

Clean Air and Low Emissions

through Next-Gen Non-road Equipment



Executive Summary

The Association of Equipment Manufacturers (AEM) is the North American-based international trade group representing the non-road equipment manufacturing industry. Engine emissions regulations are some of the most impactful requirements placed on the non-road sector, affecting the equipment's performance, R&D, design, safety, and cost. AEM members recognize the importance of improving air quality and mitigating the impacts of climate change, and for 30 years manufacturers have invested heavily to support emissions reduction updates. The most recent Tier 4 update drove significant equipment changes, including modernized electronic engines and aftertreatment for many power categories.

The last round of engine emissions regulations taught the equipment industry valuable lessons, including the inherent cost and complexity of transitioning an entire industry to a new emissions tier, as well as the value that time and customer feedback can provide manufacturers and regulatory officials. AEM and its member companies want to use our experience and expertise to share the lessons learned from the Tier 4 transition, as well as the way work is done now, the requirements of doing work in the future, and policymaking recommendations for industry stakeholders.

The industry's knowledge and past experiences produced several key recommendations to support a reasonable transition to even cleaner equipment in the future. In order to reach this goal policymakers should:

- Consider how the cost effectiveness of new requirements will influence the adoption of new products in the marketplace.
- Consider the impact of new regulations on multiple equipment types, including smaller and low-volume equipment.
- Drive emissions reductions to avoid overly prescribed regulatory requirements that neglect to consider new processes and technologies that contribute to the whole emissions reduction picture.
- Create purchase incentives for end-users to accelerate market adoption of new equipment and technology, and provide credits to manufacturers for developing new emissions reduction technologies.

- Establish regulatory approaches that ensure collaboration in the development of harmonized engine emissions regulations.
- Provide a minimum of five years of lead time and a regulatory transition program for equipment manufacturers when introducing a new technology-forcing emissions standard.
- **Implement** technology-neutral, performancebased standards, and avoid overly stringent requirements that will compromise engine capabilities, fuel economy, and equipment productivity.
- Set standards that do not require engine system packaging and installation changes in order to avoid costly equipment redesign or impact equipment safety features.

The contents of this document and the recommendations contained therein seek to educate industry stakeholders and policymakers on the challenges and opportunities facing AEM members as they work to meet future emissions requirements. AEM believes that collaboration between government and industry can deliver future environmental benefits for all. By outlining our perspectives, we hope to start future conversations and cooperation to the satisfaction of all interested partners.





Executive Summary 2
Introduction to AEM and the Non-road Equipment Industry 4
Non-road Equipment
AEM Member Sectors:
AGRICULTURE 5
CONSTRUCTION 5
FORESTRY 6
MINING 6
UTILITY 6
Introduction to Engine Emissions Rules 7
Current Emission Rules
North America
Europe9
Lessons Learned
AEM Vision of the Future: How Work Gets Done
(Market Requirements)
Time Sensitivity

AEM Vision of the Future: AEM member goals	13
Future Powertrain and Energy Storage Technologies	14
Infrastructure Needs	15
GHG Accounting	15
Industry Recommendations	16
Regulatory Approach	16
Unique Non-road Equipment Offerings	16
Holistic View When Considering Emissions Reductions	17
Harmonized Emissions Standards	18
Lead Time	18
Equipment Performance	19
Engine System Packaging	19
On-Board Diagnostics 2	20
Appendix	21
Assumptions	21



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. Our 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 equipment designed to execute specific functions relative to it's intended application 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 even further into different categories based on 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 Equipment, 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, Generators, Air Compressors, Light Towers, Concrete Saws, Crushers

Within the global emissions regulatory environment, non-road original equipment manufacturers (OEMs) share many similarities with adjacent industries, especially the automotive sector. Both industries sell complex products powered by internal combustion engines and 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 operate in harsh environments with a customer base that demands reliable, safe, and continuous operation.



AEM Member Sectors

Non-road equipment operates across five crucial sectors in the global economy: agriculture, construction, forestry, mining, 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. From an operations standpoint, 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 is extremely varied in its operations. Worksite environments differ greatly and may lack access to refueling infrastructure, especially in remote locations or areas under development. Additionally, construction projects involve repetitive tasks over large areas, and rely on minimized downtime to meet project timelines and control costs. Under this broad definition, construction can break down into additional subcategories:

Building construction focuses on the process of adding 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 include roads, bridges, tunnels, and canals.

Equipment: Dozers, Motor Graders, Pavers, Rollers, Road Reclaimers, Nonhighway Trucks, Excavators, Drills, Boring Equipment



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. Certain forestry machines are used as a method for reducing forest fuel loads to mitigate the risk of fires as well as brush and wood recycling.

Equipment: Feller Bunchers, Swing Equipment, Skidders, Forwarders, Chippers, Grinders



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 and 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 possess 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, Draglines, Excavators, Loaders, Dozers, Rippers



UTILITY

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

Equipment: Trenchers, Directional Drills, Vacuum Excavators, Telehandlers, Pipelayers, Aerial Devices, Sewer Cleaners



Introduction to Engine Emissions Rules

During the 20th century, growing public attention to air pollution issues spurred government organizations to address this rising concern. In 1970, the US government amended the Clean Air Act (CAA), requiring the newly formed Environmental Protection Agency (EPA) to define and enforce National Ambient Air Quality Standards (NAAQS). In 1974 the EPA established new mobile source air emissions rules restricting the release of criteria air pollutants: ground level ozone (O3), particulate matter (PM), lead (Pb), carbon monoxide (CO), sulfur oxides (SOx), and nitrogen oxides (NOx) in onroad light-duty and heavy-duty vehicles.

By the mid-1990s, regulatory bodies in North America and Europe looked to establish and enforce new limitations on criteria pollutants from non-road diesel engines. This effort culminated in the creation of an emissions control regime for the non-road sector following the promulgation of the Non-road Mobile Machinery Directive 97/68/EC in Europe and 40 CFR Parts 86 and 89 in the United States impacting on-highway and non-road engines. Over the next quarter century, the EPA and European Commission (EC) continued to introduce new emissions standards, commonly referred to as "Tiers" in the United States and "Stages" in Europe. Aside from a few noteworthy exceptions, Europe and North America worked to harmonize their "emission" standards, in an attempt to ensure common engine requirements across markets. This effort helped improve product availability, product reliability, and controlled costs. As shown below, this activity greatly reduced the permitted emissions levels in non-road equipment over time.



EPA and EU Non-road Emissions Regulations



Current Emissions Rules

North America

Introduced in 2004, the EPA's current generation of non-road engine emissions rule is commonly referred to as Tier 4. This rule restricted criteria pollutants to near zero levels, with PM a 95.6% reduction in NOx and a 96.3% reduction in PM, from Tier 1 to Tier 4 when compared to Tier 1 limits.

To accommodate the lead times, costs, and workload required to meet these tighter emissions standards, the EPA instituted various provisions within the regulation to help their OEM stakeholders realize these objectives. The Tier 4 regulation, phased in from 2008 to 2015, allowed for an initial criteria pollutant standard (commonly referred to as "interim Tier 4") prior to "Tier 4 final" standards. This additional interim tier allowed for a gradual phase-in of less restrictive emissions limits, prior to reaching the much more restrictive final standard. As seen below, the implementation dates for the interim Tier 4 standards differed based on power category, with the 56-130 kW range transitioning last.



During the Tier 4 rulemaking process, the EPA also recognized a concern among equipment OEMs that engine manufacturers may be unable to provide sufficient notice of possible engine design changes during the certification process. These types of design changes can cause equipment to undergo major redesign efforts to fit the engine into the equipment's engine compartment. In response, EPA promulgated the Transition Program for Equipment Manufacturers (TPEM), giving OEMS the ability to extend the introduction of compliant engines over the course of seven years. By granting OEMs this flexibility, the TPEM program helped manufacturers strategize on how best to deploy their engines to the marketplace.



It is important to mention that both Canada and the State of California have independent engine emissions regulatory frameworks within their jurisdictions. Environment Climate Change Canada (ECCC) and the California Air Resources Board (CARB) both have the authority to pass emissions regulations for certain non-road equipment, and the two have typically harmonized with the US EPA on past non-road emissions rules.

Europe

On September 14, 2016, the European Commission introduced Regulation (EU) 2016/1628, also known as European Stage V. The rule established further criteria pollutant restrictions for non-road engines, mandating a compliance date of 2019 for engines below 56 kW and above 130 kW, and another compliance date of 2020 for engines between 56-130 kW. The European Commission broke the longstanding alignment between the North American and European rules with the establishment of a particulate number requirement as part of EU Stage V.

Similar to the EPA, the EC recognized the challenges AEM members faced when dealing with potential equipment design issues that arose during the engine certification process. To accommodate these issues, the EC established a provision in the final rule allowing for manufacturers to place engines, produced prior to the applicable Stage V provisions, into the EU market provided that they complied with the requirements of the previous emissions stage. As shown below, the transition engine program allowed for extended compliance dates beyond the original allotments outlined in the final rule.



EU TRANSITION SCHEME

* Inclusive of after-treatment (if applicable)



Lessons Learned

STABILITY AND LEAD TIME: OEMs welcome the stabilizing periods between the implementation of older emissions tiers and the introduction of new rulemakings. This period helps facilitate the successful deployment of future engine technologies to the market. To accommodate the degree of emissions reductions between rulemakings, engine and equipment manufacturers require adequate lead times to fully develop and validate new technologies in a wide range of customer applications. Lead times provide specific value to equipment manufacturers, as OEMs cannot start their packaging modifications until the engine manufacturer validates and certifies its products with the appropriate regulatory bodies.

Following the implementation process, engine and equipment manufacturers need time to recover investments made in their new and improved products. These stability periods also give regulators the time to assess the real-world environmental and economic impacts of their most recently promulgated rule. Taken together, this intermission period can provide tremendous value to industry and government and help them both prepare for future emissions related developments.

 CUSTOMER FEEDBACK AND EXPERIENCE: Customers in the non-road sector udepend on equipment as an integral part of their business. Aspects of regulations that impact their total cost of ownership, as well as the reliability, durability, and serviceability of their equipment are the primary drivers of customer decision-making. Due to the longevity of non-road equipment, customers are generally able to postpone purchases of new equipment if regulatory developments adversely impact costs. End-user hesitancy due to rising cost and performance concerns can hinder the rate of market adoption of new technology and delay the realization of desired emissions benefits.

COST AND COMPLEXITY: The harmonization of emissions standards helps streamline engine development, engine certification and equipment type approval and allows for a single, globally compliant product. This helps manufacturers gain economies of scale and return on investment in the inherently low-volume non-road market. These efficiencies help focus manufacturing activities on better engine design, a more effective allocation of company resources, and a general reduction of waste. For all these reasons, engine and equipment manufacturers prefer harmonized emissions standards.

Conversely, non-harmonized global emissions standards add to the cost and complexity of engine and equipment design processes. Companies looking to sell into markets with different engine rules need to devote more time and resources to comply with each unique requirement. This increases the number of challenges, stressors, costs, and the level of intensity placed on manufacturers to comply with different rules. These issues exacerbate the challenges facing manufacturers of low-volume products which have acute cost considerations. These types of equipment do not have the volumes to recoup the associated costs of compliance and endangers the viability of these products in the marketplace.



AEM Vision of the Future: How Work Gets Done (Market Requirements)

One goal of an equipment manufacturer is to provide its customers with solutions that ensure the form and function of its products meet the requirements of the jobsite. Ultimately, end-users determine which products meet their needs and which do not, but most of these requirements will revolve around the engine and its power 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. Three factors commonly impact a customer's energy demands:

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

To successfully implement future regulatory changes, industry stakeholders need to consider the impact that any new rule may have on these factors.

Time Sensitivity

Companies in the non-road sector look to avoid delays as much as possible. Delays can lead to cascading interruptions on the jobsite, ballooning costs, project schedule slip, monetary losses, and potential public safety concerns. Site operators expect equipment to operate reliably and continuously through the duration of the projects they work on, and equipment manufacturers attempt to mitigate delays by maximizing onboard energy storage capacity while minimizing recharge and refueling time for their products.

Several examples 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 equipment that requires long refueling times, can jeopardize the profitability of an entire farm.
- Livestock feeding: Livestock require consistent and continuous care from the farm owners. Equipment must remain operational to ensure the farm needs are met.
- Emergency infrastructure repairs: Emergency repairs on crucial infrastructure require working equipment to operate on demand. Delays to infrastructure repair can risk public safety or paralyze transit.



Location

The nature and needs of the worksite in the non-road sector vary greatly depending on the nature of the job. Oftentimes, non-road equipment operates in remote locations, distant from readily available energy supplies. These sites often operate over longer time periods, sometimes as long as several months or years, and site managers 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 several 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.

A key issue that AEM members strive to address involves designing products flexible enough to operate in vastly different work environments, while at the same time maximizing the energy capacity of the equipment to meet the requirements of the end customer. Examples of these types of requirements include:

- Crop planting and harvesting
- Earthmoving and road building
- Pipeline and utilities construction
- Forestry operations



Duty Cycle

The energy demands of non-road equipment vary broadly depending on the job. High load factor applications are characterized by frequent high-power demands, near continuous use, or a combination of the two. The resulting power requirements lead to significant energy consumption throughout the workday. Examples include:

- Field tillage, crop planting and harvesting
- General earthmoving
- Pipeline construction

Forestry operations

- Minina
- Conversely, low load factor applications are characterized by low power demands, highly intermittent use, or a combination of the two. Examples include:
- Intermittent agricultural operations
- Infrastructure repair
- Certain utility operations



AEM Vision of the Future: AEM member goals

Politicians, policy makers, and environmental groups strive for air quality improvements as well as 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, AEM members believe that the interplay between new technology and improved worksite efficiencies are both required to realize these societal environmental goals. More specifically, successfully integrating technology gains with jobsite process advancements will lead to greater industrywide efficiencies and greater environmental benefits to all.

Some of these new developments include:

- No-till agricultural practices that reduce the energy required to plant crops.
- Precision agriculture, a broad term for the techniques that combine Global Positioning Systems (GPS) with equipment control to improve operating efficiency and energy consumption in a variety of agricultural operations.
- Automated systems in earthmoving equipment, such as grade control, enhance the equipment's operating efficiency.

AUTOMATION NEEGRATION ENERGY CONSUMPTION NEEGRATION NEIGRATION NEI

The adoption and integration of new technologies and practices can reduce the industry's overall energy consumption along with its criteria pollutant emissions. However, implementing new features often leads to higher equipment prices. Widespread market adoption of these features will only occur if the monetized efficiency gains more than offset the increased total cost of ownership of the equipment. Equipment manufacturers will need to strike a careful balance to meet both the demands of the marketplace as well as the policy goals of environmental decisionmakers.



Future Powertrain and Energy Storage Technologies

The industry's market requirements will continue to influence the adoption of new technology and energy carriers used in non-road equipment. Ideally, future energy carrier technologies will reduce both criteria pollutants and greenhouse gas emissions. Some of these advancements include:



While many of these technologies may reduce emissions at the equipment level, questions remain regarding their adoption in the marketplace. These include:

- **Production methods of the energy carrier:** Will energy production generate greater emissions than the reductions at the point of use?
- **Production capacity and distribution infrastructure:** Will energy be available for equipment at a reasonable price?
- Raw material availability: Will there be sufficient raw materials to produce and store the energy?
- Energy density: Is the equipment's energy storage capacity sufficient to ensure reasonable run times?
- Length of the refueling cycle: Will the refueling times be short enough to minimize jobsite disruptions?

Equipment manufacturers understand the potential for alternative power technologies to help mitigate a variety of 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 work sites may need to use internal combustion engines (ICE). To minimize 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 customers to provide specific application-based solutions.



<text>

Infrastructure Needs

New technologies and product features can offer a variety of real-world advantages to equipment owners. However, customers may resist adopting these new technologies if the product does not also contribute sufficient returns on investment. New energy carrier technology requires supporting infrastructure in order to operate efficiently and profitably. Extended refueling times and new fueling procedures that do not align with the rest of the worksite can adversely impact the equipment owner's ability to meet business objectives. Furthermore, the infrastructure requirements to service non-road equipment will differ from the onroad 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.

GHG Accounting

Finally, the introduction of new greenhouse gases (GHG) accounting requirements to achieve realworld climate benefits must consider the overall carbon lifecycle of the energy source. Hydrogen fuel produced through renewable power sources, such as wind and solar, will provide 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

AEM members support efforts to improve air quality and reduce the impacts of climate change. Since the 1990s, equipment and engine manufacturers have invested heavily to reduce NOx and PM emissions from their products. Based on this experience, there are a variety of policy solutions AEM recommends when considering the development of future rulemakings that impact emissions or future engine technologies.

Regulatory Approach

AEM's member companies appreciate the environmental goals related to air quality and climate change. While these are worthwhile societal goals, complying with engine emissions requirements remains a resourceintensive activity for engine and equipment manufacturers. More stringent emissions standards drive increased compliance costs. Therefore, it is important that rulemaking efforts consider the cost effectiveness of new regulatory provisions.

Economic factors are one of the primary considerations for non-road equipment buyers. Customers expect-newly purchased equipment to expand the capabilities and profitability of their business. The cost of ownership, including initial capital, ongoing service and maintenance expenses, as well as fuel and other operating expenditures are balanced against the perceived productivity of the machine, as well as other efficiency gains. Requirements that dramatically increase the costs of products can result in unintended consequences that will impact the wider marketplace.

Recommendation: Policymakers should consider how the cost effectiveness of new emissions requirements will influence the adoption of new products in the marketplace.

AEM members support efforts to improve air quality and reduce the impacts of climate change

Unique Non-road Equipment Offerings

The non-road sector is incredibly diverse, with a wide variety of operating conditions and application requirements. This diversity helps spur innovation but can also limit the viability of certain product offerings, risking the market's acceptance and adoption of new technologies. An emissions solution that works well at a construction site in a large city may not be suitable for a remote worksite in a forest far from established infrastructure. Likewise, smaller equipment offerings provide great utility in many end-use applications. However, the engine is a larger portion of the total cost of a smaller machine, making these unique products particularly cost-sensitive to new emissions or engine technology requirements.

Recommendation: Regulatory officials must consider the impact of new regulations on various equipment types, including smaller power and low-volume machines.





Holistic View When Considering Emissions Reductions

While internal combustion engines will continue to play a significant role in the non-road sector, the deployment of alternative power technologies can contribute, alongside ICE, to emissions reduction and decarbonization through efficiency gains. It will be important to help facilitate the contribution of new technologies in the larger emissions picture while recognizing the obstacles to their deployment, such as cost, specific application requirements, and infrastructure needs. Furthermore, the use of certain low carbon diesel fuels can help achieve lifecycle GHG emissions reductions up to 74% lower than those from petroleum diesel and provide immediate decarbonization benefits.¹ Supporting these technologies with appropriate credit and incentive programs can help drive equipment efficiency and promote emissions reductions.

Recommendation: Policymakers should accelerate market adoption of new equipment, technology, and low carbon fuels with incentives and public funding, as well as provide credits to manufacturers for developing new emissions reduction technologies.

It is important to consider that in some non-road applications, engine design changes may not provide the largest emissions reductions. Significant real-world reductions can be achieved by a variety of techniques and processes, including site automation, new machine systems, and operator efficiency improvements. Certain automated systems can demonstrate up to 34% productivity improvements through enhanced equipment accuracy². New machine driveline systems, such as electric drive, hybrid technology, and battery electric, can also provide sizeable net reductions in GHG. These advanced technologies, while providing promising GHG reductions, typically pull from the same resources as engine development. Decisionmakers must consider the resource requirements new emissions regulations place on manufacturers as they work to develop new technologies.

Recommendation: Policymakers should avoid overly prescribed regulatory requirements that neglect new processes and technologies that can contribute to decarbonization.

¹H.Huo, M. Wang, C. Bloyd, and V. Putsche, (2008) *Life-Cycle Assessment of Energy and Greenhouse Gas Effects of Soybean-Derived Biodiesel and Renewable Fuels*, Energy Systems Division, Argonne National Laboratory, Center for Transportation Technologies and Systems, National Renewable Energy Laboratory, U.S. Department of Energy

continued

² Azar, E.R., Agnew, G., Parker, A., (2015) *Effectiveness of Automated Machine Guidance Technology in Productivity Improvement: Case Study*, Construction Specialty Conference, Lakehead University, Canada



Harmonized Emissions Standards

Establishing internationally harmonized emissions standards provides clarity and certainty for engine and equipment manufacturers. Different standards across national or international markets increase the complexity, resource needs, and timing requirements for OEMs. These efforts undermine research and development investments into alternative technology solutions that can contribute to overarching societal environmental and climate goals. The time and resource costs associated with emissions compliance efforts can risk the economic viability of certain equipment. Emissions standards should strive to remain achievable and not endanger future product offerings to the market. From an equipment manufacturer's standpoint, the most important considerations are minimizing product variants across markets, working with equivalent technical standards, and the acceptance of the equivalent certification documents across different markets.

Recommendation: Policymakers should establish regulatory approaches that ensure collaboration in the development of harmonized engine emissions regulations.



Lead Time

The implementation of Tier 4 required a significant investment in equipment to allow for the installation of new engine designs and aftertreatment systems. Due to the non-road sector's large variety of complex and unique configurations, the time to redesign, validate, and launch new equipment will expend significant time and resources. Furthermore, transition programs provide significant value to equipment manufacturers by allowing engine suppliers flexibility in launches of new products as well as working to assure that emissions solutions for extreme applications are cost-effective and meet customers' needs. To effectively implement a new emissions rule, it is critical that regulators provide adequate lead time and viable transition programs which give room for OEMs to update engine systems, equipment structures, and packaging.

Recommendation: Provide a minimum of five years of lead time and a regulatory transition program for engine and equipment manufacturers when introducing a new technology-forcing emissions standard.



Equipment Performance

In addition to designing unique machine forms, equipment manufacturers also need to ensure their products deliver the operational performance, productivity, and durability capabilities their customers require. As an example, some non-road engines must provide tractive power while also operating fluid power implements and power-take-off (PTO) systems. This creates a high burden on an engine's performance capabilities, which is unique to the non-road sector. Another relevant, unique factor in this sector is the wide range of power that non-road products require, varying from 25 hp or less to 1,000 hp or more. Strict non-road emissions rules can limit engine capabilities necessary for equipment operation. Any such limitations would force significant equipment updates, such as hydraulic system redesign or an even more impactful complete equipment redesign. This type of development is impractical for equipment manufacturers, negatively impacts customer value, and may offset any emissions improvements intended by the requirements.

Recommendation: When considering new rules, regulators and policy makers should implement technology-neutral, performance-based standards, and avoid overly stringent requirements that will compromise engine capabilities, fuel economy, and machine productivity.

Engine System Packaging

Engine and equipment manufacturers have made significant engine and aftertreatment advancements since the introduction of Tier 4. These advancements, along with system tuning, make it possible to achieve significant emissions reductions without major modifications to the engine package. Maintaining existing engine packages provides several key advantages including:

- The ability to accelerate the deployment of new technology into high-mix, low-volume equipment
- · Help to mitigate safety-related risks, such as visibility and thermal surfaces
- Increase customer adoption rates due to reduced safety risks, time, and user education efforts

Recommendation: Set standards that do not require engine system packaging and installation changes in order to avoid costly machine redesign or impact equipment safety features.







On-Board Diagnostics

Regulatory agencies are considering on-board diagnostics (OBD) requirements to alert operators when malfunctions occur over the lifecycle of the engine. OBD is widely deployed in onroad vehicles today. Key OBD requirements that may carry over from the current on-highway OBD regulation include standardization of data communication protocols, component failure detection, emissions threshold monitoring, and operator notification. Many of these factors are calibrated on an application-specific basis. The developmental challenge of implementing OBD in the non-road sector, especially the calibration of emissions threshold monitors, will be significantly more burdensome due to the much larger number of application usage profiles and lower engine family volumes. Wide variation in engine operation for nonroad equipment further increases the complexity of developing OBD. Engine manufacturers have recently invested significant resources in developing engine diagnostics, including NOx and particulate control diagnostics (NCD/PCD) to identify emissions-related issues. These diagnostics strategies notify the operator, trigger inducements (engine derates), and encourage operators to correct emissions-related issues. As part of Tier 4, non-road equipment manufacturers have updated instrument clusters, added lamps, installed switches, and incorporated other mechanisms to ensure systems operate correctly and effectively. Utilizing existing NCD/PCD helps maintain some commonality in equipment design, thereby reducing costs and ensuring reliability.

Recommendation: Leverage existing non-road NOx and particulate control diagnostics (NCD/PCD) software, inducement, and derate strategies.



Appendix

Assumptions

- Internal combustion engines will continue to be used in certain applications and machine types. This will be necessary in certain applications that have no known pathway to transition away from diesel engine technologies and still meet the operational needs of the machine.
- Focusing exclusively on engines to achieve emissions reductions ignores real-world opportunities to achieve societal environmental goals. Holistic emissions reductions of all pollution sources (including, for example, site automation and new technology introductions) will be necessary to meet air emissions and environmental policy goals.
- Past experiences are a reasonable basis to judge future resource requirements. There are very real resource constraints on manufacturers looking to meet new regulatory requirements and achieve returns on investment that constrain the deployment of emissions tiers. Furthermore, manufacturers working under finite resource constraints can realize great technology improvements, but they cannot accomplish all goals at the same time under real-world restrictions.