scope of equipment that can undergo emissions reduction and electrification. There is a significant difference in terminology between the Polish traffic code and the definition provided by Regulation (EU) 2016/1628 of the European Parliament and the Council, introduced on September 14, 2016. The Polish traffic code refers to “slow-moving vehicles” capable of traveling up to 25 km/h, excluding agricultural vehicles. However, limiting the analysis to these two categories would not sufficiently cover the concept of “non-road mobile machinery” (NRMM) as defined by the European regulation.

According to the EU provision, NRMM encompasses a broad range of mobile machines, transportable equipment, and vehicles, with or without bodywork or wheels, not intended for transporting passengers or goods on roads. This definition encompasses machinery installed on the chassis of vehicles designed for on-road transportation of passengers or goods. NRMM includes various types of machinery used in sectors such as construction, agriculture, gardening, forestry, material transportation, and municipal works. These machines vary in size, weight, and engine power. NRMM also includes equipment such as chainsaws and heavy site haulers. Their contribution to global emissions is substantial and varies significantly, necessitating individual consideration for each case in terms of opportunities for local emissions reduction.

Regulation (EU) 2016/1628 establishes the exhaust gas pollution limits known as the Stage V standard, which is categorized into 10 main categories and numerous sub-categories based on engine functions and power. For our analysis, the following categories are particularly relevant:

- **NRE:** machinery typically classified as non-road machinery, primarily used in the construction industry
- **NRG:** engines used in power generators
- **NRSh:** engines for handheld equipment
- **NRS:** (engines characterized by spark ignition other than the NRSh classification).

Since January 1, 2019, the Stage V standard has been applicable to all engines. Another significant emission standard in the global machinery industry is the US Final Tier 4, introduced by the Environmental Protection Agency (EPA), which closely aligns with the EU Stage V in terms of emission levels. Similarly, other countries with significant production and use of NRMM, such as China and India, have implemented limits based on those set by the USA, albeit with delayed implementation dates.

There are perspectives that argue the legislation regarding NRMM emissions falls short compared to the standards imposed on road transport and does not effectively promote the use of innovative solutions. It is true that the provisions limiting the presence of primary harmful substances in exhaust gas (such as NO_x, HC, CO, and particulates) in Europe date back to the end of the previous century. This discrepancy can be attributed to political factors, as road vehicles are more numerous and conspicuous, attracting greater attention. However, the wide range of applications for NRMM must also be considered.

Engines in NRMM operate under significantly different conditions, even within specific categories. The tests conducted during type approval procedures are synthetic and provide data primarily for comparative purposes. Actual emissions depend to a much greater extent on the loads and the skills of the operator than in the case of road vehicles.

The current European legislation does not specifically address CO_2 emissions from NRMM, and there are no consistent efforts to define suitable limits in this regard. This can be attributed to the diverse range of applications for which adopting criteria from road vehicles, such as breakdown by gross weight, would not be applicable. However, machinery in sectors such as construction, mining, and agriculture has significant potential for reducing CO_2 emissions.

In the construction and mining sectors, electric machinery powered by the grid has been known and utilized for many years. Battery-powered solutions are also widely employed in forklift trucks and material-handling vehicles. Challenges to overcome include the development of durable batteries capable of sustaining high-power consumption over extended operating periods before requiring recharging. Additionally, efforts are being made to enhance battery lifespan and reduce charging times.

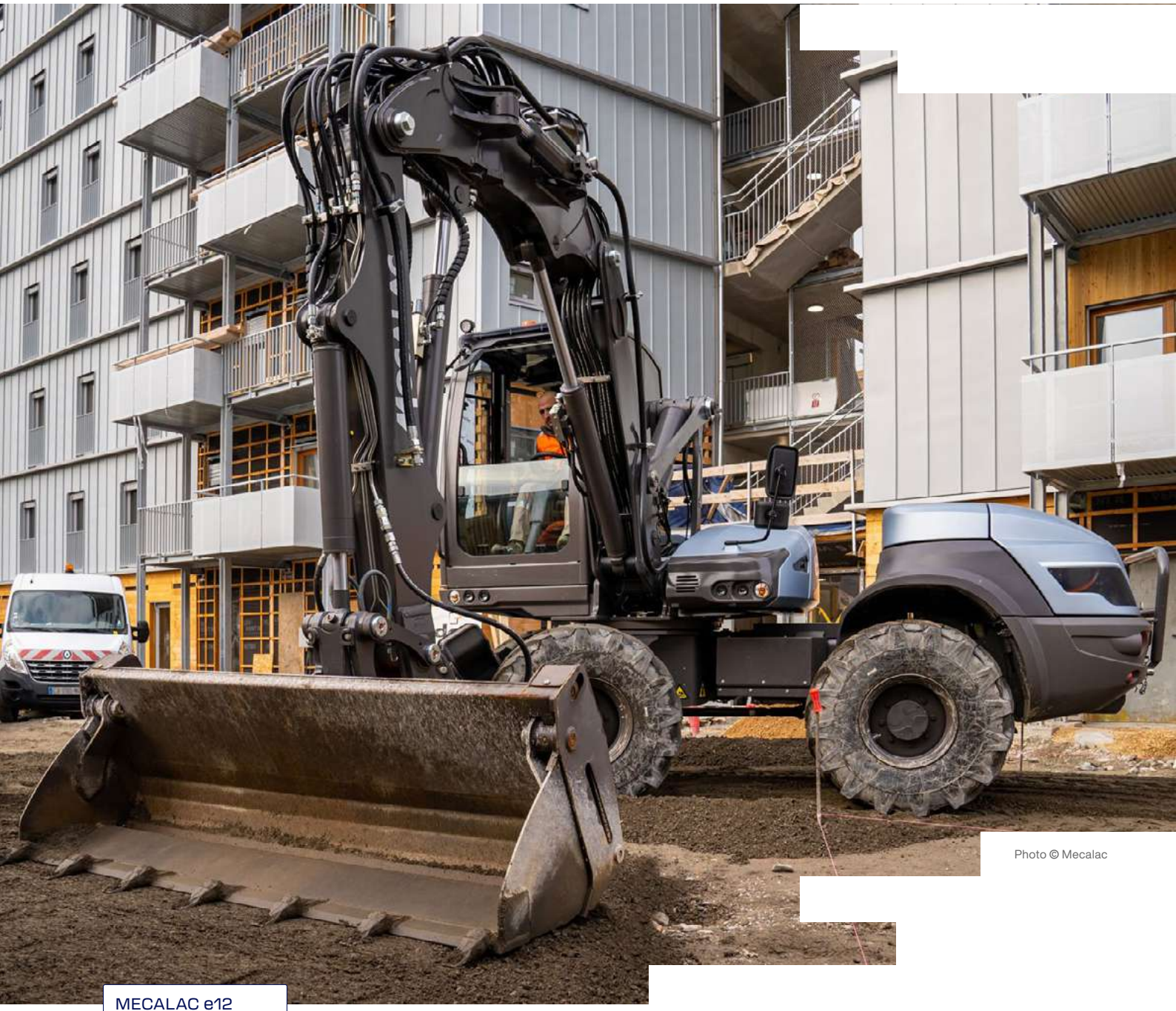


Photo © Mecalac

MECALAC e12

9. From reduced emissions to electric drives

The EU Stage V standard has introduced more stringent emissions limits for all harmful exhaust components. In the case of particulate matter, the standard not only sets a maximum mass limit (PM) but also imposes limits on the number of particles (PN) per kilowatt of power, excluding engines with power below 19 kW or above 560 kW. As a result, the widespread adoption of exhaust gas treatment systems has become necessary. These systems include selective SCR converters, which require the injection of AdBlue liquid, as well as oxidizing DOC converters and DPF particle filters.

Implementing these systems brings several benefits, such as improved combustion efficiency, increased power output, and reduced fuel consumption, leading to a decrease in CO_2 emissions. However, this solution presents challenges due to the higher operating temperatures required for efficient exhaust gas conversion and the need to find sufficient space for the SCR/DOC/DPF unit within the exhaust system.

Simplifying the design and operation of electric machinery, in comparison to machinery with internal combustion engines, is a key factor that could promote their wider implementation.

Engines that comply with the Stage V standard, particularly those used in power generators, are unable to operate effectively at idle due to the exhaust treatment system's limitations. To address this issue, resistors are installed to create an artificial load when the power demand is low. This causes fuel to be burned and emissions to be generated without any meaningful benefits.

To improve energy management, such as at a construction site, the implementation of energy storage facilities could be beneficial. These facilities would be charged with excess power from the generators and subsequently used as a zero-emission source for electric machinery batteries. Additionally, the stored energy could be utilized for other purposes, such as lighting, further optimizing energy usage and reducing emissions.

The first prototype of electric construction machinery made its debut around 2016. In 2018, Volvo CE conducted practical tests at the Electric Quarry to evaluate the potential for energy savings and emissions reduction by replacing machinery with internal combustion engines with electric machinery.

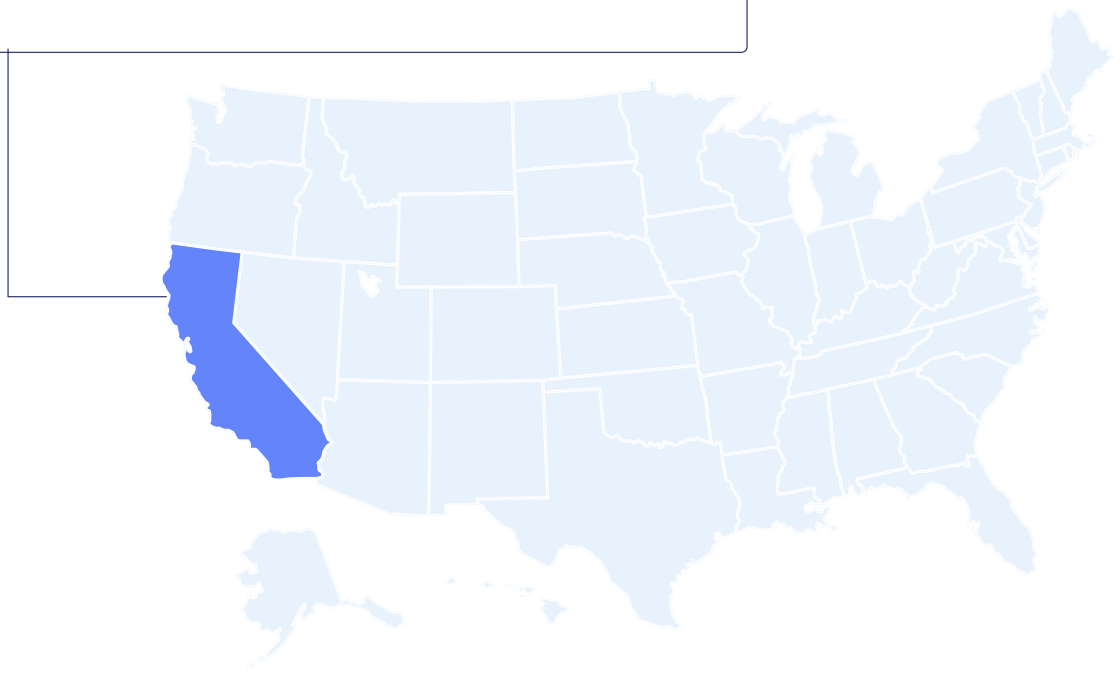
The available findings from these tests highlight three key advantages of battery-powered machinery that should be widely promoted:

- ↗ **silent operation** that does not disturb the peace of the surrounding environment,
- ↗ **absence of harmful emissions** and the possibility of unrestricted operation in enclosed or poorly ventilated spaces,
- ↗ **higher operator comfort** due to the reduction of the noise and vibrations caused by the internal combustion engine.

These three pillars have been instrumental in promoting the widespread adoption of battery-powered machinery. However, it is worth noting that in each case, the starting point involves leveraging the latest technologies of internal combustion engines. The regulations implemented by individual countries (such as Switzerland, which has additional requirements for particulate emissions), regions, or cities (such as California, the state of New York, London, and Stockholm, which mandate the use of machinery complying with the latest Tier or Stage standards for public works) are based on EU or US standards for internal combustion engines.

California

has set a more ambitious goal of completely phasing out non-road mobile machinery (NRMM) with diesel engines by 2035, as outlined in the governor's act of 2021. To support the energy transition in the state, several funds have been allocated across various sectors, including agriculture.



In Europe

efforts to increase the use of zero-emission machinery, with the ultimate goal of transitioning to exclusive usage, are driven by initiatives from Scandinavian capitals, which have been joined by cities like London and Amsterdam.

Oslo stands out as the most advanced city in this regard. Since 2019, the city authorities in Oslo have taken measures to control harmful exhaust gas emissions and noise levels during municipal works. They have introduced incentives for companies participating in tender procedures, offering bonuses for meeting environmental requirements. These “environment” requirements appeared in the tender conditions, providing both for the use of zero- or low-emission machinery and reduced emissions from the transport connected with the performed works. The works lasted one year, and they confirmed that battery-powered machinery could be used without impairing efficiency.

In 2020, **Copenhagen** inaugurated the first-ever zero-emission construction site, which utilized battery-powered machinery such as excavators, haulers, compactors, and tampers manufactured by Wacker Neuson. Notably, these battery-powered machines were also operated during nighttime.

London is in the process of formulating plans to expand the regulations of the Low Emission Zone to include non-road mobile machinery (NRMM). However, the city is exercising caution in this endeavor, awaiting legislation and support from the government before proceeding further.

Helsinki followed suit in 2021 by implementing a similar project, although they permitted the use of machinery powered by internal combustion engines using HVO non-fossil fuel.

10. Machinery available in the market

Battery-powered construction and material handling machinery is currently being produced on a commercial scale, albeit with limited lifting capacity. This limitation stems from two factors. Firstly, these machines have relatively low energy requirements, which can be easily met by the available low-power chargers and batteries. Secondly, smaller machines are often employed in close proximity to people, such as during urban renovations or material handling operations in warehouse facilities. Consequently, the aforementioned benefits are more readily achievable in such scenarios.

In certain cases, utilizing battery-powered machinery can yield positive financial outcomes. For instance, these machines can be employed in tasks that were previously performed manually, resulting in increased efficiency and cost savings. Examples of such applications include renovations in close proximity to hospitals or within sewer systems.

In the Polish market, various companies such as **Bobcat, JCB, Kramer, Mecalac, Volvo CE and Wacker Neuson** offer small battery-powered electric machinery.

JCB 525-60E

Photo © JCB

↘ JCB

Photo © JCB

Among these, **JCB** stands out with its E-TECH machinery program, which includes a range of equipment such as the 19C-1E mini-excavator weighing 2 tons, the 1TE articulated hauler with a 1-ton capacity, the HTD-5E tracked dumper with a 500 kg capacity, as well as telescopic loaders and scissor lifts. Most of these machines are equipped with lithium-ion batteries ranging from 10 to 20 kWh, providing sufficient capacity to operate for an entire shift. Additionally, JCB offers a portable battery charging station in two variants, with capacities of 23 or 46 kWh, allowing equipment to be recharged in locations without access to the power grid.

Interhandler, the Polish distributor of JCB, introduced an innovative initiative called Green Construction Sites, aimed at promoting the use of electric machinery and sustainable practices in construction projects. These projects were designed to prioritize the efficient use of energy, water, and raw materials. The five-point plan devised by Interhandler focused on creating favorable conditions for such projects.

The first point of the plan proposed the inclusion of low- and zero-emission slow-moving vehicles in the Electromobility Act, ensuring that they would be part of the minimum quota required for companies involved in large-scale projects for municipalities. However, a weakness of this proposal was the exclusion of tracked machinery, which is not legally classified as vehicles.

Another suggestion put forward was the restriction of access to low- and zero-emission areas exclusively for machinery that complied with Stage V emission requirements or electric machinery. Subsidies were proposed for these two groups to encourage their adoption and usage.

The project received support from the Polish Association of Construction Employers and the machinery rental company Ramirent. However, no concrete steps were taken to implement the project. Several factors contributed to this outcome, including the high cost of electric machinery, the lack of financial incentives for users, both in the short and long term, and the limited availability of small-scale electric machinery. JCB did not anticipate a rapid transition to electric power for medium- and large-sized machinery.

↘ Volvo CE

Photo © Volvo CE

Volvo CE, another company actively involved in the transition to cleaner energy on Polish construction sites, initiated a series of demonstrations featuring electric machinery in the autumn of the previous year. Volvo's program showcased the EC18 and ECR18 Electric mini-excavators, the heavier ECR25 Electric excavator, as well as the compact wheeled loaders L20 Electric and L25 Electric. These machines are equipped with advanced lithium-ion batteries that allow for uninterrupted operation for approximately 4-5 hours for excavators and up to 8 hours for loaders. It is important to note that these figures represent continuous operation, while actual work often involves

downtime, especially for smaller auxiliary machinery. During these idle periods, a machine with an internal combustion engine continues to consume fuel, whereas an electric machine can be switched off, effectively operating throughout an entire shift if a skilled operator utilizes each break to recharge the battery. Another advantage of electric machinery is the reduced number of operating hours, resulting in longer intervals between routine inspections.

Volvo CE is placing a strong emphasis on promoting the rental of electric machinery in Poland. Additionally, they have introduced the **"Try and Buy" offer**, allowing customers to rent a machine for a duration of 6 months. At the end of this period, the client has the option to either return the machine or purchase it under favorable terms.

↘ Bobcat

Photo © Bobcat

Bobcat offers a program featuring two electric mini-excavators. The first model available for purchase is the E10e, which is marketed as the world's first 1-ton electric excavator. Another model, the E19e, was introduced in the 2-ton category during the Bauma fair in Autumn of last year and has gained significant popularity in the Polish market. One of the key advantages of electric mini-excavators is their low noise level, measuring 72 dB compared to 80 dB in the diesel engine model.

↘ Mecalac

Photo © Mecalac

Mecalac has developed a series of battery-powered machines known as the **Mecalac Zero Emission Ecosystem**. This lineup includes the e12 wheeled excavator weighing 11.3 tons, a 6-ton capacity hauler, a loader with a 1 cubic meter bucket, and a portable power bank that facilitates machinery charging in areas without access to a power supply. These machines boast significantly higher specifications compared to the previously mentioned models. Consequently, their power supply requirements are also greater. For instance, the excavator utilizes a 150 kWh battery, whereas the other excavators have a capacity of 75 kWh, enabling it to operate for 8 hours. The charging station has a storage capacity of 150 kWh and can transfer the energy to machinery batteries within an 8-hour timeframe. Although the system is known to Polish customers, the higher energy capacities result in higher purchase prices.

Photo © Bobcat

While many clients are willing to invest in high-quality tools equipped with the latest technology, the profitability of their operation is crucial. Unfortunately, without support from the government or local authorities, electric machinery is not economically competitive in standard applications. As a result, its usage in Poland is currently limited to scenarios where the use of machinery with internal combustion engines is impractical or challenging, such as confined spaces, poorly ventilated areas, or indoor demolition and renovation projects.

Adrian Winnicki, District Manager at Bobcat Doosan

↘ Wacker Neuson

Photo © Wacker Neuson

The German company **Wacker Neuson** offers a range of battery-powered wheeled loaders, haulers, and excavators. Their lineup includes the WL20e wheeled loaders with a 0.19 m3 bucket, equipped with lithium-ion batteries of 14.1, 18.7 kWh or 23.4 kWh in capacity. These batteries can be charged using on-board chargers with power outputs of 3 kW or 6 kW. The DW15e wheeled haulers and DT10e tracked haulers have weight capacities of 1500 kg and 1000 kg, respectively, and use batteries with capacities of 14.1 kWh and 7.3 kWh. Lastly, they offer the Zero Tail EZ17e crawler excavator, which is equipped with a 23.4 kWh battery. All of these machines can be charged using either 230 V or 400 V voltage. Charging the machinery with 230 V requires overnight full charging, while with 400 V, 4-hour breaks are allowed. Wacker Neuson has also developed a system of battery-powered equipment for soil compaction, which uses an interchangeable battery known as Battery One.

↘ Kramer

Photo © Kramer

Kramer offers an electric wheeled loader with the model name KL25.5e. It features all-wheel drive and is equipped with a 0.65 m3 bucket. However, unlike other electric machines, this particular model utilizes conventional shock-resistant batteries known as AGM (Absorbent Glass Mat).

It is worth noting that **Hyundai, JCB, and Liebherr** are conducting advanced tests on machinery powered by hydrogen due to the limitations in energy and capacity of batteries they currently offer. Hyundai utilizes an electric motor with a fuel cell, while JCB and Liebherr employ a hydrogen internal combustion engine. At the Bauma 2022 construction fair, Caterpillar also showcased medium-class battery-powered machinery and batteries with enough capacity for a full shift of work using a specific mode: 4 hours of operation, quick recharge, another 4 hours of operation, followed by a full recharge during the nighttime. However, the feasibility of this scenario and the technical solutions themselves still need verification, and the targeted implementation date is set for 2024.

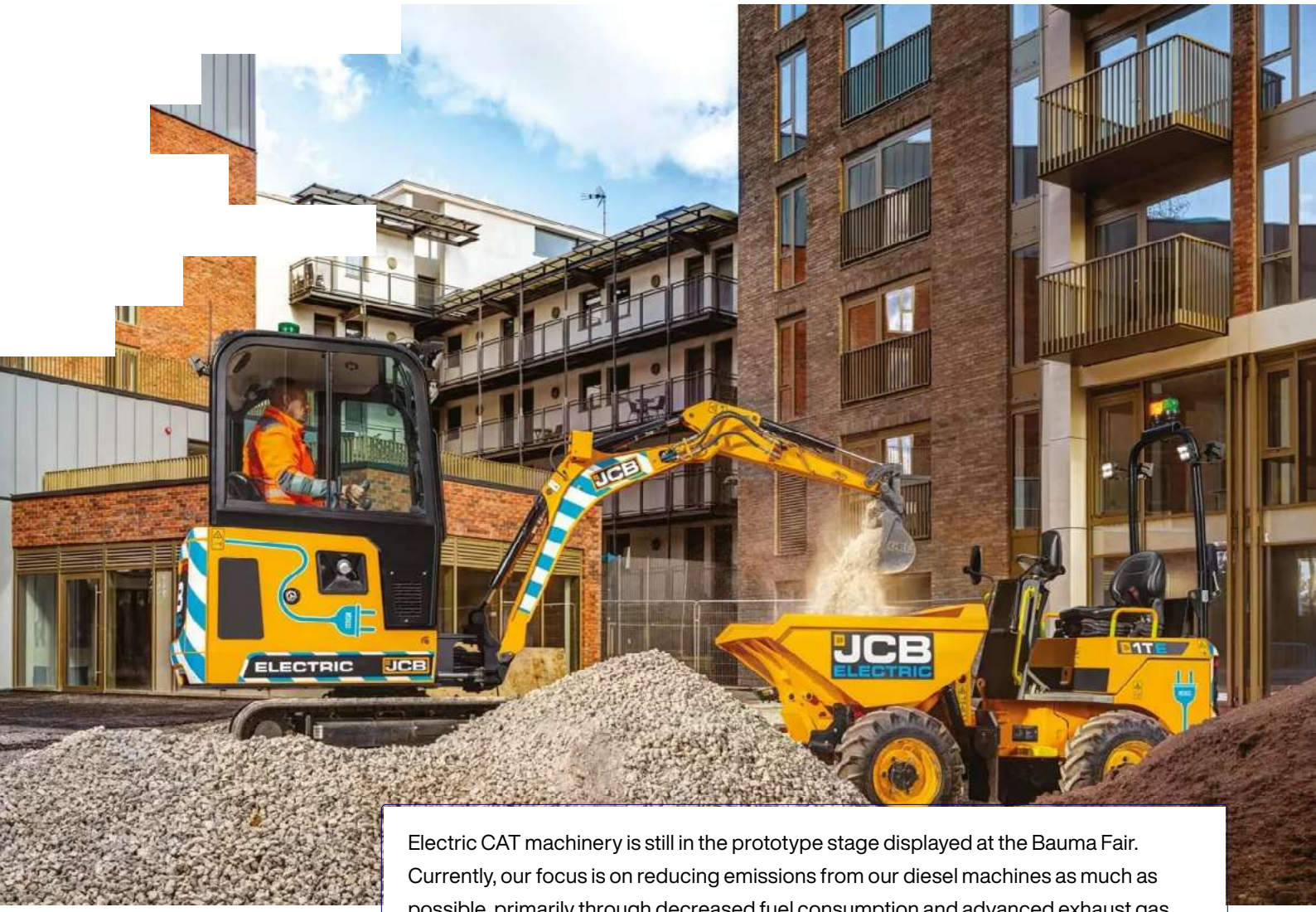


Photo © JCB

Electric CAT machinery is still in the prototype stage displayed at the Bauma Fair. Currently, our focus is on reducing emissions from our diesel machines as much as possible, primarily through decreased fuel consumption and advanced exhaust gas treatment systems. I believe that support for zero-emission machinery should primarily involve the development of charging infrastructure to eliminate the need for machines to return to the base for recharging. Additionally, a comprehensive approach to how the machine is charged is necessary. If the current is sup plied by a diesel generator, there are no environmental benefits. Regarding the machine's operating noise, it is important to remember that it is not solely caused by the engine but also by the working tools and materials being handled. Simply changing the drive alone may only provide a limited effect.

Jan Rudak, Marketing Communications Manager at Bergerat Monnoyeur, the Polish dealer of the Caterpillar brand

KGHM ZANAM

Case study

Zanper 2.0 transport vehicle

Photo © KGHM Zanam

Regarding electrification in the non-road sector, it is essential to mention **KGHM Zanam, the Polish copper giant belonging to the KGHM Group**. The company is conducting tests of the **Zanper 2.0** transport vehicle, a mining vehicle driven by an electric motor supplied by a set of batteries. This vehicle is designed for operation in underground mines, specifically in non-hazardous environments, making it a pioneering project in Poland. The Zanper 2.0 is adaptable to extreme environmental conditions in mines, capable of carrying up to 14 people, including injured individuals, from accident sites, as well as transporting materials. It is noteworthy that **KGHM ZANAM S.A. fully designed and built the chassis and undercarriage of the vehicle from scratch**. The Zanper 2.0 project receives co-funding from the NCBR – National Center for Research and Development.

The Zanper is based on the off-road Toyota Land Cruiser model, but the electric drive and software have been developed by KGHM ZANAM engineers. The power supply system uses batteries made in Poland, and the battery cooling system is suitable for the demanding conditions in mines, where temperatures can reach as high as 55 degrees Celsius. With fast-charging capabilities, the ZANPER will be ready to drive after just 30 minutes.

For KGHM, electric vehicles serve not only for transporting people. Currently, the company's mines use 40 electric blasting vehicles, and they are continually working on developing the HT24E shuttle car with an electric motor as an alternative to the machinery currently in use. According to the manufacturer, the use of these electric vehicles will ultimately lead to improved working conditions for miners, increased motor efficiency, and reduced heat and exhaust gas emissions.

11. Opportunities for the popularization of zero-emission machinery

In summary of the current situation and previous attempts at utilizing electric machinery, it is important to highlight that we are still in the early stages of their development, and the available options are limited. Essential parameters such as total cost of ownership (TCO) and residual value, which are crucial for owners of construction, agricultural, or material handling equipment, have not been widely addressed. The currently available battery-powered machinery is unlikely to deliver the same level of performance as machines with internal combustion engines, mainly due to the longer charging times required. Additionally, they are approximately twice as expensive as their conventional counterparts.

The facts clearly indicate the need for direct subsidies to facilitate the purchase or rental of electric machinery. It is also important to consider that a significant portion of machinery and equipment classified as NRMM is rented out. Therefore, efforts to stimulate the market should focus on two groups:

1) Rental companies:

These companies are responsible for acquiring and maintaining the machinery. Additionally, the seasonality of equipment usage poses challenges for battery-powered equipment due to uneven battery charging throughout the year, with more intensive charging required during certain months. These financial burdens may need to be passed on to customers.

In this case it is worth considering co-financing options for the purchase of zero-emission machinery, with the condition that a specific percentage of the machinery offered for rental consists of zero-emission equipment. To qualify for such a subsidy, rental companies would need to demonstrate a minimum annual usage threshold, which could be verified through subsequent lease instalments. However, it is crucial to carefully determine the range of machinery included in this program to prevent any potential misuse or misrepresentation.

2) Direct users:

These users will likely experience higher rates for various reasons and may also require more time to complete the same tasks compared to machines with internal combustion engines.

In this case, whether the user is the owner of the machine or a renter, they should be eligible for preferential treatment in tender procedures for works contracted by local self-government bodies or state authorities. This preferential treatment should be contingent upon meeting a specific minimum usage requirement and calls for implementing reliable monitoring to ensure compliance.

The range of machinery that would be included in the potential subsidy program is a topic that needs to be discussed with stakeholders. Taking inspiration from the current subsidy system implemented in the Netherlands, known as SEB (Schoon en Emissieloos Bouwmaterieel), it is worth considering setting a minimum engine power limit of 8 kW. This requirement is reasonable as it prevents attempts to include equipment with negligible emissions to qualify for subsidies in tender procedures.

Alternatively, it may be beneficial to prioritize a higher percentage of small zero-emission machinery and equipment in municipal works, such as those used for constructing and maintaining vegetated open spaces. This approach would offer advantages in all three aspects mentioned in section I:

- **Silent operation and elimination of exhaust emissions** would improve public acceptance of zero-emission solutions and create momentum for their implementation in other applications.
- **Better working conditions for operators**, including reduced vibrations and noise and simplified operation, could serve as a significant incentive for potential employees and enhance the perception of the profession.

In addition, the financial costs associated with battery-powered equipment are not exorbitant, and renting such equipment is also a viable option. The relatively low power consumption requirements ensure that there are no major operational challenges. Furthermore, electrification in areas such as transportation and equipment maintenance is straightforward. This sets the stage for a potential “snowball effect” over time.

12. Who is to be responsible for this?

Based on past experiences with national and municipal programs, it is evident that achieving a significant increase in the utilization of zero-emission machinery and equipment in the construction industry, municipal services, and certain agricultural sectors (e.g., gardening) requires close collaboration on the following levels:

Level 1

National government:
responsible for funding and the establishment of consistent principles for the purchase and implementation of zero-emission NRMM

Level 2

Local government:
where local plans will be created regarding the potential use of zero-emission machinery and the principles for public tenders that are advantageous to contractors that use such machinery

Furthermore, it appears unlikely that regulations on Level 1 are introduced on the same scale as the Electromobility Act or the machinery is included in the act. Introducing further amendments to the Act could potentially have adverse effects. Instead, it is recommended to establish a time frame and a "road map" outlining the potential integration of zero-emission machinery. This roadmap should include detailed specifications of the necessary resources and guidelines for their utilization.

The local government level plays a critical role as it is the level at which the feasibility and benefits of introducing zero-emission solutions can be assessed in relation to the local environment and the well-being of residents, taking into account factors such as local conditions and the intensity of municipal works. To prepare for the implementation of more stringent emission requirements, local governments should take immediate actions by:

- ↗ Mandating the use of machinery and equipment that aligns with the Stage V standard for public contracts. It would be beneficial to specify minimum contract prices or establish multiple thresholds
- ↗ Providing incentives for contractors using energy-efficient solutions, such as requiring operators to undergo training in efficient fuel consumption practices, for example, by reducing idle operation time.

The next stage involves establishing guidelines for tender procedures aimed at reducing emissions. It is crucial to adopt a holistic approach to this task, considering not only the emissions from machinery but also energy consumption, logistics of material deliveries, waste removal, and employee transportation. Contractors utilizing electric machinery should receive the highest rating in these procedures. In cases where electric solutions are not feasible, vehicles powered by biogas or HVO fuels should be considered as alternatives.

Summary

Photo © Wacker Neuson

Summary

One of the biggest challenges to electrification is to understand that it is not just a question of replacing a diesel engine with a battery. Engineers need to consider what goes into the design of the whole system, as batteries alone cannot produce enough power to run the entire operation.

With all vehicle electrification, the biggest challenge is to discover how to get enough power on board to meet the users' expectations. With passenger cars, this means providing longer driving ranges and access to fast chargers. For heavy-duty mobile machinery, the challenge is how to operate an entire fleet efficiently, especially with those machines that run 24/7. In most cases, when a machine is at a charging station, it is removed from production time.

Key component availability is a huge obstacle, although components based on new technologies are developing rapidly. Sourcing new components like batteries, in particular, has been difficult. Therefore, it is essential to find good components and reliable suppliers.

The biggest challenge, however, will be finding the competence needed to facilitate the technology shift. This includes top academic researchers who can help companies stay two to three steps ahead of the industrial transformation. There is no longer time for 15-year-long research programs. Competence needs to be developed faster to help the manufacturers stay agile.

One big learning during a technology shift is to understand the natural cycle of innovation: test, fail, learn and develop again. Companies cannot simply go shopping for the key components – they do not exist as off-the-shelf items. They must be designed specifically for the electric application in question.

It is vital to understand the end application as well as its subsystems in terms of cost and efficiency. Small things can become big things at the end of the day. One important learning is to have a deep understanding of the application. Manufacturers cannot outsource this. They need to be on top of the design and development of their equipment and solutions.

The professionals needed to engineer and maintain electrical machines require completely different skill sets than those needed for combustion engines. Therefore, it is important to train personnel accordingly.

Clusters bring their members greater bandwidth to solve many of the key issues. To develop new competence, clusters help attract future students and talent to the mobile machinery industry by raising awareness of jobs that exist or will soon be created. Clusters like SIX Mobile Work Machines allow its member companies to work together to encourage universities to develop these competences and to find ways to apply academic research to the industry.

Summary

All cluster members appreciate that sharing research results, technology and components shortens development times, allows the mutual use of special components and accelerates time to market.

How other countries can take advantage of Finland's experience

The urgency of decarbonizing is becoming increasingly clear, with a significant impact on OEM strategies and planned investments. Decarbonization of vehicles, including heavy-duty off-road ones, is accelerating rapidly. Mobile working machines and their operating environments can contribute to carbon-neutrality targets, creating new, unseen value for companies and entire value chains.

Finnish companies and research institutions are at the forefront of developing electrification and digitalization technologies to decarbonize heavy-duty mobile machinery. Companies in other markets around the world can tap into this unique collaboration with Finnish companies to gain access to the latest technology and expertise.

Finland's strong tradition of knowledge sharing, its excellent education system and broad-based clusters, such as the SIX Mobile Work Machines cluster, provide opportunities for companies from other countries to build their own capacity in research, development and innovation. Companies like Mitsubishi Logisnext have even decided to bring their R&D operations to Finland to take advantage of the local skills, expertise and collaborative nature needed for effective research, development and innovation work.

Finnish policies to promote decarbonization and electrification, such as carbon pricing, renewable energy targets and energy efficiency standards, can serve as models for other countries to accelerate their own decarbonization efforts.

Those companies driving the decarbonization transformation in their home countries can gain a competitive advantage by generating new and profitable business opportunities.

Poland challenges

This year presents an opportune time to initiate preparations for a more widespread adoption of zero-emission NRMM in the Polish market. Stable electricity prices and record-high electricity generation in 2022 indicate a reduced risk of crises and blackouts. The demand for machinery, including those used for auxiliary works and cleaning operations, is being driven by municipal and industrial projects. The necessary steps can be summarized as follows:

Summary

- ↗ Municipal and local government authorities should create favorable conditions for companies using battery-powered NRMM in cities. State financial support may also be considered.
- ↗ Prior to implementing electric solutions, stricter emission requirements should be imposed on conventional machinery and equipment compared to the current standards.
- ↗ The energy transition in NRMM should be based on pilot programs conducted under different local and weather conditions. Local government support, including covering electricity costs if necessary, can aid in assessing the actual benefits of battery-powered equipment.
- ↗ Zero-emission machinery and equipment should be given preference in tender procedures, considering them as one of the factors in the environmental assessment of services. Other factors may include overall energy savings, reduction of material losses, or waste reduction.
- ↗ Given the high price and limited capabilities of battery-powered equipment, rentals are expected to be more common than purchases. Mechanisms should be established to enable rental companies to acquire a specific share of machinery, equipment, and battery charging stations, while keeping rental costs acceptable to clients. This could take the form of direct subsidies, tax benefits, lower electricity rates, and other appropriate measures.

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