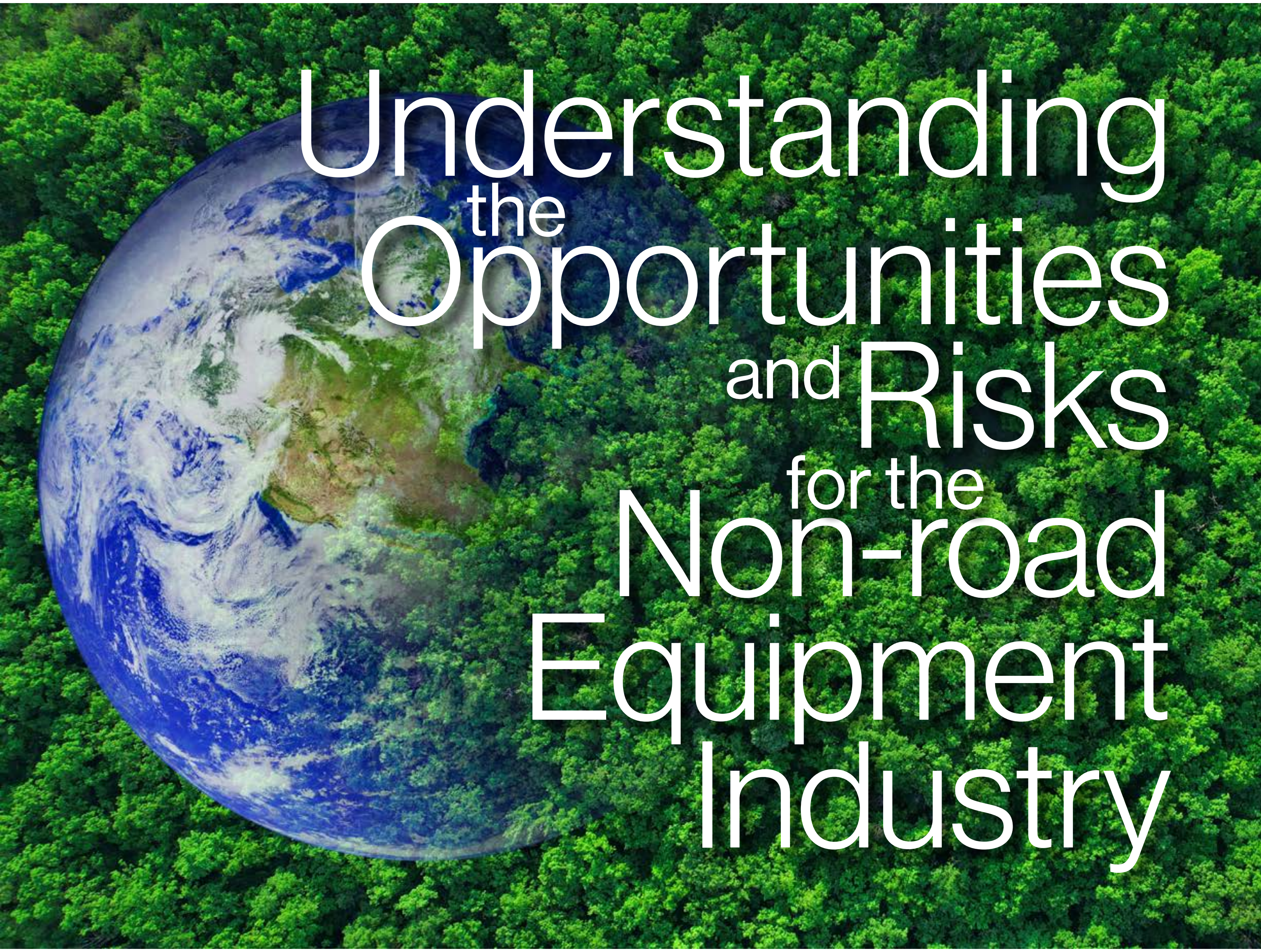
AEM
Association of Equipment Manufacturers

Moving Forward with Alternative Power:

Understanding the Opportunities and Risks for the Non-road Equipment Industry



Executive Summary

Association of Equipment Manufacturers (AEM) member companies recognize the benefits of decarbonizing and reducing greenhouse gases (GHG) for the betterment of our society as they work to produce the equipment that builds, powers, and feeds the world. And while the industry is dedicated to continuing its march toward reducing its carbon footprint, it is critical for policymakers to understand just how much is invested in terms of cost, time, and effort to decarbonize and reduce the impact of GHG emissions.

For AEM's member companies, powertrains are among the most crucial component systems in non-road equipment, impacting various aspects of the machine including performance, safety, and cost. Manufacturers have long invested heavily in powertrain improvements, new technologies, and emissions reductions. These investments have enhanced the environmental profile of their products, with each incremental improvement having been the result of both significant effort and ingenuity.

Alternative powertrains are widely seen as a key enabler of decarbonization of the non-road equipment industry. First and foremost, however, equipment manufacturers must provide their customers with solutions that ensure the form and function of their products meet certain work requirements.

Ultimately, the end-user determines which products meet their needs and which do not, but most of these requirements revolve around common characteristics: time, location, duty cycle, and the total cost of ownership. To satisfy these concerns, manufacturers will use these variables to determine which alternative power technologies make sense for the unique end-use applications of their customers.

As industry continues to invest its resources into new alternative power technologies, a variety of energy carriers may be deployed:

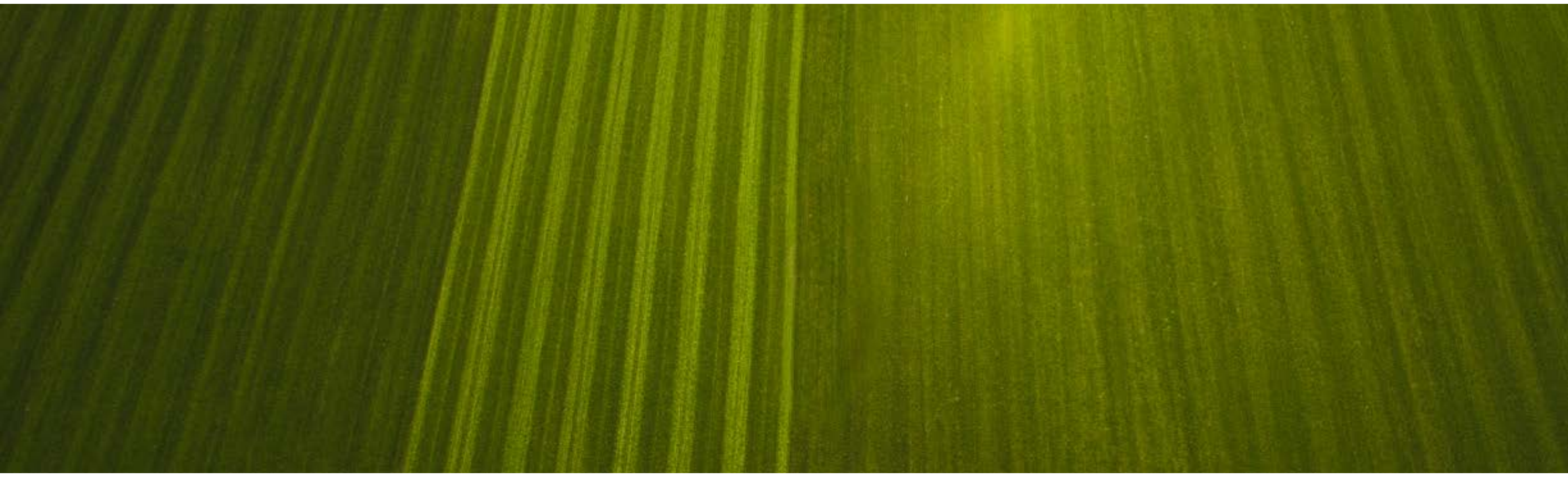
- Internal combustion engines – diesel, biofuels, low carbon fuels, hydrogen
- Batteries
- Fuel cells
- Grid connections
- Hybrid technologies

Decarbonizing the non-road equipment industry will take many years of technology advancements, research investments, customer acceptance, and infrastructure developments. Each of these obstacles requires committed resources from industry, friendly policy decisions from government, and growing customer demand. AEM's members have several key recommendations that will ensure the smoothest transition possible.

To reach the goals of policymakers, all stakeholders must:

- **Consider a holistic approach** to GHG reductions, rather than simply "focusing on the tailpipe," to ensure a flexible and robust decarbonization transition.
- **Consider avoiding overly prescribed policy approaches** that neglect to consider new processes and technologies that can contribute to GHG reductions, and which allow flexibility for OEMs as they develop these alternative power solutions.
- **Consider broad-based incentive programs** to accelerate future adoption of alternative powered equipment.
- **Support flexible infrastructure planning** when determining the role of alternative powered equipment in the construction, agriculture, forestry, utility, and mining sectors.
- **Appreciate the lead time necessary** for industry to develop these technologies and allow for ample time for a robust market to develop.
- **Promote worksite safety training programs** for users of these new technologies.
- **Consider the impact** that other global regulatory actions may have on the transition to a decarbonized non-road sector.

The contents of this document and their corresponding recommendations seek to educate industry stakeholders and policymakers on the challenges and opportunities facing OEMs as they work to meet future market demands while taking steps needed to decarbonize the industry. AEM believes that collaboration between government and industry can deliver future environmental benefits for all, and that perspectives described herein can spur future conversations and cooperation to the satisfaction of all interested partners.



Purpose

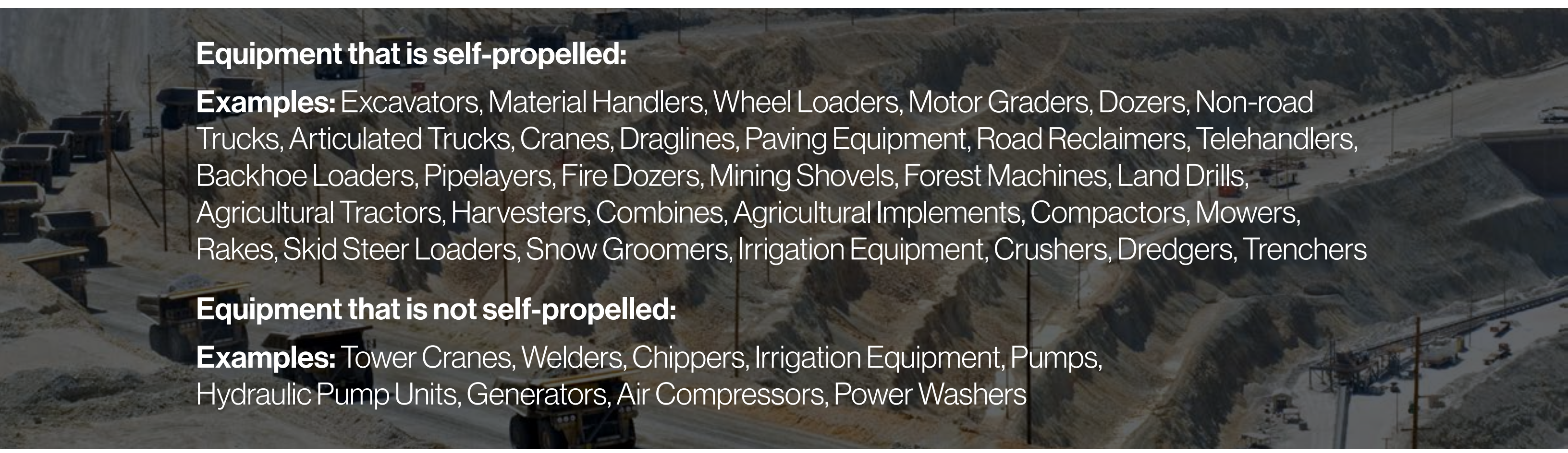
AEM believes it is important to introduce and educate industry stakeholders on the challenges and opportunities regarding decarbonization, as well as provide industry recommendations to support the deployment of alternative powertrain solutions. Understanding the risks and opportunities in the decarbonization process is crucial to support the non-road equipment industry's transition to the adoption of these technologies.

Introduction to AEM and the Non-road Equipment Industry

The Association of Equipment Manufacturers (AEM) is the North American-based international trade group representing non-road equipment manufacturers and suppliers, with more than 1,000 member companies and over 200 product types across five diverse industry sectors. AEM members develop and produce a multitude of technologies in a wide range of products, components, and systems that ensure non-road equipment remains safe and efficient while operating in some of the most demanding and severe environments on earth.

Non-road Equipment

Under the broadest definition, non-road equipment is designed to execute specific functions relative to its intended applications in non-road environments. These functions include operating in the construction, agriculture, mining, forestry, and utility sectors. More specifically, non-road equipment can be broken down further into specific categories based on its operations and functionality.



Equipment that is self-propelled:

Examples: Excavators, Material Handlers, Wheel Loaders, Motor Graders, Dozers, Non-road Trucks, Articulated Trucks, Cranes, Draglines, Paving Equipment, Road Reclaimers, Telehandlers, Backhoe Loaders, Pipelayers, Fire Dozers, Mining Shovels, Forest Machines, Land Drills, Agricultural Tractors, Harvesters, Combines, Agricultural Implements, Compactors, Mowers, Rakes, Skid Steer Loaders, Snow Groomers, Irrigation Equipment, Crushers, Dredgers, Trenchers

Equipment that is not self-propelled:

Examples: Tower Cranes, Welders, Chippers, Irrigation Equipment, Pumps, Hydraulic Pump Units, Generators, Air Compressors, Power Washers

From a global regulatory perspective, non-road original equipment manufacturers (OEMs) share many similarities with adjacent industries, especially the automotive sector. Both the non-road and automotive industries sell complex products powered by internal combustion engines and are comprised of thousands of parts and components sourced from overlapping supplier networks. However, the non-road sector possesses a variety of distinct differences from the automotive industry, including longer lifecycles, higher costs, a larger number of parts with lower volume of products, and end-use applications which often operate in harsh environments with a customer base that demands reliable, safe, and continuous operation.

Non-road Industry Sectors

Non-road equipment operates across five crucial sectors in the global economy: construction, agriculture, mining, forestry, and utility. Each sector requires non-road equipment to provide unique functionality and accomplish tasks specific to each industry.

AGRICULTURE

Agriculture is the practice of cultivating crops and livestock. In this sector, farmers use agricultural equipment to plant, cultivate, and harvest crops. The locations are commonly rural, lack access to infrastructure beyond traditional fuels, rely on minimized downtime, and demand high-power densities when engaged with the earth.

Equipment: Tractors, Combines, Planters, Sprayers, Implements

CONSTRUCTION

The construction industry commonly involves a type of manufacturing focused on building, repairing, and maintaining infrastructure. Construction work encompasses many different types of jobs. Worksites operate in many different environments with varying levels of access to refueling infrastructure, often in remote locations or areas under development. Additionally, construction projects frequently involve repetitive tasks over large areas, relying on minimal downtime for contractors to meet project timelines and control costs. Under this broad definition, construction can break down into these additional sub-categories:

1. Building construction focuses on the process of adding and improving physical structures to an area. Examples include residential housing, commercial spaces, and public buildings.

   Equipment: Cranes, Excavators, Piledrivers, Loaders, Dozers, Pipe Layers, Material Handlers, Lifts, Trenchers

2. Public infrastructure focuses on the built environment commonly associated with earthmoving projects. Examples may include roads, bridges, tunnels, and canals, etc.

   Equipment: Dozers, Motor Graders, Pavers, Rollers, Road Reclaimers, Non-highway Trucks, Excavators, Cranes, Drills, Boring Machines

FORESTRY

Forestry is the process of managing, cultivating, extracting, and repairing forests and woodlands. The equipment used in this industry typically operates in remote areas with limited access to established infrastructure.

Equipment: Feller Bunchers, Excavators, Skidders, Forwarders

MINING

Mining is the process of extracting, processing, and managing solid minerals from the earth. The equipment in this industry normally engages directly with the ground to drill, dislodge, extract, and move materials from surface or underground mines to processing facilities. Equipment in this sector can be exceptionally large, requiring substantial power requirements to accomplish work tasks. In many instances, worksites may possess their own developed onsite infrastructure. This developed infrastructure can facilitate a wider variety of fuel and power types for mining equipment.

Equipment: Haul Trucks, Shovels, Drilling Equipment, Drag Lines, Excavators, Loaders, Dozers, Cranes , Rippers

UTILITY

The utility industry primarily focuses on maintaining existing public infrastructure, including operations in electric power, natural gas, water supply, and sewage removal. Equipment operating in this sector may work in urban or rural environments and provides niche end-use functionality which leads to low volume product offerings for customer use.

Equipment: Trenchers, Directional Drills, Vacuum Excavators, Cranes, Telehandlers, Pipelayers, Generators, Gas Compressors, Pumps

Today's Work Requirements

Equipment manufacturers consider a number of factors to ensure the form and function of their products meet the requirements of the jobsite and end-user. Many of these requirements will revolve around the powertrain and its energy source.

Diesel fuels are the dominant energy carrier for non-road equipment, followed by gasoline and liquid petroleum gas (LPG). The energy density, as well as the ease of transporting and handling these fuels, have long satisfied the equipment users' energy requirements. Four factors commonly impact a customer's energy demands:

- **The time sensitivity of work**
- **Worksite location relative to an energy supply**
- **The engine duty cycle**
- **Total cost of ownership**

To successfully implement future alternative power solutions, industry stakeholders need to consider the impact that any new policy may have on these factors.

Time Sensitivity

Businesses using non-road equipment look to avoid delays as much as possible. Delays can lead to cascading interruptions on the jobsite, ballooning costs, project schedule slip, monetary losses, increased fuel consumption and potential public safety concerns. Site operators expect equipment to operate reliably and continuously through the duration of the project, and equipment manufacturers attempt to mitigate delays by maximizing onboard energy storage capacity while minimizing recharge and refueling times.

Several examples can help illustrate this customer need:

- **Crop planting and harvesting:** Due to the unpredictable nature of the growing season, farmers have limited windows to both plant and harvest crops from their fields. Inoperable equipment, or machines that require long refueling times, can jeopardize the profitability of an entire farm.
- **Livestock feeding:** Livestock, like all animals, require consistent and continuous care from their owners. Equipment must remain operational to ensure the farm animals' needs are met.
- **Emergency infrastructure repairs:** Emergency repairs on crucial infrastructure requires working equipment to operate on demand. Delays to infrastructure repair can risk public safety or paralyze transit.
- **Construction:** Worksites require maintaining site conditions, managing local commuter traffic, material deliveries, equipment transportation, and contract deadlines. Delays on the job result in longer project timelines, increased equipment usage, higher costs, and more GHG emissions.

Location

The nature and needs of the worksite in the non-road sector can vary greatly depending on the objectives of the job. Oftentimes, non-road equipment operates in remote locations, distant from readily available energy supplies. These sites may operate over long time periods, sometimes as long as several months or years, and equipment operators in these locations often find it practical to build temporary fuel stations on location. Other projects may require a piece of equipment to move to multiple locations over a given day, or gradually migrate long distances while performing continuous work, all without returning to an established energy resupply base. To prevent work delays, operators assess their site requirements and either establish procedures to bring liquid fuel directly to the equipment or allow the equipment to return to a refueling station at the end of the workday.

Modern equipment must provide the flexibility to operate in vastly different work environments, while at the same time maximizing the energy capacity of the machines to meet the requirements of the end customer. Some examples of these requirements include:

a. Crop planting and harvesting

b. Earthmoving and road building

c. Pipeline and utilities construction

d. Forestry operations

Duty Cycle

The energy demands of non-road equipment will vary depending on the end-user requirements. High load factor applications are characterized by frequent high-power demands, near continuous use, or a combination of the two. Unlike on-road vehicles where power is used to accelerate the vehicle and overcome air resistance, non-road equipment is often moving material or performing work that is an order of magnitude higher in terms of energy demand. The resulting power requirements lead to significant energy consumption throughout the workday. Examples include:

a. Field tillage, crop planting and harvesting

b. General earthmoving

c. Pipeline construction

d. Forestry operations

e. Mining

Conversely, low load factor applications are characterized by low power demands, highly intermittent use, or a combination of the two. Examples include:

a. Intermittent agricultural operations

b. Infrastructure repair

c. Certain utility operations

Moreover, some equipment types (e.g., generators and pumps) must meet both high and low average power usage due to specific worksite requirements.

Total Cost of Ownership

For equipment owners, the lifetime costs of a machine, both before and after purchase, are a major contributor to the overall profitability of their business operations. The total cost of ownership (TCO) is the estimated lifetime expenses associated with the purchase, deployment, and operation of a piece of equipment. TCO incorporates a variety of factors which include the initial purchase price, maintenance costs, operational expenses, and end-of-life considerations, among many different variables. Whichever way a customer in the non-road space calculates their TCO, it is a highly important factor to consider when making important business decisions.

New GHG reducing processes and technologies with advanced features often lead to higher equipment prices. The continued adoption of these practices and features will reduce energy and emissions, but equipment owners will broadly adopt these features and practices only if the monetized efficiency gains more than offset the increased TCO of the machine.

The Future of Power

The characteristics of different powertrain systems will be a major factor in their adoption. However, the factors listed above (i.e., time sensitivity, location, duty cycle, and TCO) will continue to be the primary drivers in the equipment owner's decision making. OEMs looking to incorporate new energy carrier technologies will prioritize these variables when developing products to meet their customers' needs.

As investments into new technologies proliferate, several potential energy carrier candidates currently stand out:

- **Biofuels**
- **Battery electric**
- **Mainline electric**
- **Hydrogen**

Biofuels

Biofuel describes a wide range of fuels derived from biological feedstocks. Examples include ethanol, biodiesel, and hydrotreated vegetable oil. These fuels are generally intended to provide energy through internal combustion engines (ICEs). Equipment powered by ICEs has the advantage of using previously existing drive systems. Equipment powered by biofuels will produce emissions similar to those powered by fossil fuels at the point of use. Net emissions from using biofuels as an energy carrier will depend on the fuel's production method and energy input source, fossil fuel vs. wind, solar, or nuclear. However, net emissions of carbon dioxide can approach zero depending on the source of those energy inputs.

Engines using certain biofuels require engineering modifications unless the biofuels are blended in low concentrations with conventional fossil fuels. Examples are E10, a gasoline blend with 10% ethanol, and B20, a diesel fuel blend with 20% biodiesel. Other biofuels such as hydrotreated vegetable oil (HVO) are similar enough to fossil fuels that they offer the possibility of use in most unmodified ICEs.

Due to the energy density of biofuels, equipment using them as energy carriers are well suited for jobs that have severe duty cycles and those that are a significant distance from energy infrastructure.

Battery Electric

The automotive industry's adoption of, and transition towards, battery powered cars has created an expectation of similar applications in non-road equipment. Battery power produces little to no emissions at the point of use, with the net GHG emissions dependent on the generation method of recharge (i.e., fossil fuel vs. wind, solar, or nuclear). Despite real-world successes and the future potential of this technology in the non-road space, there are factors that impact its viability in certain applications.

The most important factors when considering battery technology are the duty cycle and time demands of the worksite. Due to the limited energy storage capacity of modern battery technologies, especially when compared to diesel and gasoline fuels (roughly equivalent to 5% in a similar volume comparison), their adoption in non-road equipment will likely remain limited to jobs with light duty cycle requirements and flexible time demands during recharging periods, either at a home base or a jobsite charging station. Quick change batteries can mitigate some delays, but the limited energy storage capacity still restricts this approach to jobs with light duty cycles, otherwise the battery change frequency could become excessive. This quick change, light duty cycle approach is far more practical for manually handled battery packs and limits their potential to smaller equipment.

Mainline Electric

Electrically powered machines have the ability to use the electric utility grid under the right circumstances. Similar to battery technology, equipment powered by the grid produces no GHG emissions at the point of use, with net emissions dependent on the method of generation, i.e., fossil fuels, wind, solar, or nuclear. While using the energy grid helps solve many issues related to recharge time and battery handling, this type of energy carrier is best suited for long-term or permanent jobsites that allow installation of power infrastructure and equipment that is static or near static while in operation.

If required, portable generators can replace a grid connection on temporary jobsites. The energy source of these generators will heavily influence the net emissions of the complete system. Under most circumstances the increased efficiency of variable speed electric drives reduces the energy consumption, and therefore the total GHG emissions, of the machine when compared to hydraulic motors. However, these efficiency improvements depend greatly on the generator's energy source, as using fossil fuel would likely cause substantial increases to site GHG emissions when compared to renewables.

Hydrogen

Hydrogen is an emerging mobile energy carrier. It has the potential to power equipment through conventional ICEs or hydrogen fuel cells.

Hydrogen powered ICEs are quite similar to those powered by fossil fuels. Equipment powered by these engines can use technologically mature drive systems, similar to those found in their fossil fueled counterparts. This similarity provides the greatest advantage to OEMs, as it limits the research and development investments required to integrate this energy carrier into the machine and keeps the upfront costs of the machine relatively low when compared to competing energy carrier technologies.

The use of hydrogen as an energy source in ICEs eliminates most regulated exhaust emissions as well as carbon dioxide at the point of use. However, the combustion process still produces oxides of nitrogen, possibly requiring exhaust after-treatment for the machine. Furthermore, the common feedstocks for hydrogen production are water or natural gas. Net emissions from the use of hydrogen as an energy carrier depend on its production method and the energy input source, fossil fuel vs. wind, solar, or nuclear. Additionally, the disposal of carbon byproducts from natural gas as a feedstock may also affect net emissions.

Hydrogen fuel cells have powered space vehicles for decades, but they are an emerging technology for mobile equipment. In a fuel cell, a chemical reaction between hydrogen and oxygen creates electrical energy. That energy can then power equipment through an electric motor. Compared to other energy carriers, fuel cells respond poorly to varying power demands. So, many types of fuel cell powered equipment will likely need batteries to maintain a level load on the fuel cell while meeting the variable power needs of the equipment. The use of hydrogen fuel cells eliminates all emissions at the point of use.

Hydrogen presents many interesting advantages for non-road equipment. In order to successfully and safely implement this technology in the non-road sector, industry will need to solve several real-world challenges prior to its adoption. For instance, to maintain energy density, hydrogen is stored at pressures requiring the use of pressure vessels and pressure regulating systems at fueling stations, for transport (e.g., via truck), and on equipment powered by hydrogen. When stored under pressure, hydrogen contains about 12% of the energy stored in a similar volume of diesel fuel. Therefore, its best use would likely be on jobs that create a light duty cycle or that require the equipment to remain static, or near static, while working.

Hydrogen is an incredibly small molecule when compared with other energy related feedstocks (e.g., methane). Its relatively small size makes hydrogen more likely to leak, creating safety concerns around its storage, transmission, and use. Site operators will need to take these risks into consideration prior to implementing this technology on their worksite.

Summary

No one energy carrier can satisfy the future needs of the entire non-road equipment industry. OEMs will deploy a variety of different technologies to reduce their product's carbon emissions. As previously mentioned, factors of time sensitivity, location, duty cycle, and TCO will establish which energy carrier best suits each function, job, and customer.

Future Industry Goals

Politicians, policy makers, and environmental groups strive for potential solutions to address a changing climate. Oftentimes, engine technology is seen as a singular cause of, and solution to, answering these issues. While equipment manufacturers will continue to introduce advancements in their product offerings, OEMs believe that the interplay between new technology and improved worksite efficiencies are both required to realize these societal environmental goals. More specifically, to reduce GHG emissions, the industry will need to successfully integrate technology gains with jobsite process advancements to realize efficiency improvements and greater environmental benefits to all.

Alternative Power Usage Requirements

The industry's market requirements will continue to influence the adoption of new technology and energy carriers used in non-road equipment. These advancements may include the following, some of which have already been described in detail:

- **Battery electric**
- **Power grid** (mainline electric)
- **Fuel cells**
- **Internal combustion engines**
- **Low carbon fuels**
- **Hybrid technologies**

While most of these carriers reduce, or in some cases eliminate, emissions at the point of use, when considering the holistic GHG picture, questions about their implementation remain. These concerns include:

- **Production methods of the energy carrier**: Will energy production generate emissions greater than the reductions at the point of use?
- **Production capacity and distribution infrastructure:** Will energy be available to equipment when and where it is needed, and at a reasonable price?
- **Raw material availability:** Will there be sufficient raw materials to produce and/or store the energy?
- **Energy density:** Will equipment energy storage capacity be sufficient to ensure reasonable run times?
- **Length of the energy replenishment cycle:** Will the time required to replenish energy be short enough to minimize on-the-job disruptions?

Equipment manufacturers understand the potential for alternative power technologies to help mitigate certain environmental issues. Many of AEM's member companies are working diligently to develop and introduce new power source solutions for select applications. However, not all solutions will work for every end-user need, and both OEMs and their customers require the necessary time and flexibility to ensure the technology suits the requirements of the end-use application. Specific product lines may need multiple power source offerings depending on the work environment. For instance, urban locations may be able to take advantage of battery electric technology, whereas remote worksites may need to continue to use ICEs. To minimize the potential unintended consequences associated with new technology adoptions across the diverse needs of the non-road sector, OEMs require the flexibility to collaborate and coordinate with their customers to provide specific application-based solutions.

Infrastructure Needs

New technologies and product features can offer a variety of real-world advantages to equipment owners. However, customers may resist adopting new technologies if the product does not also contribute sufficient returns on investment. New energy carrier technology requires supporting infrastructure to operate efficiently and profitably. Extended refueling times and new fueling procedures that do not align with the rest of the worksite can increase a product's TCO and adversely impact the equipment owner's ability to meet business objectives. Furthermore, the infrastructure requirements needed to service non-road equipment will differ from the on-road sector, adding complexity and expense to meeting equipment users' needs. To achieve climate goals, policymakers must provide the appropriate infrastructure and energy carrier support foundations to enable industry-wide adoption of new powertrain solutions.

Lifecycle GHG Emissions

Finally, the introduction of new GHG accounting requirements to achieve real-world climate benefits must consider the overall carbon lifecycle of the energy source being utilized. Hydrogen fuel, for instance, when produced through renewable power sources such as wind and solar, provides higher carbon reductions than hydrogen production coming from a coal-fired energy source. It is important for policymakers to appropriately structure their incentive programs so that companies using lower GHG energy sources can realize an accounting benefit.

Industry Recommendations

The non-road equipment industry stands at the intersection of societal environmental goals and the practical commercial requirements of today's end-users. This position requires manufacturers to strike a perfect balance between the work requirements of their customers and the aspirations of the public and global policymakers. Despite this tension, the non-road manufacturing industry remains committed to providing solutions that can satisfy both stakeholders. As our industry looks to the future, there are a variety of policy solutions AEM recommends to policymakers when considering the development and adoption of future powertrain technologies.

Market Incentives to Reduce GHG in the Non-road Industry

Any discussion on the adoption of alternative power technology starts with the customer. A product that does not meet the needs of the task at hand simply will not be purchased. Owners need their equipment to perform work and complete jobs within specified timelines. This desire for efficiency leads to investments in new automation and interoperability technologies for the worksite. These systems reduce machine movement, increase communication and collaboration between equipment, and raise productivity of the worker and the jobsite.

After efficiency, the second most important factor for the customer is the owning and operating costs of their equipment (e.g. fuel consumption). Fuel costs are one of the largest cost centers for an operator. Lowering these costs through better fuel efficiency increases profits and encourages more investment in, and adoption of, alternative power technologies.

Customer demands already highly incentivize the market to lower GHG emissions through the adoption of new technologies and different work methods on the jobsite. However, customer demands are highly focused on making their operations efficient and timely, followed by operating costs.

Recommendation: Policymakers looking for wider market adoption of alternative power technologies should focus on strategies that will accelerate the deployment of infrastructure and products which lower the TCO of the machine and enhance the adoption of the most efficient products.

Holistic Approach to GHG Reductions

In the non-road space, many stakeholders tend to focus on the engine when looking for GHG emissions reductions, more specifically, through the adoption of alternative powertrain systems. And while engine output represents a significant source of GHG emissions, improving on engine emissions or efficiency does not always translate to overall machine efficiency, due to challenges with work output and transient loads. Simply mandating new energy carrier systems is not the only path to achieving real world results. Policymakers need to understand that the engine is a single piece of a larger GHG reduction puzzle, and there are a variety of different pathways available for the industry to walk down.

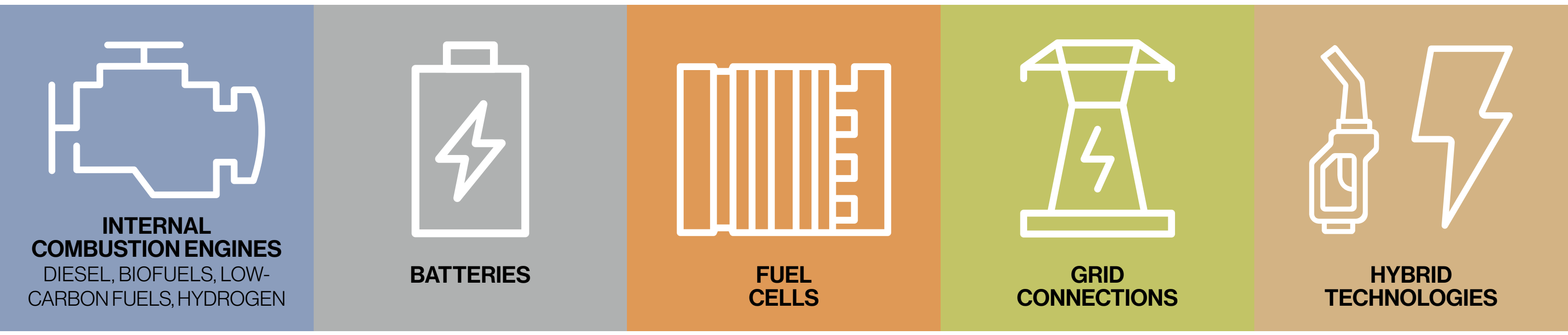
Non-road equipment works in a wide range of locations with different levels of established infrastructure, all performing different energy intensive tasks. This wide variety of work conditions makes a single energy carrier solution for the entire industry a highly unrealistic standard to meet the demands of the modern work environment. There are, fortunately, multiple options available to achieve real-world GHG reductions. Among these potential steps are:

- **The adoption of hybrid systems**
- **The use of low carbon/renewable fuels**
- **The implementation of autonomous systems to optimize the worksite**
- **The implementation of more efficient worksite practices**
- **The electrification of low duty cycle urban machines vs. high duty cycle rural equipment**

Recommendation: Policymakers should look at incremental steps and technology adoption requirements when looking to reduce GHG emissions. These steps can make a real-world impact on mitigating the effects of climate change while avoiding broad-based mandates for specific alternative powertrain solutions across the industry.

Technology Uncertainty

As stated previously, the non-road equipment industry will need to rely on many different powertrain technologies to satisfy the safety, performance, durability, and customer demands of the marketplace, because no single technology exists that meets all these requirements for the entire sector at once. The industry will need to rely on a variety of different technologies in the future, which include:



On certain worksites with easy access to recharge stations and relatively mild duty cycles, battery electric technologies may provide the best option for customers looking to decarbonize their fleets. This same technology, however, may not work in remote locations far from reliable recharge equipment. In these cases, the use of low carbon liquid fuels or biodiesel may be the only realistically option available to equipment operators. Similarly, hydrogen fuel cells may provide the necessary power for severe cycles for certain equipment types but may present unique safety issues related to storage and transfer systems in hazardous locations. Without the flexibility to adopt the right technology for the right job, large swaths of industry may cease to function.

Despite these challenges, customers are already coming to manufacturers looking to lower their total cost of ownership through lower fuel consumption. This desire will drive industry to invest their resources to meet these market requirements. OEMs will learn more about the limitations and opportunities in the marketplace and address these challenges, reducing the need for more regulatory requirements in the future.

Recommendation: Policymakers should avoid overly prescribed approaches that neglect to consider new processes and technologies that contribute to GHG reductions and, additionally, allow flexibility for OEMs as they develop these alternative power solutions.

Incentive Programs

While new technologies can move the industry in exciting new directions, these changes will also likely result in higher costs for end-users. Costs that are too high may hinder market adoption of more energy efficient, or zero emissions, technologies. Government incentive programs for end-users and OEMs can help alleviate some of this reluctance.

Incentive programs should target different business cost centers and avoid targeting a single technology solution. Government national testing laboratories can focus on developing pre-competitive research, R&D tax credits can help lower the costs associated with new technology development, and voucher plans for end-users can lower barriers to entry for owners looking to adopt new technologies. If these incentives are widely available at different levels of the product development process, are scaled appropriately, and remain available for varying technology choices, policymakers will see quicker and more widespread market adoption of alternative power applications.

Recommendation: Incentive programs are crucial to the future adoption of alternative powered equipment due to the higher capital investment required for the new technology. Incentive programs will help bring technology to market quicker and will help lead to larger market-wide adoption of these new technologies. Policymakers should continue to incentivize the development and deployment of alternative power technologies. Ideally, these programs should coordinate with OEMs to ensure that government money is targeting the right technology solutions and not one, single option.

Infrastructure Requirements

As discussed throughout this paper, the successful market adoption of many of these new technologies will require new infrastructure development (e.g., hydrogen availability, biofuel availability, electric grid). Due to the variety of different machines, worksites, and job functions in the non-road sector, the industry will likely adopt several different alternative power technologies. Undoubtedly, this variability makes policy decisions around infrastructure development more complex and difficult. That said, it is important to make sure that future infrastructure plans allow for maximum flexibility in energy carrier solutions.

Recommendation: Policymakers should be flexible with infrastructure planning. Mandating a single technology option will limit the ability of industry to develop and implement the correct technology for their machines.

Time

Companies looking to develop new technologies require an investment of capital, knowledge, and time. New equipment systems need to meet safety, customer, regulatory, legal, quality, and performance requirements. Testing and validating new components and systems may take years before a manufacturer deems the product safe and ready for the marketplace. Furthermore, many current alternative power technologies do not meet the safety and performance needs of a wide variety of jobsites and equipment types. Rushing the development process toward a predetermined solution introduces safety, performance, and quality risks to the final product.

Furthermore, various regulatory bodies are starting to look at the next tier of engine emissions regulations. As these rules start to take effect, equipment and engine manufactures will need to spend considerable amounts of time and resources over the next decade redesigning their products to meet these new emissions requirements. Due to the resource intensive nature associated with complying with these rules, OEMs will need time to recoup their investments in these new technologies and sustain adequate periods of production stability with the design changes.

These engine emissions requirements will directly compete with alternative power for the same limited R&D resources. When compared with other industries, the non-road equipment sector consists of highly variable product types with markedly lower sales volumes. The low product volumes and high R&D costs create very real challenges for OEMs looking at returns on their investments. If OEMs need to focus on lowering emissions and implementing zero emission powertrain technologies at the same time, they will need substantial amounts of time to accomplish both.

Recommendation: Developing alternative powered equipment is an important but slow process. To usher in a successful transition, policymakers need to give industry the appropriate amount of time to make sure the process is done correctly.

Worksite Safety & Workforce Training

The adoption of new technology in equipment and on the worksite will introduce additional risks that the industry needs to address. Safety issues related to lack of familiarity with new technologies, in particular, present a major concern for manufacturers and worksite owners alike. Industry stakeholders will need to develop training programs and build knowledge around the operation and maintenance of high voltage batteries and recharge systems, hydrogen transfer and storage systems, as well as new lighting and marking symbols. This training will take time and resources and is necessary to help the workforce understand and gain the proficiency needed to avoid future worksite safety issues.

Furthermore, it is likely that policymakers may develop new regulations and safety requirements associated with the use of these new technologies. It is important when adopting new rules that the regulatory structure makes sense. Understanding the scope of these rules, as well as the timeline for their introduction, will help manufacturers reduce their compliance burden.

Recommendation: To maximize safety on the worksite, policymakers should work with relevant stakeholders to develop:

- Awareness of industry best practices
- Cooperation on future regulatory activities
- Knowledge of new safety systems and procedures
- Training resources for workers in the non-road sectors

Regulatory Uncertainty of Per- and Polyfluoroalkyl Substances (PFAS)

OEMs and engine manufacturers are looking at many new alternative power sources and technology solutions to meet future business goals. While industry will continue to innovate and experiment in this space, it is clear there are potential risks to the future development and adoption of these systems. Two of the most widely discussed new technologies, hydrogen fuel cells and lithium-ion batteries, use per- and polyfluoroalkyl substances (PFAS) as a critical component in their functionality.

PFAS are a large group of synthetic organofluorine chemical compounds characterized by linear or branched carbon-fluorine chains connected to a functional group. The PFAS class contains thousands of chemical entities, and the exact number of PFAS chemicals can vary greatly depending on the specific definition and reference source.

PFAS can vary widely in their chemical and physical properties, environmental fate, mobility, degradation, and toxicity profiles. These characteristics will differ based on the carbon chain length, degree of fluorination, overall chemical structure, and extant functional groups. For many industries, including the non-road sector, PFAS chemistries are selected to provide high thermal and chemical stability, a resistance to heat, pressure, chemical, and friction stressors, and have very low surface tensions, making them repellent to both water and oil.

Despite the numerous useful applications of PFAS, the global regulatory community is expressing concerns over their historic uses and proliferation around the world. Various legislative and regulatory bodies are moving quickly to address these concerns. As of this writing, there have been more than 203 legislative and regulatory actions addressing PFAS across 31 U.S. states. In seeking to address these concerns, this recent governmental activity risks industry's access to many, if not all, of these valuable chemistries.

As stated above, many alternative power technologies are acutely reliant on PFAS to function. For instance:

- **Batteries** utilize chemical binders to hold the internal active materials together to maintain a strong contact between the electrodes and the current collectors. Battery manufacturers use polyvinylidene fluoride (PVDF) as a binder in lithium-ion batteries due to its electrochemical and thermal stability, as well as its acceptable binding properties for the cathode. Additionally, certain fluorinated compounds are also used to coat the anodes to prevent unwanted reactions with the electrolyte. Due to their long lasting and chemically stable properties, the fluorinated compounds help extend the useful life of the battery.

Under standard industry practices, these batteries are manufactured in clean-room conditions, preventing the release of any PVDF into the surrounding environment. These closed systems make it impossible for any PFAS materials to escape. Furthermore, battery recycling operations recover the PVDF through hydrometallurgical treatment processes. The collected PVDF is further broken down and captured by gas scrubbers, preventing any further release.

- **Hydrogen fuel cells** use a proton exchange membrane (PEM) to separate the anode and the cathode. The PEM uses fluoropolymers to separate the protons from the electrons at the membrane surface, allowing only the protons to permeate to the cathode. In this technology, the fluoropolymers provide crucial properties that enable the fuel cell to produce electricity. The fluoropolymers used in the fuel cell PEM have no known alternative replacement.

PFAS provides the functional characteristics required to implement alternative power technologies. Without access to certain PFAS chemicals, none of these technologies will remain viable.

Recommendation: Policymakers should work with industry as well as other stakeholders to make sure PFAS prohibitions do not stop the adoption of new technologies.

The non-road equipment industry will continue to innovate and develop the technology solutions demanded by our customers and needed to solve the challenges of the future. This road will require a commitment to the time, resources, flexibility, and investment needed to reach an alternative power future. However, the non-road equipment industry will also need to overcome a variety of real-world challenges. To ensure success, non-road equipment manufacturers strive to be a key stakeholder in these policymaking decisions going forward.

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