Chapter 13
Can Freight Trains Be Electrified?

High-speed passenger rail is all the rage, but when it comes to electrification of America's freight trains there's no buzz, almost total silence. Europe and Russia have electrified freight trains, so why doesn't the U.S.?

European and Russian governments paid for electric passenger rail, and electric freight trains joined the party. Europe's electric rail is 80 % passenger trains, which have priority over freight, making cargo delivery less reliable. That's one of many reasons why Europe's freight trains hauled 60 % of all cargo in 1950 but only 8 % now (Vassallo 2005).

In America, freight railroads are built and maintained by private industry. Absent public tax dollars, U.S. freight railroads can't afford the tens of trillions of dollars electrification would cost. Even so, American rail kicks European and Russian freight train's butt, hauling 45 % of freight in the U.S. (by ton-miles) at less cost, much faster, and more energy efficiently (Economist 2010; Eurostat 2015).

U.S. rails can't be beaten. Trains can go across the North American continent from Mexico to Canada, unlike Europe, where different rail widths (gauge) and different electric catenary systems stop trains at borders. Besides, American trains are *already* electric. Diesel-electric locomotives use their diesel engines to power electric motors instead of using electricity generated by nonrenewable coal, natural gas, and nuclear power.

Electric rail makes more sense for passenger trains, which stop, start, accelerate quickly, and travel at high speeds. An energy efficient freight train is the exact opposite: accelerate slowly, stop or start as little as possible, and travel at slow speeds to reduce aerodynamic drag.

U.S. railroads are as likely to electrify as elephants are to buy hang gliders and jump off of cliffs. It would be economic suicide since they can barely afford to run, maintain, and grow what they have. Besides, they're only using 2 % of all U.S. transportation fuel, which is 18 % of their overall $64.1 billion annual budget. Even when oil prices skyrocketed in 2008, there was no move to electrify (AAR 2012; Iden 2009; NPC 2012).

Rail is highly invested in diesel-electric locomotives that cost $2 million each and are expected to last for 30 years. All-electric locomotives cost about $5–$10 million each (SCAG 2012; Pernicka 2010) and may not be powerful enough to

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haul America's freight trains, which are much heavier and longer than in other nations.

Even the cost of a fleet of electric locomotives pales in comparison to the cost to install a power distribution system to electrify the rails. More power generation, new transmission lines, substations, and overhead wiring above the tracks would be required. America has 200,000 miles of freight rail. Even if only the most traveled tracks carrying 21 million tons per year were electrified, distribution would need to stretch for 50,000 route miles plus cover nearby sidings, parallel, and terminal tracks (NPC 2012).

Exactly how much it would cost to electrify America's freight trains is hard to know, because most estimates for electrification are for passenger rail. The only freight electrification project being considered in the United States is a $28 billion dollar project in the Los Angeles area combining electrified passenger trains with trains that carry containers from ports to inland distribution centers about 30 miles away (SCAG 2008, 2012).

California's 520 miles of planned high-speed passenger rail is estimated to cost $68 billion (Nagourney 2014), or $130.7 million per mile which means $26.7 trillion for 200,000 miles of freight rail. Since freight trains need a great deal more power than passenger trains, the cost would be *much* higher (Table 13.1).

Overhead wires are mandatory, because a third rail for freight trains is too dangerous, unable to deliver the high power needed, and easily clogged with leaves and ice. That's a shame, because overhead wires are expensive, and raising them much higher than any other nation to accommodate stack trains (two containers high) is likely to add to the cost (plus raising bridges and tunnels). Just the overhead wires for 200,000 miles of railroad tracks would cost $800 billion [$3.98 million/mile = the average of $3.96 million (SCRRA 1992), $4.55 million (Caltrain 2008), $3.42 million (Metrolinx 2010)].

An electric locomotive is an awesome beast. Just one 4400 horsepower locomotive is the electrical equivalent of 2200+ plug-in hybrid vehicles being recharged. So the current U.S. fleet of 25,000 locomotives would use as much electricity as 55 million electric cars, and it's not clear where all this electricity would come from. Passenger trains need only 25 kV lines, but freight needs at least 50 kV to minimize the number of substations (Iden 2009).

Table 13.1 Train power demand

Rail operation	Power demand per train in Megawatts (MW)	Equivalent horse power
Light rail	1	<1400
Heavy commuter	3–4	4000–5400
High-speed intercity	4–6	5400–8000
High-speed trains (TGV)	8–10	10,700–13,400
European freight	6–10	8000–13,400
U.S. freight trains	6–24	8000–32,000

Source Iden (2009)

To electrify the 2000 miles of rail from Chicago to Los Angles, at least 1500 MW would be required. This is equal to three large conventional power plants (FRA 2009), so to electrify our major routes with 160,000 miles of tracks, you'd need the equivalent of 240 power plants (some of which already exist). Additional power infrastructure also would be needed since railway electrification load is one of the most difficult for an electric utility to cope with, and parts of the power grid have little spare capacity (Boyd 2009b). Would trains need to stop at peak demand times so that people could turn on their lights and do so without blowing up the grid?

D'oh! Why Electrify? Diesel-Electric Locomotives Already *Are* Electric and *More Efficient Than All-Electric Locomotives!*

U.S. trains are powered by diesel-electric locomotives. Diesel-electric is the way to ride. Instead of sucking electricity via hundreds of miles of overhead wires from a distant power station, diesel-electric locomotives have their own power generation plant on board—a 40 % efficient diesel engine (Hoffrichter, USDOE). The electricity generated onboard drives traction motors to move the wheels, with no mechanical connection between the engine and wheels, which is far easier, cheaper, and more efficient than pure electric locomotives (James 2011; Smil 2013).

Electric locomotives get their electricity from inefficient power plants with a 32.8 % average efficiency, plus another 6 % loss over transmission and distribution lines. By the time the energy gets to the train wheels, you've lost 75 % of the energy, giving electric locomotives an overall efficiency of 22.9 %, which is 7.1 % less than diesel-electric locomotives (see detailed calculations).

These electric locomotive calculations do *not* include the energy to construct new power plants and thousands of miles of overhead wires, substations, electric loading and unloading of train car and other infrastructure to deliver electricity to all-electric locomotives or replace diesel-electric locomotives.

Detailed Calculations. Every Step Reduces Efficiency

30 % Efficient Diesel-electric Locomotives: 40 % diesel engines × 92 % generator × 98 % rectifier × 92 % electric motor × 95 % transmission × 95 % traction auxiliaries (Hoffrichter 2012)

22.9 % Efficient Electric Locomotives: 100 % electricity at locomotive × 95 % feed cable × 95 % Transformer × 97.5 % Control system/power electronics × 95 % electric motors × 95 % transmission × 95 % traction auxiliaries (Hoffrichter 2012) × 32.8 % overall average energy efficiency of electric power generation plants × 92.4 % transmission and distribution losses (NRC 2015)

Electrify with Batteries? Been There, Done That. It Didn't Work Out

Railroads have been experimenting with electric locomotives since 1838. In America, 126 battery-operated locomotives have been built, 14 of them battery only, whereas the others had gas or diesel engines as well. Not a single one was a long-haul locomotive. They all were local, yard switcher locomotives that assembled and disassembled trains where they could easily be recharged or fixed when batteries failed entirely.

What have we learned? What all of these experiments revealed is that batteries weigh a lot, break easily, are difficult to maintain, have little usable power, and often have to be replaced, going beyond expected costs. When pushed beyond their safe depth of discharge, or damaged after a jarring, hard coupling, the train might stop running, not such a great thing in a switching yard, and definitely not cool if an all-battery long-haul locomotive broke down in the middle of nowhere, blocking the trains behind it (Iden 2014).

Energy storage devices are too expensive and incapable of moving a train a reasonable distance (Vitins 2011). Just one railcar can weigh 286,000 pounds, so a 100 railcar train could weigh 28.6 million pounds, the weight of over 190,000 150-pound people. Batteries don't have enough oomph—enough power and energy—to move that much load.

Batteries for regenerative braking? Locomotives have very little room to accommodate regenerative braking batteries. Instead, a battery tender car coupled-and-connected to the real locomotive, or a separate locomotive devoted only to energy storage would need to be built (Iden 2014).

It is hard to capture regenerative braking energy, because much of the time the train isn't using the brakes because the ground is flat or slightly undulating. Centuries of railroad engineers have sought out and purchased the flattest routes, and invested a lot in building them. Only a small minority of tracks known as "hogbacks" can capture regenerative braking, which are steeper uphill and downhill grades about the length of the train. And a mile-long train can be going downhill, uphill, and level at the same time, requiring train engineer to play the two types of braking system used on trains like a concert pianist.

The 80 trains going down California's steep 25-mile Cajon pass grade every day, one of the few grades this steep in America, could generate as much as 1200 kWh per train with regenerative braking. The downside is that this would require 525 tons of lead–acid batteries. That's a lot of deadweight to haul when the train returns uphill to the Cajon pass, and is not economically viable because it would only save 70 gallons of fuel (Painter 2006). If you tried to haul fewer batteries to save on weight and cost, complex systems to monitor the batteries to prevent them from overcharging would be required.

Other Issues with Electrification

Single point of failure. Many events can stop the flow of electricity, causing severe and expensive congestion on the most trafficked routes. What could stop an electrified rail line? Landslides, earthquakes, high winds, hurricanes, washouts, heat waves, lightning (Smith 2008), locomotive mechanical or electric failure, wires getting struck by vehicles at road crossings, lack of power due to not enough substations, sabotage, and terrorist attacks (NRC 2012). In those circumstances, electric-only locomotives will be stuck dead on the tracks, and need to be rescued by diesel-fueled locomotives (SCAG 2012) creating costly and severe congestion on many heavily traveled routes.

Even if the electric grid were beefed up, occasions would occur when it might not be powerful enough to meet the high energy demands of freight trains. For example, when there are several trains near each other, peak demand, or the locomotives need a lot of power to go uphill, with perhaps 22 MW or more needed.

Political and institutional hurdles. The SCAG rail electrification project in Los Angeles will be difficult to implement since it encompasses six counties and 197 cities that will want to have a say in the project. Now multiply the complexity and number of affected local, state, and government agencies by tens of thousands when considering a national-scale project to electrify rail. The Los Angeles project is child's play.

Diesel-electric locomotives can't be beat. Mechanically, diesel-electric engines keep getting better, last a long time, are rugged enough to handle rough patches of rail, and can be rebuilt. Many locomotive engines achieve the equivalent of one million miles before overhaul, equal to 36,000 MWh (USDOE 2002).

Electrification makes more sense for passenger trains servicing highly populated areas since electricity is useful for rapid acceleration (not at all necessary for freight trains), high speeds, and frequent stops. Freight trains are the opposite—they travel outside of densely populated urban areas, are slow, rarely stop, and need power, not acceleration. Speeding up non-aerodynamic freight trains wastes energy. Since most of what's being hauled doesn't spoil, freight doesn't need to get anywhere soon. There are about five derailments a day in North America. Imagine the damage a 25 million pound electric train derailing at 100 mph would cause, plus the added costs of the overhead wires being pulled down. High speeds would also wear out tracks out faster, requiring expensive maintenance.

Nations that electrify their freight rail lines often do so because they don't produce petroleum, and, in some cases, oil-producing countries that want to export oil will electrify (NPC 2012).

Europe’s Freight Trains Are Inferior. Why Copy Them?

In much of Europe, borders are open and the Euro is a common currency. Ironically, trains can’t travel between countries because in Europe there are three types of rail gauges, four different voltages, eleven different ways of hooking to the overhead wires, and half their rail lines aren’t electric.

U.S. freight trains haul about seven times more freight by weight than in Europe due to continent-wide interoperability with the same rail gauges across America, Canada, and Mexico, and railroads share their tracks and other infrastructure with one another. This is why American rail freight is the cheapest in the world, half as much as in Europe and Japan (Iden 2009).

Electrify Just the Busiest Corridors

Let’s say the oil available to power diesel locomotives becomes scarce or expensive. Would it then make sense to electrify just the busiest American corridors?

Here’s what would happen: Interoperability would be reduced if electric and diesel locomotives had to be swapped at every electric and non-electric border, with double the staff to maintain both electric and diesel infrastructure. This would delay trains long enough to shift some freight to trucks, because swapping locomotives, pressurizing brake systems, and safety inspections would take 3–6 h (SCAG 2012).

That’s why the railroads have insisted that the only acceptable solution is dual locomotives that are both electric and diesel. One small problem: There is no freight dual-locomotive yet (Boyd 2009a, b). To convert an existing diesel-electric locomotive, you’d need to add a 50 kV step-down transformer to the engine (or auxiliary car) weighing 20,000 pounds that takes up 480 cubic feet of space, plus supporting equipment in a locomotive that’s already at the maximum height, width, length and weight limit. Even now, there is little space left in a locomotive due to equipment added to comply with EPA tier 4 emission standards. Oh, and you want regenerative braking? That’ll take even more space (Iden 2009).

Conclusion

Why electrify U.S. freight rail? It already is electric. Instead of electrifying rail, which uses only 2 % of all U.S. transportation fuel, we should discourage light-duty cars and light trucks, which guzzle 63 % of all transportation fuel and give the fuel saved to diesel-electric locomotives.

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