Rail Electrification in North America: Benefits and Barriers

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For the Rail Electrification Council

I. Introduction

"The intelligence of the institutions we create, not that of the hardware and software we deploy, will determine whether the industry that created the world's wealthiest and most powerful nation will lead that same nation to a new, more productive, and sustainable future." (Fox-Penner, *Smart Power*, 2010) Rail electrification entails modernization of two of our most critical network industries. The generation and delivery of electric power, and its end-uses, are being driven to change by policy imperatives to reduce the impacts of global climate change and to achieve greater energy security as well as by new technologies, capital costs, and availability, impatience with incremental change in the face of enormous environmental and economic challenges. Rail transportation is not static. Innovations such as positive train control and containerization have improved the efficiency of this critical, if aging, component of the North American supply chain. So, the question is, what is to be gained by the collaborative modernization of these critical network institutions, with electric power as the driver? The answer is sustainability, environmentally but also economically and ethically.

Electrification of the transportation sector is today focused primarily on electric highway vehicles, but it will impact other modes of transport and will resonate in other industry sectors as electricity displaces other "fuel" in the coming two or three decades. We are expecting almost inestimable benefits from commercial and industrial digitalization, productive energy efficiency strategies, public policy arising from climate change and health concerns, the transformation of electric generation resources, including from low-cost natural gas and the declining cost of renewable resources, efforts to de-congest supply chains for goods and services, and the evolution of interregional and continental energy markets. This is the dynamic context in which we place rail electrification and why rail electrification is so important and so timely now.

Infrastructure electrification and modernization are expected to drive and sustain many social and economic developments across North America. Electrification trends on this continent will be even more consequential than elsewhere, in part because of their respective starting points. These two core industries are generally planned, operated, and regulated in separate silos in the U.S. are largely privately-owned, unlike those in the EU and the great Asian economies. Though regulated, recent history has been a struggle to rationalize public policy and how their property rights should be affected with the public interest in the new economy. If more strategically and effectively integrated in their respective operations and objectives, these industries could provide even greater efficiency and environmental benefits to freight shippers and consumers, to consumers of electricity, to the threatened climate, to investors focused on ESG and sustainability, and up and down North America's congested supply chains. This enquiry explores only how current railroad and power company operations can be sustained in the face of powerfully transformative and disruptive influences that stand to overwhelm the comforts of stable short-term returns on investment, historical operational norms, and existing regulatory compacts.

II. Background

The conversion of freight rail transportation from steam to electricity began in the United States at the turn of the 20th century. Electrification of major rail lines such as the Milwaukee Road was common up through World War II. Electric freight rail was comprised of many different grid delivery systems in different geographical areas, but the practicality of that concept was not in question. There were (5) drivers for rail electrification in North America in this initial era of steam powered engines

- Tunnels: Early railroad electrifications took place in long tunnels where congestion and pollution became more prevalent
- Mountains: Tunnel electrifications paved the way for larger projects and longer installations where electric power proved to be an advantage on steep inclines
- Passenger Terminals: Electric multi-unit passenger trains that could operate in both directions, eliminating the switching moves required by steam engines
- Short lines: Successful electrical installations on a number of short line railroads
- Smoke abatement: Policy decisions by local governments lead to electric installations

By the mid-20th century, steam engines had been replaced by more efficient electric locomotives and diesel-electric locomotives. U.S. railroad companies transitioned to diesel over electric locomotives because of diesel's lower up-front costs. Railroad operators in many other industrialized countries switched to electric locomotives partly because the railroads were owned by foreign governments that could afford the required investment in infrastructure. In the U.S., railroads have always been a regulated but privately-owned industry not unlike utilities. This and certain structural problems presented U.S. railroad companies with challenges when financing electrification upgrades. As a result, the U.S. today lags behind many other nations, such as the European Union and China, with respect to electrification of major railroad lines, despite its unparalleled ability to deliver heavy freight long distances. The story is one of unrealized potential. Despite significant land grants for the original development of railroads, including rail yards and appurtenant supporting facilities, the lease or allocation of those real estate resources to electric power or other energy resources have been done sparingly, ostensibly out of concern for safety and communications. The considerable revenue potential to railroads of such co-location arrangements remains unrealized. Similarly, experts agree that the potential benefit to proponents and customers of a more integrated electric grid of having a coherent and manageable regime for siting high-voltage long-line transmission, without employing eminent domain or interminable permitting processes, is still an unrealized objective. Proponents of the so-called "macrogrid" await such an opportunity.

III. Today's Challenges, Tomorrow's Benefits

The economic, health, and societal benefits of transportation electrification are potentially massive. As railroads adapt to this form of energy and also participate in integration of the grid, the benefits of these developments will become more evident. For now, they are contingent and diffuse. There are benefits (1) to society generally and individual communities from access to lower-cost renewable energy, reduced emissions, climate mitigation and progress toward "net-zero" objectives, more flexible and faster railroad services, and innovations like EV charging in rail yards; (2) to shippers and consumers of goods delivered by rail through more efficient supply

chains; (3) to railroads in the form of more agile operations and cost savings; (4) to investors in infrastructure improvements; and (5) to the competitiveness and productivity of the industry and the overall economy. Those benefits will increase exponentially if based on collaboration between these industries.

A. Overcoming Inertia.

Regulation of the power and rail industries was restructured in basic ways during the de-monopolization era of the Carter Administration. As happened in a range of industries, the "deregulation" of electric power in 1977-78 and railroads in 1980 set off an explosion of competition, a flood of market entrants and new services, and initially a decline in market concentration. The new environment afforded railroads greater flexibility and stability. But, as the Chairman of the Surface Transportation Board has observed, railroads are still regulated in the public interest and the rate and productivity benefits unleashed by the Staggers Act have diminished over time. For the utility business, new competition resulted in successive waves of reform at the federal level which infused competition into the business and began development on larger power markets and integration of what had been a patchwork of state utility service territories into regionally managed grids. That painfully incremental restructuring continues 40-plus years after the National Energy Act legislation but in full anticipation that the industry has room to deliver significant additional economic and environmental benefits.

At the current inflection point in railroad and utility development, it is fair to enquire what additional public benefits can be wrung from these infrastructure networks in response to opportunities and challenges that did not exist in the 1970s. The transportation sector represents the single largest user of non-electrical energy; accounting for 25% of total U.S. energy use. Economists and analysts are coming to recognize that the transportation sector (principally EVs and trucks) will become increasingly electrified in the next quarter century. This means 70 GW of new electricity demand by 2030 and up to 130 GW more by 2050. Under current market and public policy trends, this electrification will entail greater production of renewable energy and a marked decline in the use of fossil fuels. Renewable energy resources like wind are location-constrained — the best resources are in the Great Plains states where there are fewer customers. The switch to renewables therefore translates to concomitant demand for expansion and upgrade of the transmission grid. Even there, railroads have a competitive challenge because electrification of highway transportation will also increase substantially.

B. Railroads' New Realities

The network of Class I (long line freight) railroads and Class II and III (regional and short line) railroads, and their associated facilities has been a critical backbone of interstate commerce in the U.S. for more than 150 years. Railroad companies often own substantial established rights of way. Today, freight rail transportation has natural advantages for transporting bulky products over great distances. Compared principally to highway transportation, rail moves 41 percent of all ton-miles of freight and 16 percent of freight measured by the value of transported commodities. Its market share has nevertheless declined in the first two decades of the Twenty-first Century and its rolling stock is aging. The transport of coal by rail, destined primarily for electric generation plants, has been among the principal sources of revenue for railroads for decades but it too has declined as utilities rely more heavily on natural gas and non-fossil resources to generate power. Locomotives nevertheless remain predominantly powered by fossil fuels. Typically, diesel-powered electric generation (and regenerative braking as a train slows) drives a locomotive's

electric traction motors. Although (and maybe because) continental transportation of freight by rail can lay claim to significant efficiencies due in part to intermodal arrangements and only modest impacts on land use, railroad companies have seldom been identified with companies for which climate change mitigation or development of clean energy resources are a priority. Electricity is already the strength of most commuter rail. No other mode of transportation whisks people in and out of commercial centers more efficiently and cleanly than electric rail. However, ESG reporting, including of EPA's Scope 3 emissions, and emerging energy and climate policies is likely to impact all rail company strategic plans, making electrification more central to the sector's goals over time.

Like electric utilities, freight railroads are therefore today facing some new realities which must be addressed. Likewise, there are new opportunities that await a possible strategic reassessment. Declining coal shipments, fossil fuel emissions and climate change concerns, rising demand for renewable energy resources often located along rail systems, and competitive pressures from other forms of transportation (which are electrifying at a remarkable rate, often with government funding support) are among the challenges and opportunities that rail executives face.

When Congress reinvigorated the railroad industry in 1980 by reducing federal regulation, it made rail transport more flexible and competitive relative to the new interstate highway system. The industry recouped its strength in subsequent decades. Its financial strength is reflected in part by continued consolidation and stock buybacks. The emissions profile of rail transportation also gave it a head start. Today's railroads contribute far less greenhouse gas and other pollutants than competitive modes of freight transportation, namely trucking. The current fuel efficiency of trains (relative to the size of loads) is undeniable. The ratio of rail fuel efficiency to the fuel use of trucks moving the same freight, typically measured in tons of freight moved a distance (ton-miles) per gallon of fuel, is between 3:1 and 4:1. This advantage belies the fact that freight transport by rail often depends on trucking at either end of the "haul."

Although the strength of diesel-electric locomotives is acknowledged, the system lacks the flexibility and capacity that can adapt to new demands, including the cost of replacing or rebuilding the current operational stock of locomotives (25,000 units) to operate electrically could be in the hundreds of billions, at a price of $2-3 million per locomotive (depending on the installed mode of electrification). That does not include the investment in facilities required to deliver grid power (catenary), which would entail $2 million per mile, for 137,000 miles of track (not including sidings and double tracking), or battery and regenerative power. A ballpark total for complete electrification of $150 billion suggests that full electrification of Class I freight lines may be years away. Clearly, passenger rail will move more quickly and new funding for Amtrak will accelerate that development in some regions. As most railroads move toward electrification (as the Council believes they should), they will need to ensure safe operations, revenue-neutrality over the long haul, and benefits for both the companies, consumers, and public policy.

C. Electrification Benefits to Railroads

1. The Rail/Green Energy/Grid Symbiosis

As other major sectors of the economy become electrified, the advantages of rail electrification may become even more evident. This is also a transformative time for the electricity industry and the bulk power grid upon which it depends. The expansion of electric transmission facilities that move large amounts of power dates from the turn of the 20th century, but truly integrated regional

grids have developed in only the past 50 years or so. Much of today's electric transmission system remains a patchwork within states or service territories. Moreover, many transmission facilities have far exceeded their useful lives. Electro-mechanical controls are not unusual. That is now changing in profound ways. Emerging regional and national power markets and the push by states and consumers to access remotely located renewable resources have increased pressure to build more transmission, including major HVDC facilities. However, the electric system is regulated largely by the several states with respect to siting and permitting transmission facilities, in addition to federal rate and environmental regulation.

These layers of regulation make planning and development of the kind of cross-border or interregional transmission that is required for a vibrant energy market a difficult, expensive, and frequently unsuccessful process. The timeline of typical transmission line development (planning, permitting, siting, and construction) is completely out of sync with the expectation that the grid will deliver such great quantities of non-fossil energy by 2035 or 2050 as to virtually decarbonize the grid and curb climate deterioration. While these two infrastructure networks railroads and electricity transmission carry critical goods and services across multiple states and into adjacent foreign countries, they are planned and operated differently. Their owners and operators seldom communicate or collaborate in pursuit of economic efficiency or environmental benefits. Nevertheless, the changing dynamics of the energy landscape create opportunities and pose challenges to both industries.

Now is a propitious time to consider how rail electrification opportunities and more coordinated planning and operation of both sectors can yield additional benefits to both industries. For example, the electric transmission industry has a known interest in utilizing rights of way to route its high-voltage lines, although rail safety and other concerns have deterred or deferred efforts to tackle the complexities of such arrangements. Existing railroads are uniquely positioned to provide strategic access to new clean energy resources rail rights if railroad rights-of-way (ROW) care sufficient in size and location to be employed in siting transmission. Moreover, new ROW revenues could help railroads finance rail electrification. It must be acknowledged that electrifying Class I (and to some extent Class II) freight railroads is an expensive proposition, whether done with catenary systems or third rail technology up to $2 million per double track mile. Electrifying rail parks offers more favorable cost-benefit ratios. However, the magnitude of the long-term benefits to regional and national economies makes this an objective that should be explored and soon.

2. Operational Benefits of Electrification

The case for electrification is based in part on the potential economic efficiency of electric drives as the motive force of freight rail, as well as on powerful environmental and public policy considerations. The delivered cost of electricity from the grid (assuming the massive investment in new delivery infrastructure) would be significantly lower than electricity from a diesel engine (which drives the traction motors), especially if low-cost renewable resources are integrated more heavily into the grid. Electric engines, perhaps augmented by battery storage or hydrogen-based power, can reduce fuel costs overall, even when accounting for the generation of that power at a plant some distance away. The advantages of electric drives also relate to lower maintenance and operation costs, reductions in fueling time, increased acceleration to allow more trains ("sprinter" service) on same tracks, and having railroads serve as the foundational customers of remote renewable power sources and rural communities. Finally, the importance of the rail network to national security has been recognized by the military's designation of 36,000 miles of

rail as the Strategic Rail Corridor Network ("STRACNET") for movement of military equipment among 170 military installations.

3. Leveraging Railroad Real Estate for Revenues.

The historical rail system is an ideal connector between location-constrained renewable resources that are increasingly in demand and major power markets. Railroad rights-of-way could be employed to site linear electric transmission infrastructure, providing a source for fresh revenue. These revenues could be used to spur railway electrification. Battery powered trains also have the capability to sell excess energy, including regenerative power, back into the grid, as noted above.

In order to meet the demand for new jobs, the public sector, industry, and educational institutions will have to devote necessary resources to worker education and training. Major questions persist about the returns that rail companies can expect from the changes that are suggested in this paper. The federal government's unprecedented infusion of capital into the rail industry (Infrastructure Investment and Jobs Act of 2021) affords the rail industry a major opportunity to upgrade and modernize. On the transmission side, developers and utilities are expected to continue to spend $20-40 billion annually for the foreseeable future to modernize and integrate the grid. Beyond that, the IIJA likewise directs the electric industry and the Department of Energy to "build a better grid" as quickly as possible. These measures should arguably diminish, if not eliminate, any hesitancy by the industry to move forward with innovative strategies and new investment. So-called "macrogrid" – a national-in-scope HVDC transmission overlay that would tie all regional power markets together and enable the transfer of gigawatts of power anywhere – is emblematic of the kind of thinking emerging in the staid utility business and the critical future need to site grid facilities across the "greenfield" real estate like railroads and highways where permitting promises to be less onerous.

4. Competition Benefits

Analysts also agree that long haul transportation can be more efficient and less expensive by train than by truck. The physics of steel rolling on steel is much more efficient from an energy transfer perspective than that of rubber on concrete. Trains are more efficient aerodynamically than trucks and a cleaner more robust electrified railroad system could replace substantial amounts of truck traffic, easing highway congestion and pollution in urban areas. Commuter rail is able to move more people into and out of commercial centers than any other mode of transportation. Electrification of passenger rail enhances the benefits to consumers and those living near the system in terms of emissions, land use, and efficient commercial activity. Intermodal arrangements have also helped utilize both freight rail and trucking capacity more efficiently. However, railroads remain a vastly underutilized asset.

Compared to diesel locomotion, electric railways offer operational advantages substantially better energy efficiency, lower emissions, and lower operating costs. Electric locomotives have quicker acceleration, lower fuel cost, and fewer CO2 emissions; they can be lighter and therefore create less wear on rail beds; they are more powerful, more responsive, and

just as reliable compared to diesels. Looking ahead in a few years, they may offer energy storage and flexible electricity dispatch potential for the electric grid.

5. Lower Total Cost of Ownership.

Diesel prices are at historically high levels, and reliance on fossil energy entails long-term risks like price volatility. Oil prices are set by global markets and can be very volatile. The diesel supply chain can become entangled in issues of foreign policy and energy independence. Conversely, electricity prices are falling especially with the increasing use of renewable energy sources such as solar. Electric-powered trains are also more efficient than those powered by diesel. As an example, diesel-powered trains transfer about 30-35% of the energy generated by combustion to its wheels, whereas supplying electricity directly from an overhead line transfers about 95%. Moreover, there exists the potential for locomotives to sell excess power back to the grid. Finally, electric trains can accelerate faster and stay at top speeds longer.

D. Societal Benefits of Electrification

Job Creation: The transition to electrified transportation will lead to new industries and job opportunities. Specifically, it could spur new jobs in charging infrastructure engineering, battery manufacturing, software development, and machine learning appealing to labor unions. Part of the rail industry's current financial advantage is a huge employee to ton-mile ratio.

Environmental benefits: Reducing or eliminating diesel-powered locomotives can reduce air pollution including soot, volatile organic compounds, nitrogen oxides, and sulfur oxides, all of which affect public health as well as the environment. This is especially important as many railroads pass through congested urban areas. It would also reduce noise levels in cities. Switching from diesel to electricity would also address the challenge of replacing petroleum-based liquid transportation fuels with cleaner alternatives as we look to lower total greenhouse gas emissions and to open another front against climate change.

Policy innovation: Railroad electrification will be a long-term project and a major investment nationally. Currently, neither railroads nor their regulators have a strategy for electrification except for commuter lines or speculative high-speed rail lines. Despite their importance to the economy, major rail companies are not active in climate change, smart grid, or national energy policy conversations. Investors are watching their ESG reporting with increasing interest. Within the U.S., most railroads and electric utility infrastructure are privately owned and operated. While this can make it challenging to secure financing for major infrastructure investments, the lack of coherent national policy on electrification may be a more important impediment. For both rail and transmission infrastructure, innovative policies are needed to spur this discussion.

Technology innovation: The electric grid can be tapped for wayside and crossing signals, switch heaters, trackside cameras, transponders for freight tracking, and climate control for refrigerated containers and boxcars. Locomotives and freight railcars can become power generators through regenerative braking and even PV rooftop panels. A more flexible, innovative, digitalized railroad network holds enormous market potential for electric power, technological inventions like 5G, major battery installation, control and monitoring systems, environmental and safety standards, cables, converters and new conductors, trackside equipment, catenary

systems, and methods of hydrogen propulsion. In sum, the two industries described above are ripe for collaboration and innovation.

Public-Private Partnerships: New collaborative efforts could become viable solutions for funding an electrified rail network by using a combination of federal, state, private sector, and possibly regional resources. The PPP model has had some success for Class II and regional railways across the country. Freight railway electrification will positively benefit a variety of other industries. For the agriculture sector, rail electrification could represent cost savings and efficiency in transporting food to market. Agriculture goods usually represent a much smaller portion of freight rail and, with the increased capacity that electrified railways could provide, rail shipments could become much timelier and more frequent than they are today. A more agile electrified rail network will benefit rural communities and both shippers and travelers.

For electric manufacturing and technology firms, more extensive electrical applications would mean a significant new market and new products. For electricity producers (conventional or renewable), rail electrification would mean new load and support for generation plant development. For railroads themselves, electrification could reduce congestion, create new jobs, and make operations more competitive with highway freight transport. For public policy makers, it would translate into cleaner energy (and fulfillment of state renewable energy requirements), lower emissions, and constructive contribution to climate mitigation.

Electric generators and transmission providers should also play a role in supporting the electrification of railways. Utilities have been among freight rail's largest customers, primarily for the delivery of coal to power plants and hauling away coal ash. They are now becoming major developers of renewable energy projects and purchasers of wind and solar power, even when those resources are distant. As utilities become less dependent on coal, the revenues of freight rail will come under pressure. It remains to be seen whether greater reliance on new resources like wind and solar, as well as batteries and other distributed resources, will compensate the power industry monetarily for the loss of base load coal plants and the reliability insurance they historically provided. Likewise, unless the railroads take the new challenges and opportunities into account and critically reassess the viability of their current operations, they will find the energy and public policy environments increasingly challenging in the years to come.

IV. Conclusion

America is transitioning to a transportation future that is increasingly electrified. While highway vehicle electrification is at the forefront of this trend, an electrified rail infrastructure also has the potential to transport freight efficiently and reliably and/or passengers while also benefitting the overall environment. Equally noteworthy and critical to the Council's mission is the need to explore utilization of railroad rights-of-way to co-locate electric transmission and electric generation facilities. Disruptive changes in U.S. electricity generation and transmission, principally in the switch from coal-powered generation to natural gas and remotely located renewable generation resources and increasing climate change concerns, are elevating the importance of overcoming barriers to infrastructure expansion. This second aspect of rail electrification potentially will increase the value of longitudinal rail real estate and stimulate a re-examination of the value and availability of these legacy assets.

The Rail Electrification Council, an affiliate of the National Electrical Manufacturers Association, is

exploring opportunities and challenges inherent in electrification and emerging energy and transportation policies and practices. The Council will promote the adoption of electricity as the principal motive power of domestic railroad (freight and/or passengers) transportation and the use of rail rights-of-way as an enabler of electric grid integration and innovation through transmission co-location. Membership in the Council is open to both NEMA Members and non-Members such as railroad companies, utilities, renewable energy developers, service and technology companies and state and federal agencies. To join, contact Steve.Griffith@nema.org.

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