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Written Testimony

Railways play an essential role in the US economy as they uniquely combine speed and energy efficiency to safely move large quantities of freight at low cost. Although US freight railroads continue to improve fuel efficiency, they consume over 3 billion gallons of diesel fuel each year. Despite representing less than two-percent of transportation-related emissions, freight railroads, like all industrial sectors, must act to reduce carbon emissions in an effort to stem climate change and health impacts on adjacent communities. However, freight railroads must be allowed to decarbonize at a pace that respects the current state of zero-emissions locomotive technology, and in a safe manner consistent with the operational realities of an integrated North American rail network. Unfortunately, the aggressive timeline and scope mandated by the CARB In-Use Locomotive Regulation cause concern on both of these fronts.

Although a number of technologies offer the promise of future zero-emissions freight rail transportation, none of them are currently commercialized for North American heavy-haul freight mainline operations. Several of the technologies have seen implementation within yards and terminals, where locomotive power demands and duty cycles are quite different from the mainline, and the locomotives remain close to specialized energy supply infrastructure installed specifically to support the locomotives assigned to that facility. While testing and operating experience gained in yard and terminal applications can help inform potential mainline performance, the demands of long-distance mainline freight service can vary considerably between each route and type of freight train service. In terms of North American heavy-haul freight mainline operations, each zero-emission technology has unique technical, safety and implementation challenges that must be addressed before widespread deployment is possible.

Traditional electrification through overhead wire (overhead catenary system or OCS) is the most mature of the zero-emissions technologies under consideration by the freight rail industry. However, most North American experience with OCS is in the context of passenger and transit systems, or a small number of isolated industrial railroads that do not interchange locomotives with other railways. Although freight operations with OCS is widespread internationally, the freight trains operated on those networks are far shorter and lighter than freight trains operated in North America. Accordingly, international electric locomotive designs are optimized to those freight train sizes and allowable axle loads, and are not directly transferable to mainline freight operations in the US. It has been several decades since the last new North American mainline freight electrification was implemented in Canada in the mid-1980s. As such, implementation of OCS requires development of new electric locomotive designs meeting the horsepower and tractive effort performance requirements of current North American freight operations. A primary benefit of OCS is that it will make the most efficient use of electricity, a key consideration when multiple electrification technologies across different transportation modes will all be competing for electricity generated from renewable sources. Traditionally, the main obstacle to electrification via OCS is the high initial investment in the overhead catenary infrastructure across extensive portions of the network required to support a critical mass of train operations. New approaches, such as dual-mode locomotives that can draw power from OCS when it is available but use other energy sources (diesel or battery) outside OCS territory, can reduce the amount of OCS infrastructure required by facilitating partial or discontinuous electrification strategies. These approaches have yet to be demonstrated for North American freight operations, but are particularly attractive where overhead clearance constraints in tunnels and under highway overpasses substantially raise the cost of OCS. In the past, investment in traditional OCS electrification infrastructure has always been judged as a trade-off between the cost of electrification and the cost of continued operations with diesel-electric locomotive operations. Future decisions on which corridors to electrify with OCS must be made from the perspective of determining the most economical and effective way to decarbonize relative to the costs of other zero-emissions locomotive technologies. Thus, there is considerable uncertainty and risk remains regarding how electrification through overhead wire compares to other emerging technologies.

Battery-electric locomotives (BELs) have seen limited mainline testing, and thus their long-term range and battery-life performance under various climate, topography and operating conditions is uncertain. US freight railroads have begun to implement BELs in yard service where they can remain close to their charging infrastructure and power demands are a better fit for the amount of available onboard battery storage. For mainline freight applications over long distances, the energy storage of a BEL cannot match that of a diesel-electric locomotive. BELs with over 14 MWh of battery storage have been proposed for service on dedicated iron ore railways in Australia, but these locomotives require 8 axles to distribute the weight of the locomotive over the robust heavy haul track structure. Current North American freight locomotives have six axles and thus can only support BEL storage capacities in the range of 8 to 9 MWh. This capacity alone is not sufficient to power freight operations over many long-distance routes, even when energy is recaptured and stored in the batteries during braking on downhill segments. Various options have been proposed to extend the range of BELs, such as on route charging from short segments of OCS, additional battery storage on tenders coupled to each BEL, or modular "battery packs" that could be swapped on and off locomotives at intermediate stops between origin and destination. However, these proposals remain concepts as none of these technologies have been demonstrated for freight operations, and thus further research and development is needed prior to commercialization. Another compounding factor that may limit BEL capability is the viability of high-power charging to support economical locomotive utilization. Research is still ongoing to develop 1 MW and 2 MW chargers that could recharge an 8 MWh BEL in eight or four hours, respectively. These long recharging periods will limit the amount of time BELs are available to haul freight, increasing the required locomotive fleet size and investment relative to other locomotive technologies.

Hydrogen fuel cell locomotives are only beginning mainline prototype development, and thus our understanding of their long-term performance, durability and safety is in its infancy. Because of the relative energy density of hydrogen, fuel cell locomotives will require tenders for mainline applications. Operations with tenders, whether for hydrogen or batteries, pose operational constraints on the 70 percent of the US mainline freight network composed of single track with passing sidings. The lengths of these passing sidings, or short sections of double track where trains travelling in opposing directions can pass each other, effectively limit train length. Allocating some of this train length to tenders will decrease the amount of freight that each train can carry, reducing productivity and overall energy efficiency. Hydrogen fuel cells, because of the numerous energy conversion steps required to produce, compress and use the hydrogen, will make the least efficient use of electricity and thus place the greatest new renewable power demands on the electrical grid.

While the railroads, railway supply industry, government agencies, academia and national labs can likely partner to overcome these challenges, it will require years of further research, development and full-scale service testing of each technology, followed by years of commercialization and deployment. There are numerous historical examples of railway technologies that appeared to be good ideas on paper or in the lab, but failed when rushed to market without proper testing to expose them to the long-term realities of North American heavy haul freight mainline operations. A relevant example of this effect is that of "genset locomotives" that were designed to reduce emissions by using multiple smaller high-speed diesel-generator sets in place of the single conventional low-speed diesel engine found in typical diesel-electric locomotives. After the concept was demonstrated via a single full-scale prototype, the technology was quickly commercialized and many genset locomotives were deployed in local service within urban areas with the aid of Federal and local grants aimed at improving air quality. During the initial deployment, many problems were encountered with the technology, and many of the genset locomotives partially funded by the public were removed from service. Adequate time to test additional genset locomotives in revenue service could have potentially allowed manufacturers to identify and mitigate trouble points, with a better long-term outcome for this emissions-reduction technology. With its aggressive timelines, the CARB regulation risks exposing emerging zero-emissions technologies to suffering a similar fate as the genset locomotive.

All three zero-emissions locomotive technology options described above will require extensive and expensive investments in energy supply infrastructure, whether it be overhead catenary wire, high-power battery chargers, or hydrogen production and fueling stations. Should a technological pathway prove not to be viable, early investments in associated energy supply infrastructure will become stranded assets. While dual-mode locomotives can help mitigate this risk and reduce infrastructure requirements, they remain an unproven concept in the freight environment and require time for development and testing.

Further, to truly achieve zero emissions, the three technological options must be supplied with renewable electricity (or "green hydrogen" produced from renewable sources). Although none of the technologies will produce mobile source emissions from locomotives, the global emissions of all three technologies are dependent on the generation mix of the electricity available in the local electrical grid. Given that other transportation modes are also pursuing electrification pathways, demand for generating, transmitting and distributing renewable electricity will increase substantially over the coming decades. As mentioned above, the many inefficient steps required to produce and use hydrogen will increase the amount of electricity required to satisfy a given freight rail transportation demand, exacerbating pressure on the grid. Electrification via OCS presents fewer losses and will use electricity much more efficiently, minimizing electricity requirements for a given freight rail transportation demand. Time and research are required to better understand how these relative efficiencies translate into trade-offs between investments in energy supply infrastructure (OCS, chargers, and hydrogen compressor/fueling stations) and the additional transmission grid infrastructure and renewable generation capacity required to support railway transportation demands. Even if matured and commercialized, there is no guarantee that any of the zero-emissions technologies discussed above can be consistently supplied with renewable electricity in the future.

Finally, the CARB regulation poses concerns from an operational an implementation perspective. The North American fleet of 25,000 locomotives represent long-lived assets that are highly utilized and standardized for interchange across all rail carriers. Because locomotives are interchanged across the interconnected North American freight rail network, allocating specific locomotives to operate in certain areas introduces inefficiencies that increase the required locomotive fleet size. Since existing locomotives can operate in mainline service for 20 to 30 years before being cascaded down to local and yard service, the locomotive fleet requires multiple decades to turn over, and, correspondingly, any change in technology will require a lengthy transition period.

Given this operational and implementation context, complying with the CARB regulation leaves freight railroads with two undesirable alternatives. The first is to isolate new locomotives to operations within California by having all freight trains stop and swap locomotives at "exchange points" just outside the State. In 2016, a CARB-sponsored study[1] documented the negative impacts of these exchange points on railway operations, including a potential shift of freight from rail to less efficient trucks due to the additional shipment transit time. This shift of freight from railways, with their own dedicated infrastructure, to trucks operating on highways will also increase traffic congestion in California, further decreasing the efficiency of both heavy trucks and light-duty passenger vehicles.

The second alternative is a network-level implementation of a given zero-emissions locomotive technology which, for all of the technical, development and implementation reasons described previously, is impractical under the mandated timeline, and represents a tremendous investment risk given the current state of zero-emissions locomotive technology.

The combination of dual-mode locomotives and partial or discontinuous electrification on certain higher-density corridors, in conjunction with batteries or hydrogen on other lower-density routes, could provide a third implementation pathway with greater long-term flexibility and feasibility. Designs for converting existing locomotives to dual-mode operations using tenders carrying batteries or equipment to collect power from OCS where available have also been proposed as a way to utilize the sunk investment in the current locomotive fleet during the transition to zero-emissions operations. However, these dual-mode locomotive designs, locomotive conversion kits and electricity-collecting tenders are still only engineering concepts that have not yet been produced in prototype form or tested for freight operations. Further research and extensive testing are required to prove the viability of these more flexible concepts and overall deployment strategies that better fit railway operating patterns across mainlines of different traffic density. Unfortunately, the CARB regulation does not afford railroads the time or flexibility required to achieve this more likely multi-technology implementation scenario.

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1 Dick, C.T., Y. Ouyang, and G. Fullerton. 2016. Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California: Operational and Economic Considerations. Final Report. State of California Air Resources Board. Sacramento, CA, USA. Available at: https://ww2.arb.ca.gov/sites/default/files/classic/railyard/docs/uoi_rpt_06222016.pdf