**A Vision for Decarbonizing the Nation's Freight Railroads—
Without Breaking the Bank**

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Freight trains are heavy and consume a lot of power, making carbon-neutral railfreight solutions out of reach, according to conventional wisdom. The best compromise would be some type of hybrid powertrain where braking energy is recaptured, but new energy comes from green hydrogen or renewable diesel made from modern biomass.

Until now.

The reason previous efforts to electrify strategic freight rail corridors in the U.S. has been met with stiff opposition is due to two basic impediments: economic and technical. Infrastructure costs are very high, on the order of $10 million per mile or more, and fuel savings—even at elevated diesel prices—do not generate a positive return on investment. Plus there are all the usual practical concerns about how to fit double-stack containers or wide loads underneath the high voltage overhead catenary.

Two vendors' recent announcements of 7.2 megawatt-hours (MWh) capacity battery electric locomotives (BELs) is an enabling technology. The train performance calculations published in our paper in *Engineering Archive* show that—in place of two 4,400 hp diesel locomotives—four battery locomotives can haul an 8,000-ton freight train for more than 200 miles without recharging.

They can be fully charged in four hours under high-voltage electric wires, which also works out to be about 200 miles of travel at normal freight train speeds. This means we only need to build half as much wire as before; the train would operate under the wires (and charge up while in motion) from say, Omaha to Iowa City, and then would be able to run to Chicago without having to recharge.

This concept is called "intermittent electrification." In essence, where there's wire, we use one watt for propulsion now, then take another watt to go for the road.

Applying battery-electric locomotives to freight haulage is not a new concept, and issues requiring technical and economic solutions have been laid out by retired Class I railroad professionals. We used broadly similar assumptions to advance further towards a solution by combining intermittent electrification with high-capacity BELs.

How does the business case stack up? A lot of this would depend on the relative energy prices of electricity versus diesel and the specifics of the terrain that the train encounters. We ran the numbers for a small hypothetical Class I railroad that connected major Midwestern cities with the Mid-Atlantic Region, crossing the Appalachians at an elevation of 2,258 ft on the route of the Amtrak Capitol Limited.

At $6 per gallon, we found that diesel is still the cheapest option, but intermittent electrification could convert 76% of train-miles on this railroad to carbon-neutral electric haulage for a modest 7.3% increase in overall costs. Compared to the conventional method of electrifying only the busiest rail segments (which delivers only 61% of electric train-miles for a cost increase of 26.6%), it is a much more competitive option.

Looking at it from an infrastructure utilization point of view, we could achieve 71% electrified train-miles by wiring up just 38% of route-miles. This could put us at the forefront of battery-electric technology and leapfrog Europe and Asia, which have a huge installed base of costly, legacy electrification systems.

So what needs to be done? Some engineering problems remain to be solved, such as making overhead electric wires compatible with double-stack intermodal container trains that are an increasing share of the rail industry's market. Recently, designs were announced that allowed precisely this; double-stack trains (with distributed power mid-train pusher locomotives) are running under electric wires on the Western Railway of India today. We'll need a pilot program to demonstrate that this technology works in North America and provide an opportunity to work out the bugs.

There are some other environmental issues to be considered. The U.S. currently generates 61% of its electricity from fossil fuels. The costs and environmental effects of battery fabrication and disposal—and the consequences of mining the necessary semi-precious metals—are major unknowns. Wholesale transition of the electric grid to carbon-neutral power generation and further improvement in battery chemistry would be necessary to ensure that electrification is as environmentally friendly as possible.

However, the biggest challenge may be the risk of technology change. The U.S. rail industry is highly optimized around diesel-electric traction. There is little incentive for a mature industry to invest in a sea-change that will not necessarily deliver a positive return on investment from the shareholder's perspective.

However, even a transition of 50% of America's total freight train-miles from diesel to electric could save 1.7 billion gallons of diesel fuel annually and remove 38 billion pounds of carbon dioxide from the atmosphere.

Appropriate incentives and planning leadership from the Federal government could be all that are needed to kickstart this green railroad revolution. We outline the next steps here.

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