# How "digital twins" will speed up adoption of off-highway electric vehicles

Our new joint study examines the key drivers and most promising technology to produce industrial electric vehicles sooner than expected

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GAMMA TECHNOLOGIES

Roland Berger

# Management Summary

**Industrial vehicles are ripe for electrification.**
**Research shows segment will soon adopt electric drive trains due to growing market pressures.**

Despite record disruption within the automotive industry, one thing is certain: electric vehicles are here to stay. This is reflected by large R&D investments, global demand, and the accompanying regulations for more sustainable, zero emission transportation options. Although industrial, commercial, or other off-highway vehicles represent just 3% of the total automotive market, passenger car trends, innovations, and electrification will soon be found on industrial vehicles.

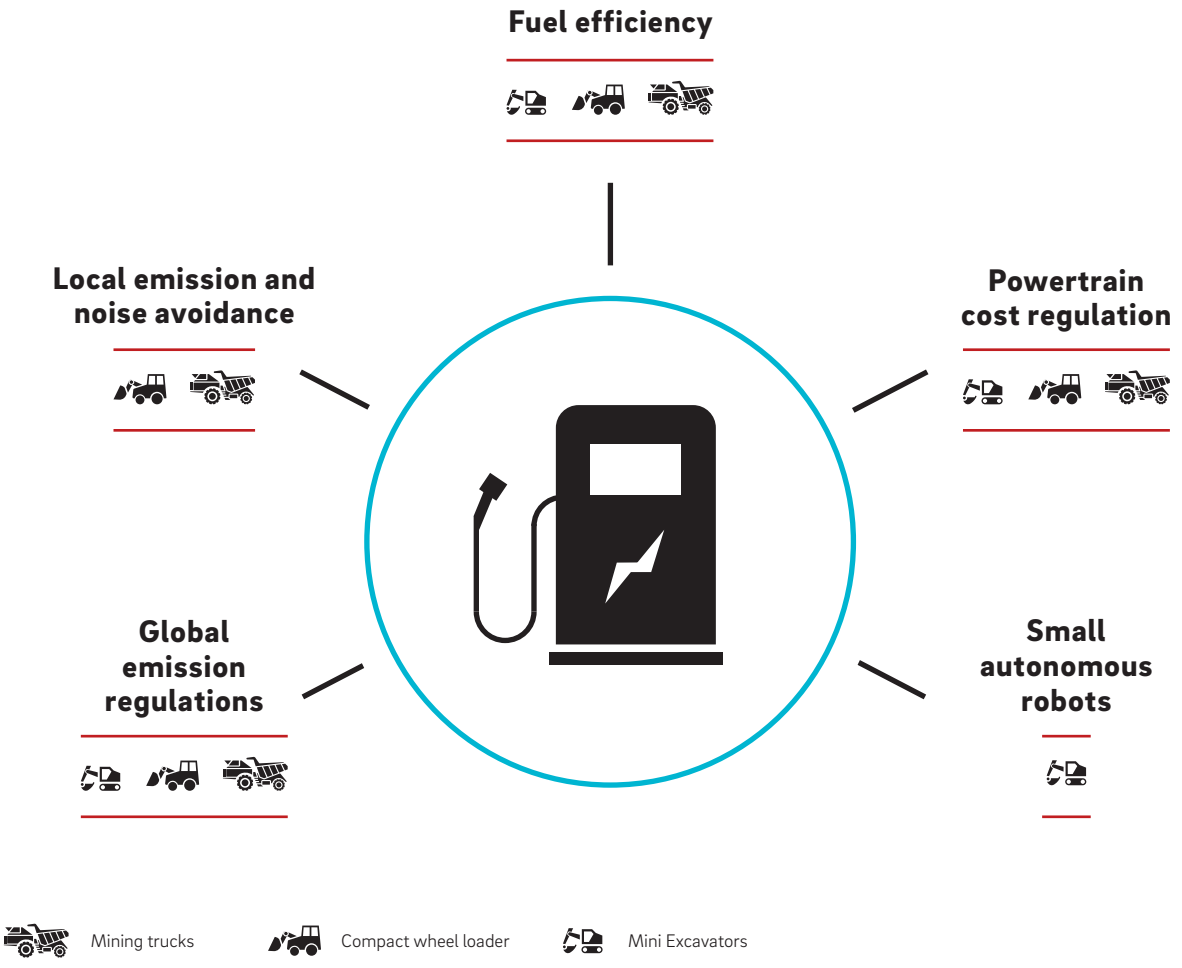
# The 5 main drivers of industrial electrification.
## Emission regulations, powertrain cost regulation, and technology development are big ones.

After recently reviewing the electrification trend of off-highway vehicles, we have identified five key drivers of rapid adoption:

1. **Global emission regulations**
2. **Local emission and noise avoidance**
3. **Fuel efficiency**
4. **Powertrain cost regulation**
5. **Small autonomous robots**

In our view, these drivers will push electrification to all key sub-segments of the off-highway segment. This will be led by compact and underground mining vehicles, given their favorable total cost of ownership, followed by other off-highway applications in agriculture, construction, and material handling.

**OVERVIEW DRIVERS FOR OFF-HIGHWAY ELECTRIFICATION**




Source: Gamma Technologies, Roland Berger

# Sustainability a top priority (and business case) for industrial electrification.

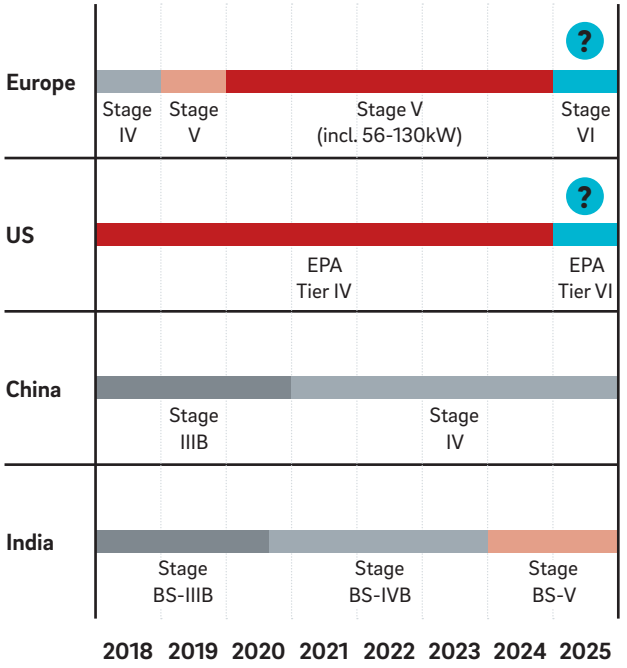
Emission standards in the US, Europe, China, and India are increasingly becoming stricter. Although heavy-duty vehicles still aren't required to meet specific $CO_2$ targets, that could change as early as 2025, when new, country-specific regulations are expected to become law.

Additionally, local emissions and noise ordinances in urban settings are making it increasingly difficult for traditional industrial vehicles to comply with bylaws. Consequently, industrial electric powertrains are rapidly becoming the preferred method in cities to meet the added emissions and noise standards.

But sustainability also makes more business sense. Leading industrial manufacturers including Komatsu, CAT, Hitachi, John Deere, and Volvo expect between 20-50% in fuel cost savings for electrified off-highway vehicles and less time spent refueling and maintaining when compared to diesel vehicles.

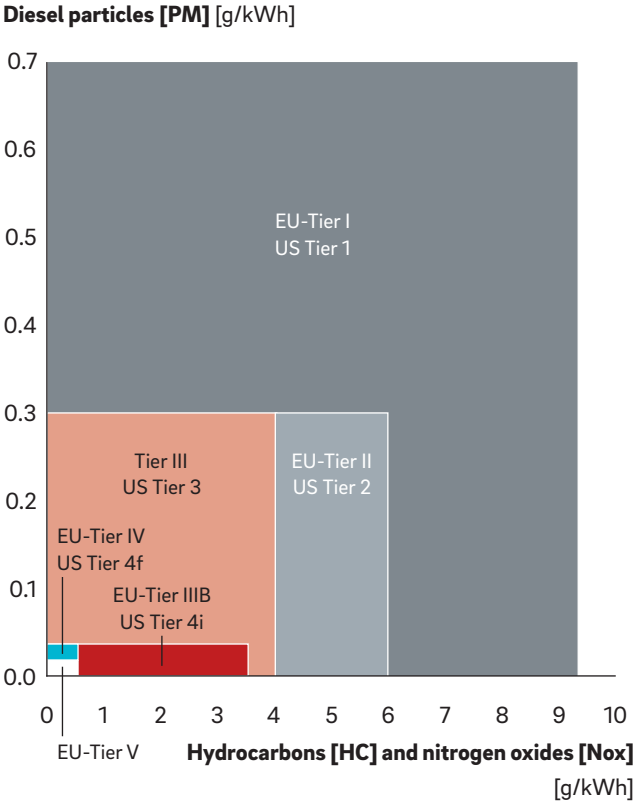
## OVERVIEW ACTUAL/ COMING REGULATIONS

### Overview actual/coming regulations




## OVERVIEW EMISSION GOALS NRMM[1]

### Overview emission goals NRMM[1]




1 Non-road mobile machines 2 Valid for all fuels while EPA is only Diesel relevant

Source: Press research; Delphi worldwide emissions standards; Hydac international

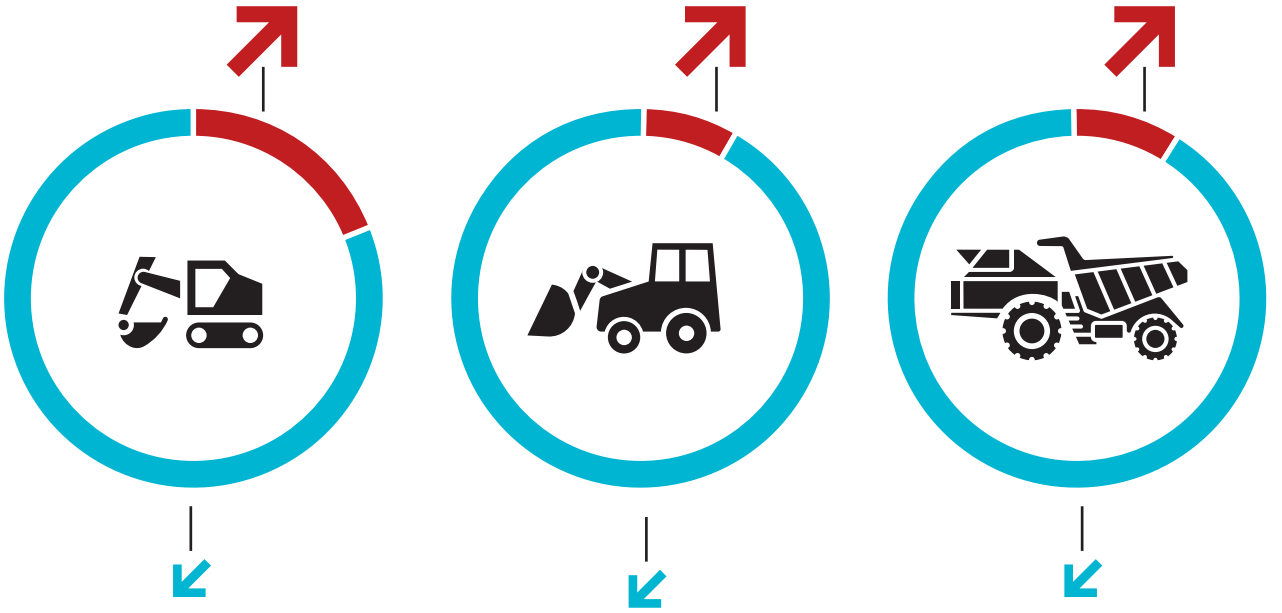
# Key electrical considerations by industrial segment.
## Small equipment applications in mining and urban construction will lead the charge.

In terms of industrial electric adoption, different rates are expected depending on size of equipment and the choice of drivetrain (diesel, hybrid, or battery electric). Larger equipment will favor the diesel powertrain going forward, partly due to its established technology and higher power density. However, smaller equipment including mining vehicles, some construction excavators, and industrial forklifts will be electrified as early as 2023, at which point we predict penetration rates between 10-20%.

On the other hand, the agriculture segments are less applicable for electrification, partly due to the large areas the equipment needs to cover, inability to use tethered drivelines, and increasing size of tractors to reach better economies of scale. Furthermore, noise requirements and emission standards are not enforced in the same way as in urban areas, which is why we expect a slower adoption of electrification in this subsegment.

While hybrid is expected to be a mid-term solution, battery electric vehicles will win the "end-game" of most industrial electric vehicles. Regardless of approach, TCO (Total Cost of Ownership) is expected to improve through better utilization, fuel economy, and technology.

**SELECT OFF-HIGHWAY SUBSEGMENTS, 2025+**
[m units, %]




Source: Gamma Technologies, Roland Berger

# R&D digitization a key enabler for electric transformation. New testing and live monitoring tools will hasten adoption.

Digitization will play a key role when researching, testing, and developing off-highway electrification in faster and cheaper ways when compared to conventional methods.

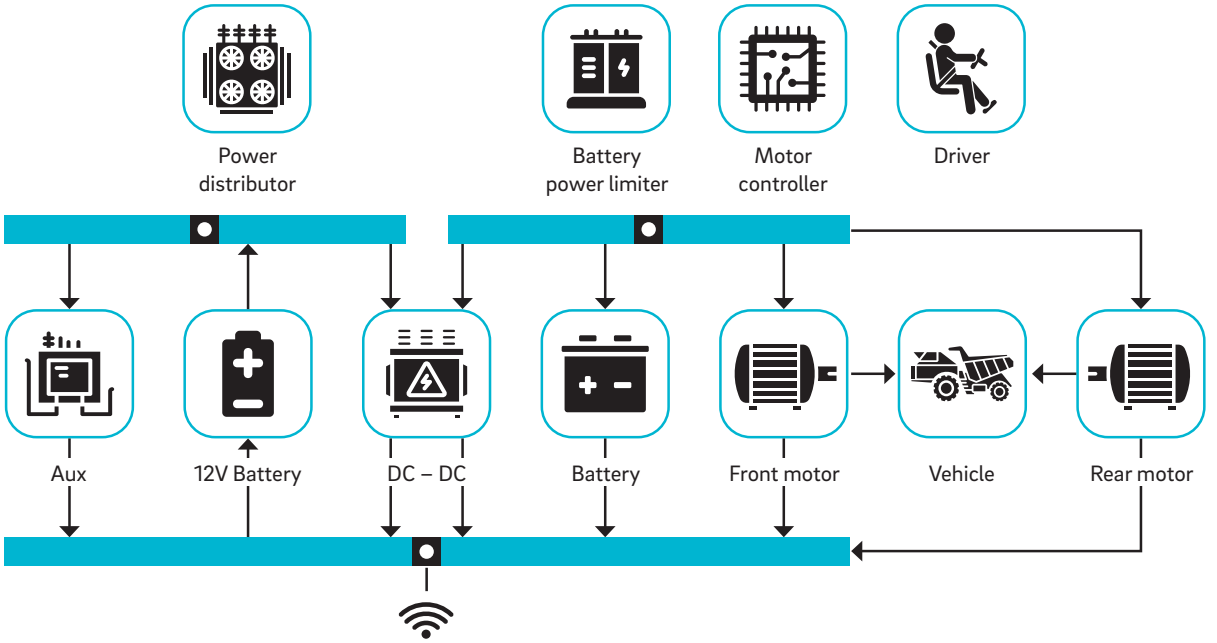
Thanks to the advancements in virtual testing and in-field sensors, modern computer-aided engineering must work as a "learning framework" to increase value during the vehicle development and vehicle operation phases. With the help of new digital tools, today's engineers can uncover uncertainties sooner in the development process with faster testing and gain greater confidence in the field with more immediate and real-time feedback.

For complex systems such as electric vehicles, however, testing components in a standalone mode is insufficient to understand vehicle performance under real-life conditions. Thus, considering the interactions between various subsystems is essential and the only accurate way to predict system performance in early design stages while exploring "what-if" scenarios under different conditions.

## EXAMPLE – TRANSFORMATION OF PHYSICAL VEHICLE INTO DIGITAL MODEL

### Physical vehicle

### Digital vehicle model




Source: Gamma Technologies, Roland Berger

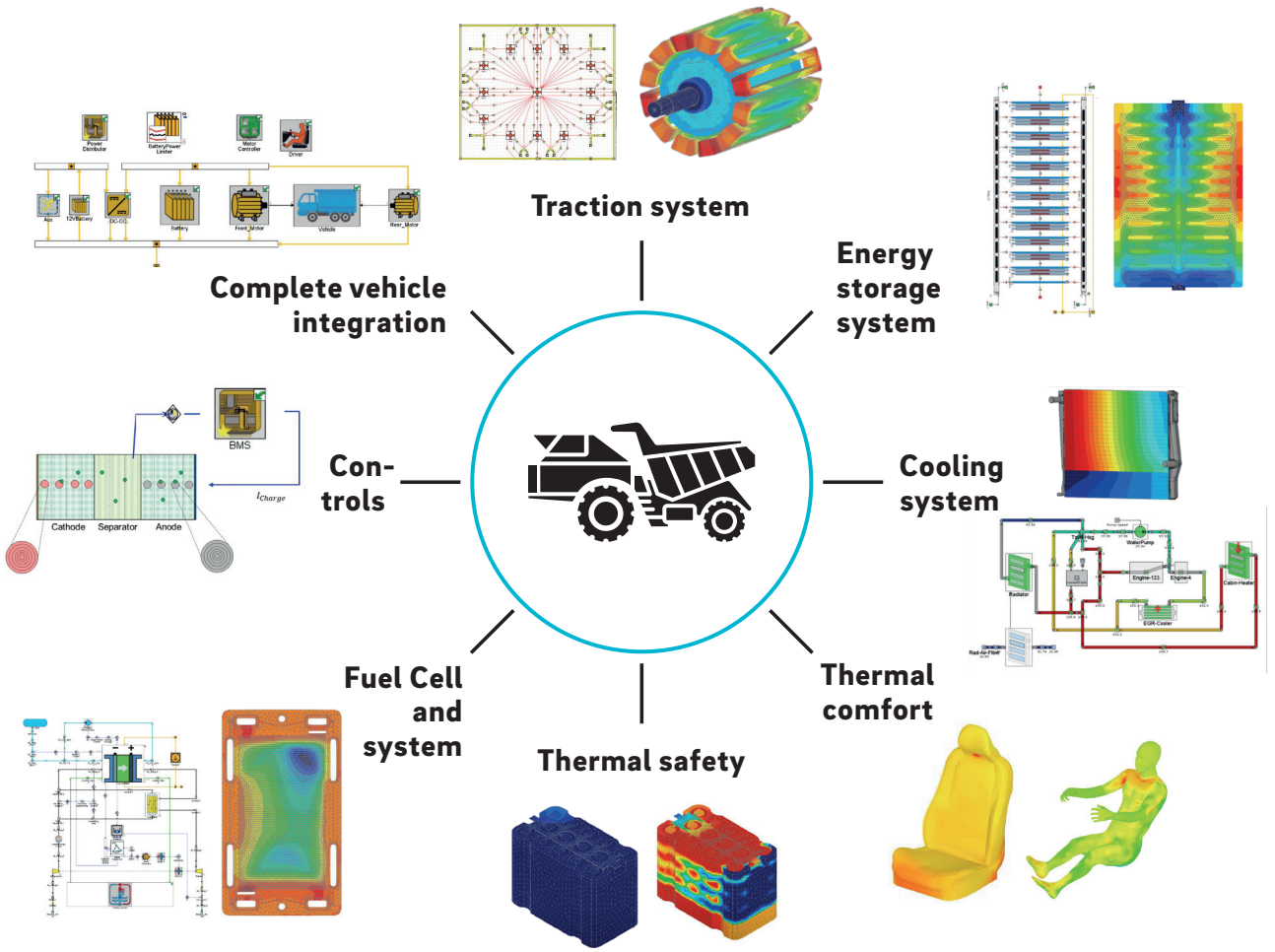
# Digital twins a promising R&D and in-field engineering tool.
## Providing faster feedback and insights into complex systems and production environments.

Of all available technologies, digital twins represent the most powerful tool in the hands of decision-makers to offer live monitoring of an asset's overall health, preventive maintenance capabilities, life span maximization, and lower cost of ownership.

Although electrification presents a new set of challenges for R&D departments, the competitive landscape, stricter regulations, and ecological warnings all require a fast response from the entire industrial ecosystem. In our view, digital twins are better able to investigate the behavior of a product early in the design process to speed up its development.

Since they can be used well beyond the R&D phase, they also act as real-time virtual companions of a product such as a vehicle, production line, an entire factory, or even a supply chain. Thus, the digital twin can better predict in-field operations, prevent potential failures, and improve efficiency.

### MULTI-DISCIPLINARY SYSTEM SIMULATION




Source: Gamma Technologies, Roland Berger

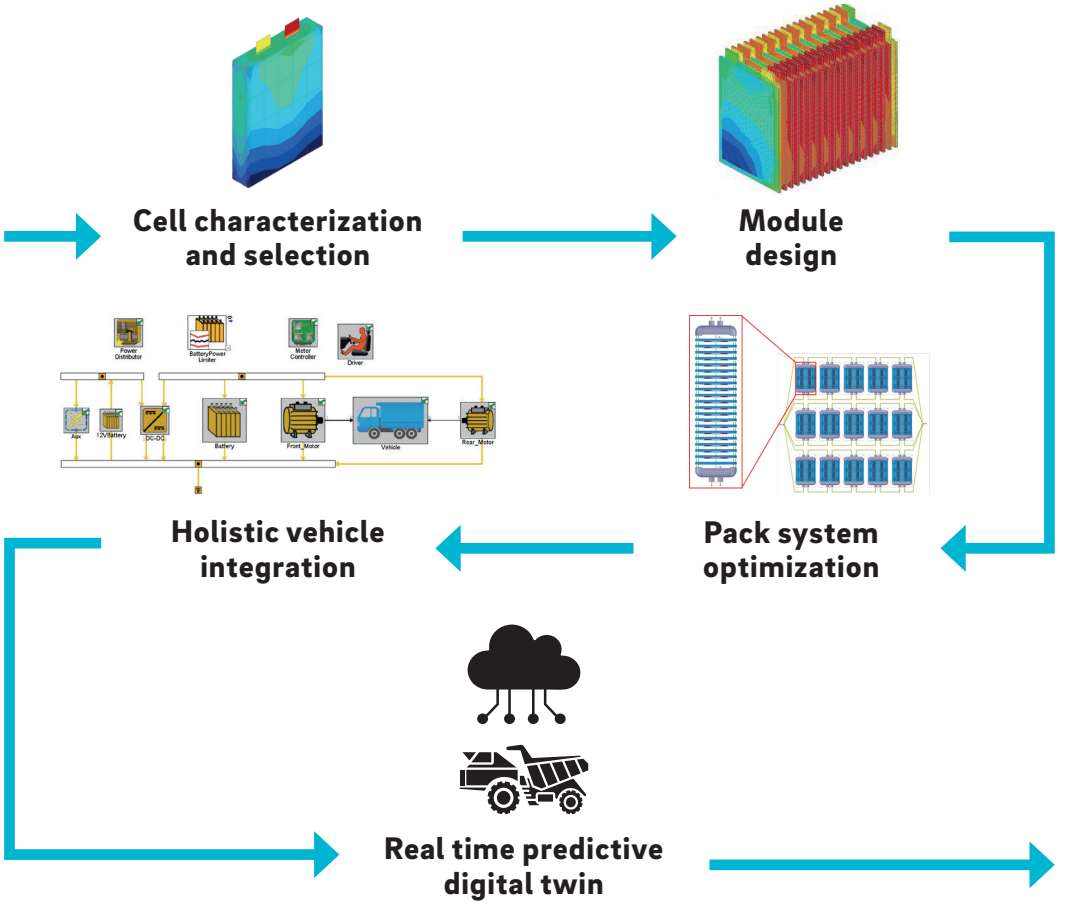
Images: Gamma Technologies LLC

# Digital twins can be used on both microscopic and macro levels. The multi-physics replicas depend on in-field sensors to share information faster than before.

With state-of-the-art digital testing, tomorrow's industrial components, electric vehicles, and their underlying production can be combined into one virtual model, allowing investigations from a microscopic level (such as electro chemical reactions of batteries), to large scale analysis (such as complete fleet performance). In that way, digital twins make it possible to explore different "what if" scenarios without compromising the safety or performance under different conditions.

But digital twins are not just fixed simulation models using predefined conditions. A true digital twin represents an accurate multi-physics based replica that evolves and degrades similarly to the physical product, which it continuously exchanges data with. Sensors to gather real-time data from the physical product supply inputs to the digital twin, which in return delivers information about vehicle status and optimal operation strategy. The ultimate goal is to improve the reliability of the vehicle and have fewer unplanned stops of the entire fleet.

## DIGITAL TWIN MODELS FULLY CAPABLE ON MICROSCOPIC AND MACRO LEVELS




Source: Gamma Technologies, Roland Berger

Images: Gamma Technologies LLC

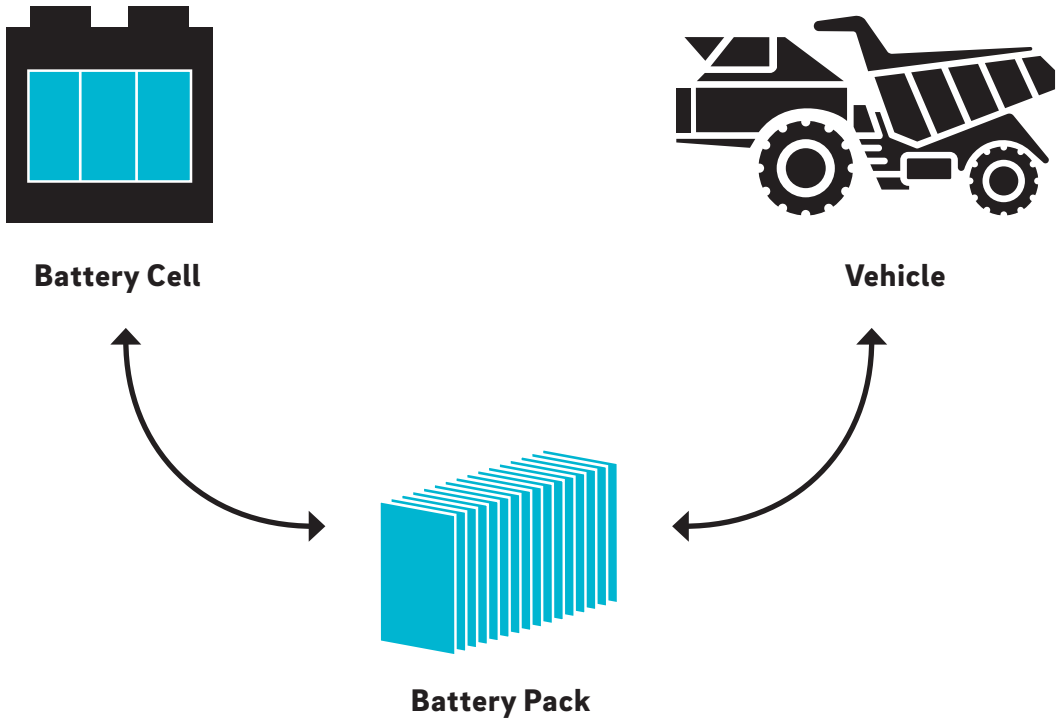
# More good news: the future has already arrived!
# New case study validates digital twins for industrial use

We recently partnered and co-sponsored the development of a multi-physics digital twin on behalf of a client while designing the battery system for a new electric mining vehicle. In our tests, the pack model accurately measured observations within 1.7% of the terminal voltage and between 4%-7% for temperature predictions.

After different cell designs were identified, the most favorable design was selected by iteratively evaluating performance at the chosen design. This type of cell-to-pack multi-physics simulation and analysis expands the possibilities for novel design that cannot be obtained through traditional simulation methods.

Furthermore, our approach proved capable of being integrated into an entire vehicle fleet or "system-of-systems" operation to minimize cost and enhance equipment reliability.

**INTERACTIONS BETWEEN COMPONENT, SUB SYSTEM, AND SYSTEM LEVELS IN BATTERY POWERED VEHICLES**




Source: Gamma Technologies, Roland Berger

## Now is the time to act. Digital twins not only speed up the development of industrial electric vehicles, they allow decision makers to mitigate risk

Industrial electric vehicles not only provide clear benefits in terms of emission, noise, and cost benefits, but powerful opportunities when combined with digital twin technology. Although industrial adoption will likely be slower than for passenger vehicles, there is no denying that electrification is already affecting the off-highway market and will continue to do so at increasing speed.

How that change affects your business is entirely up to you. But we can help to identify how and where electrification makes the most sense, and then use digital twin technology to lessen the burden of transformation in both R&D and in-field operations.

## Contact us for an expert discussion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GAMMA TECHNOLOGIES is the leading multi-physics system simulations provider. With a complete physics based modeling solution portfolio include: powertrain, vehicles, driveline, battery electrochemistry, power electronics, thermal safety, transmission, hybrids, exhaust aftertreatment chemistry, acoustics, cooling & thermal management, HVAC, hydraulics, fuel systems, lubrication, and others. GT is regarded as the standard system simulation solution in the automotive industry used by all major OEM's and suppliers.

We at GT are dedicated in building the most advanced system simulation tools complemented with carefully designed software solutions that provide major productivity improvements for our customers.

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