INTERMITTENT ELECTRIFICATION WITH BATTERY LOCOMOTIVES AND THE POST-DIESEL FUTURE OF NORTH AMERICAN FREIGHT RAILROADS

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Engineering Archive

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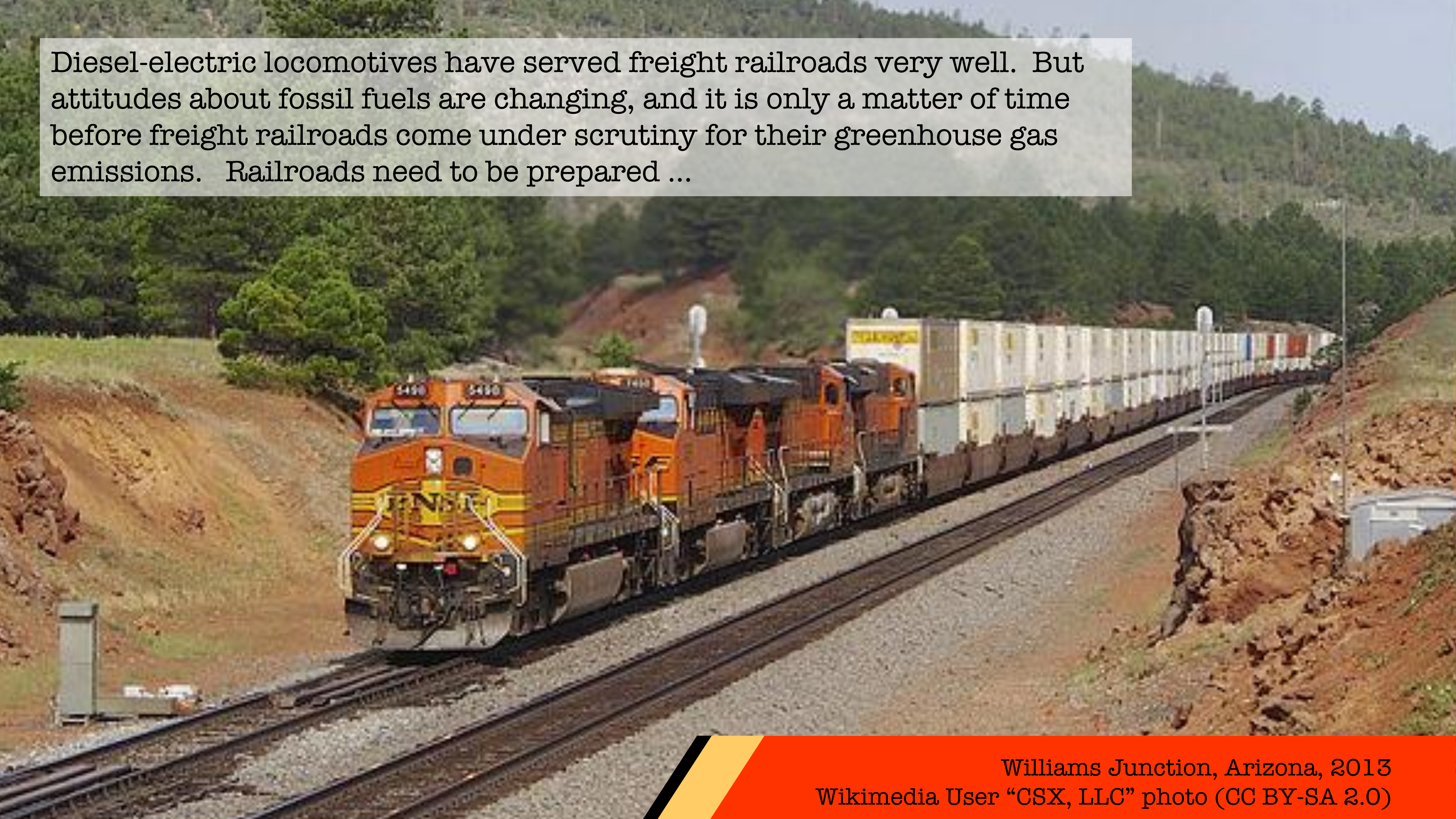
Diesel-electric locomotives have served freight railroads very well. But attitudes about fossil fuels are changing, and it is only a matter of time before freight railroads come under scrutiny for their greenhouse gas emissions. Railroads need to be prepared …

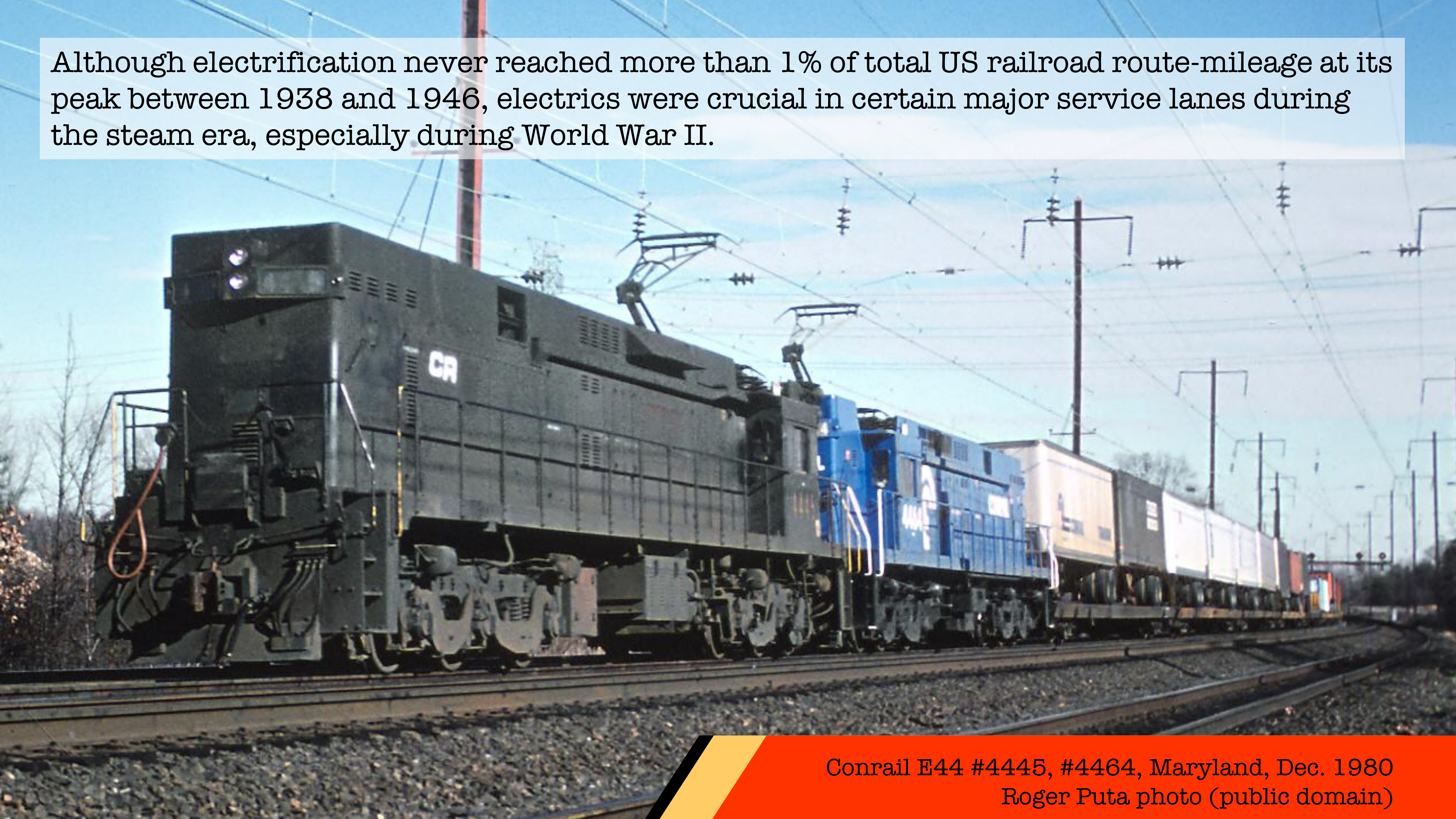


Williams Junction, Arizona, 2013
Wikimedia User "CSX, LLC" photo (CC BY-SA 2.0)

... for the twilight of the diesel era. But what are railroads to do? There are unresolved questions about the range and recharging needs of battery power, hydrogen's energy storage leaves much to be desired, and the high capital cost of electrification scares the industry away.

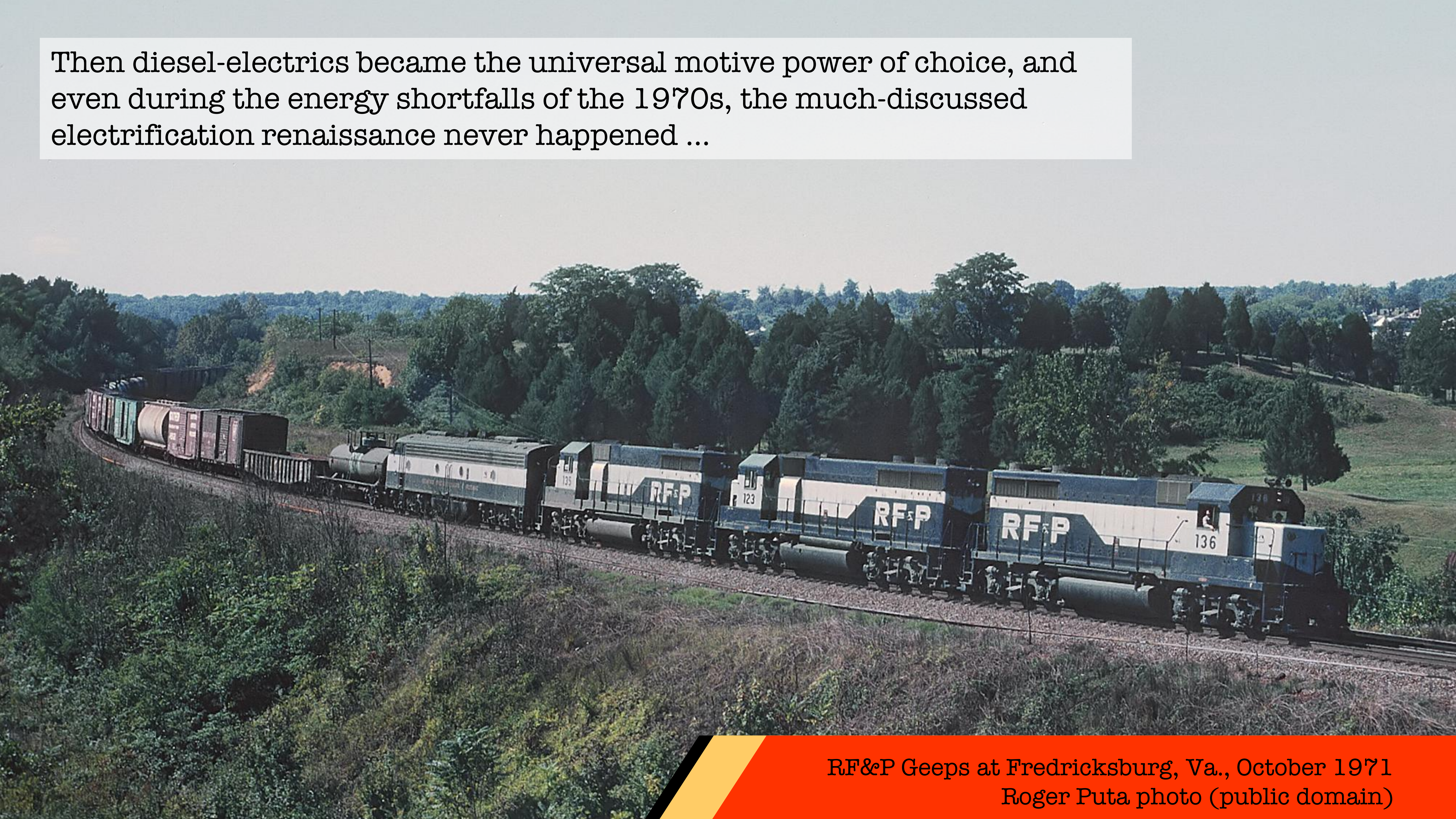
Berryville, Virginia , 2010
Wikimedia User Jpmueller99 photo (CC BY 2.0)

Although electrification never reached more than 1% of total US railroad route-mileage at its peak between 1938 and 1946, electrics were crucial in certain major service lanes during the steam era, especially during World War II.

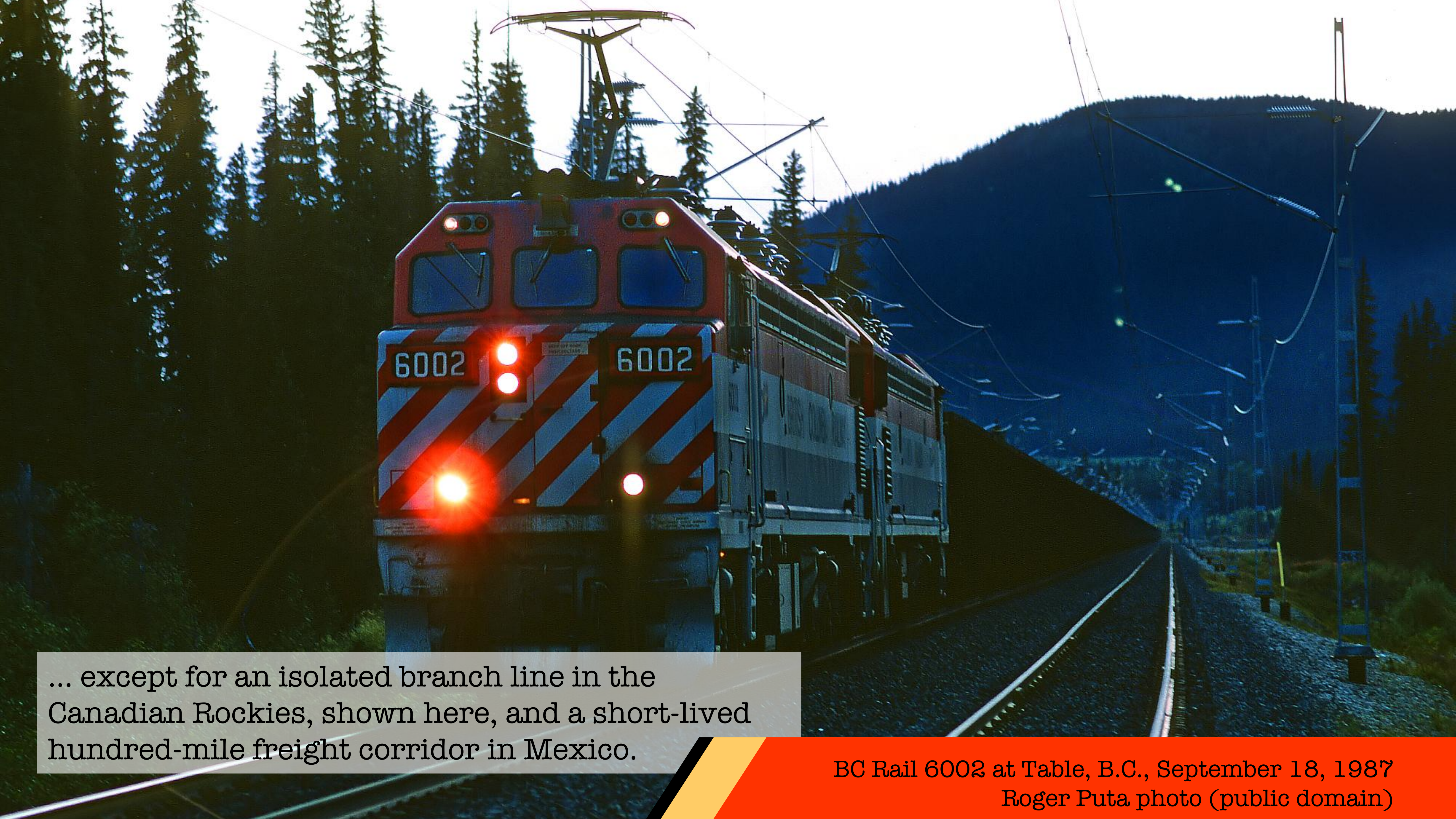


Conrail E44 #4445, #4464, Maryland, Dec. 1980
Roger Puta photo (public domain)

Then diesel-electrics became the universal motive power of choice, and even during the energy shortfalls of the 1970s, the much-discussed electrification renaissance never happened …



RF&P Geeps at Fredricksburg, Va., October 1971
Roger Puta photo (public domain)



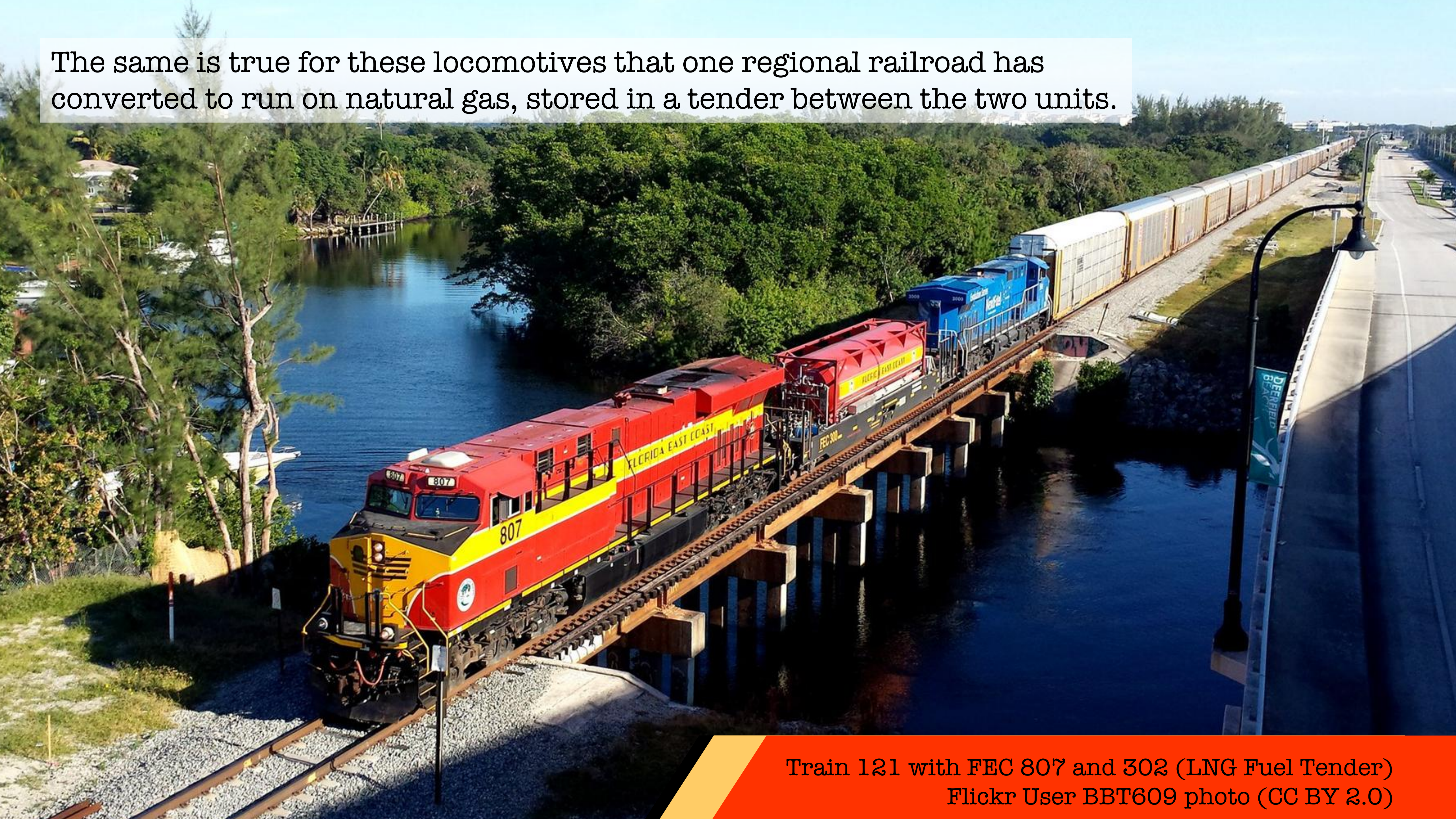
… except for an isolated branch line in the Canadian Rockies, shown here, and a short-lived hundred-mile freight corridor in Mexico.

BC Rail 6002 at Table, B.C., September 18, 1987
Roger Puta photo (public domain)

Meanwhile, there have been some experiments with alternative fuels and technologies, but no breakthroughs. Of course, ultra-low emission units reduce, but do not eliminate emissions.

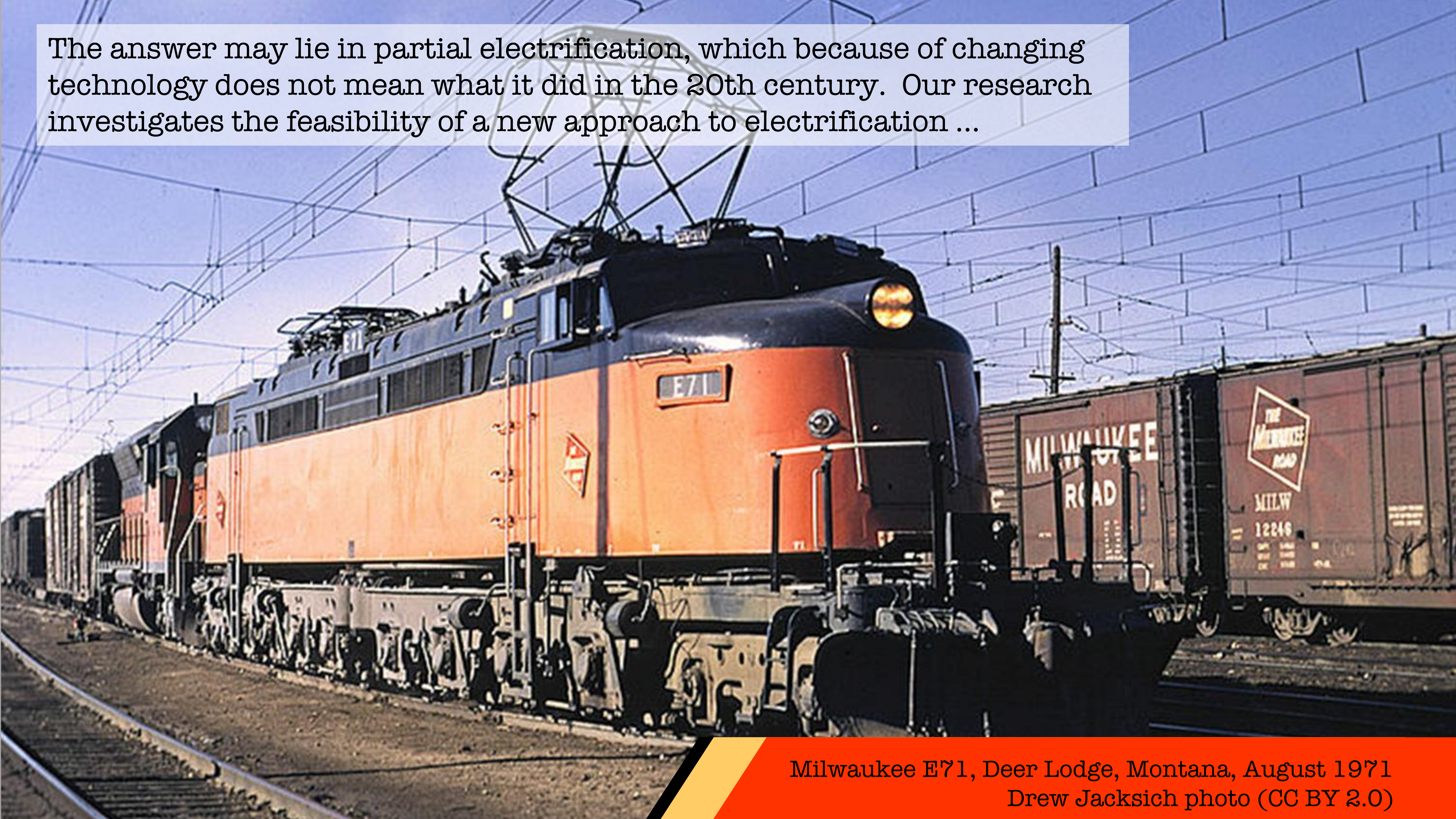
NRE 3GS21B on Olive St., Anaheim, California, 2007
Matthew "Morven" Brown photo (CC BY-SA 3.0)

The same is true for these locomotives that one regional railroad has converted to run on natural gas, stored in a tender between the two units.



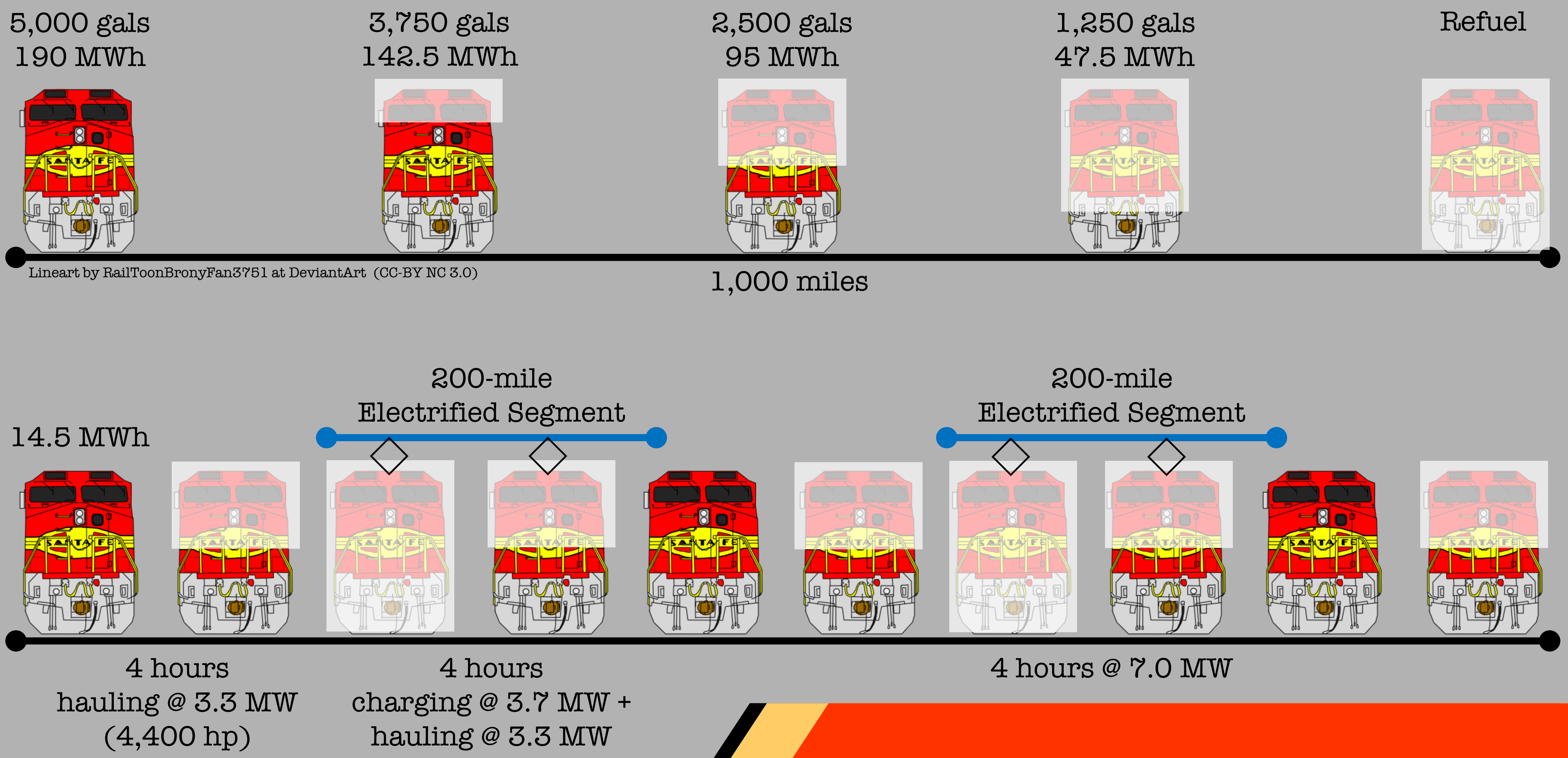
Train 121 with FEC 807 and 302 (LNG Fuel Tender)

The answer may lie in partial electrification, which because of changing technology does not mean what it did in the 20th century. Our research investigates the feasibility of a new approach to electrification …

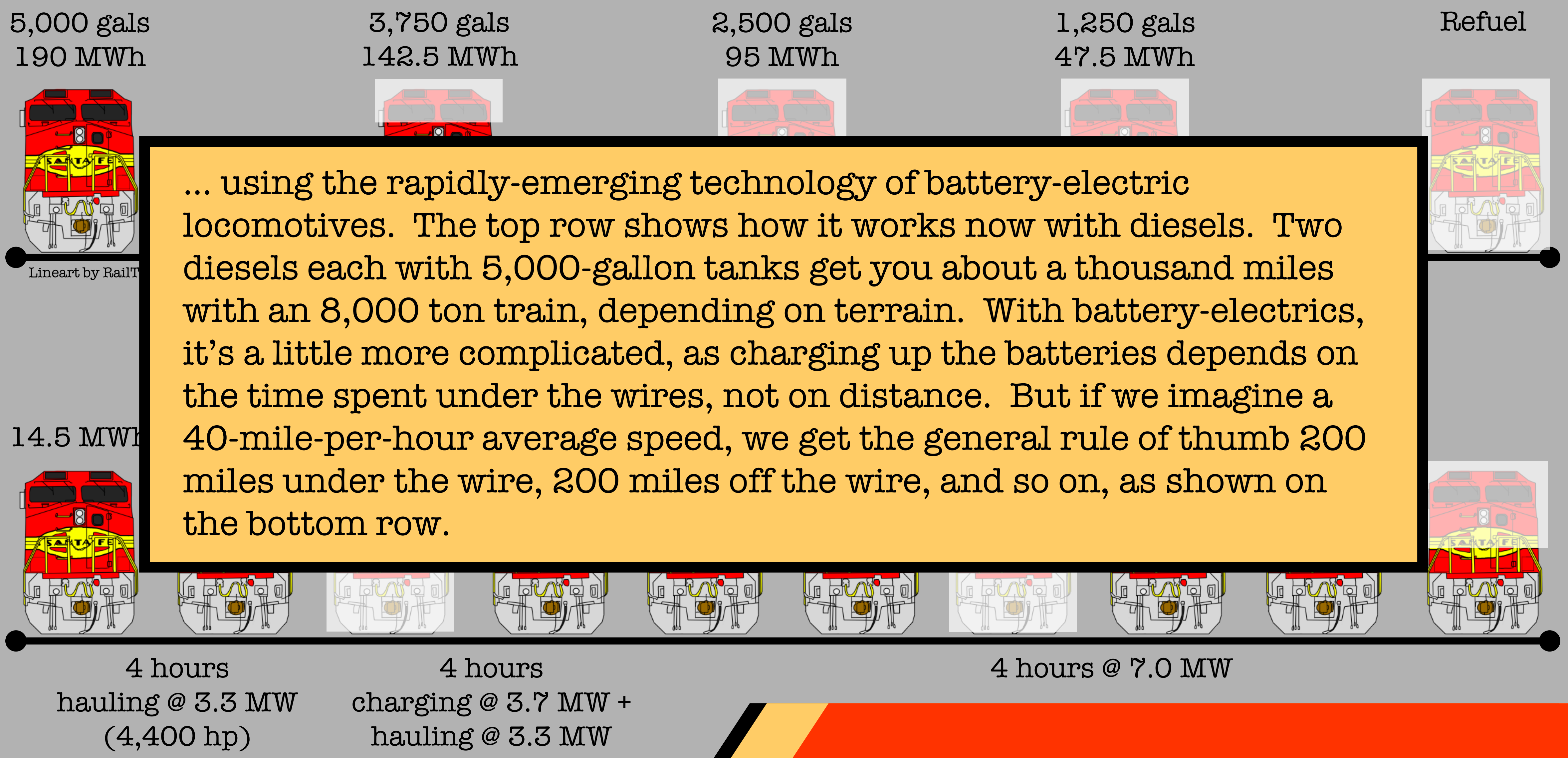


Milwaukee E71, Deer Lodge, Montana, August 1971
Drew Jacksich photo (CC BY 2.0)

BATTERY-ELECTRIC VS. DIESEL



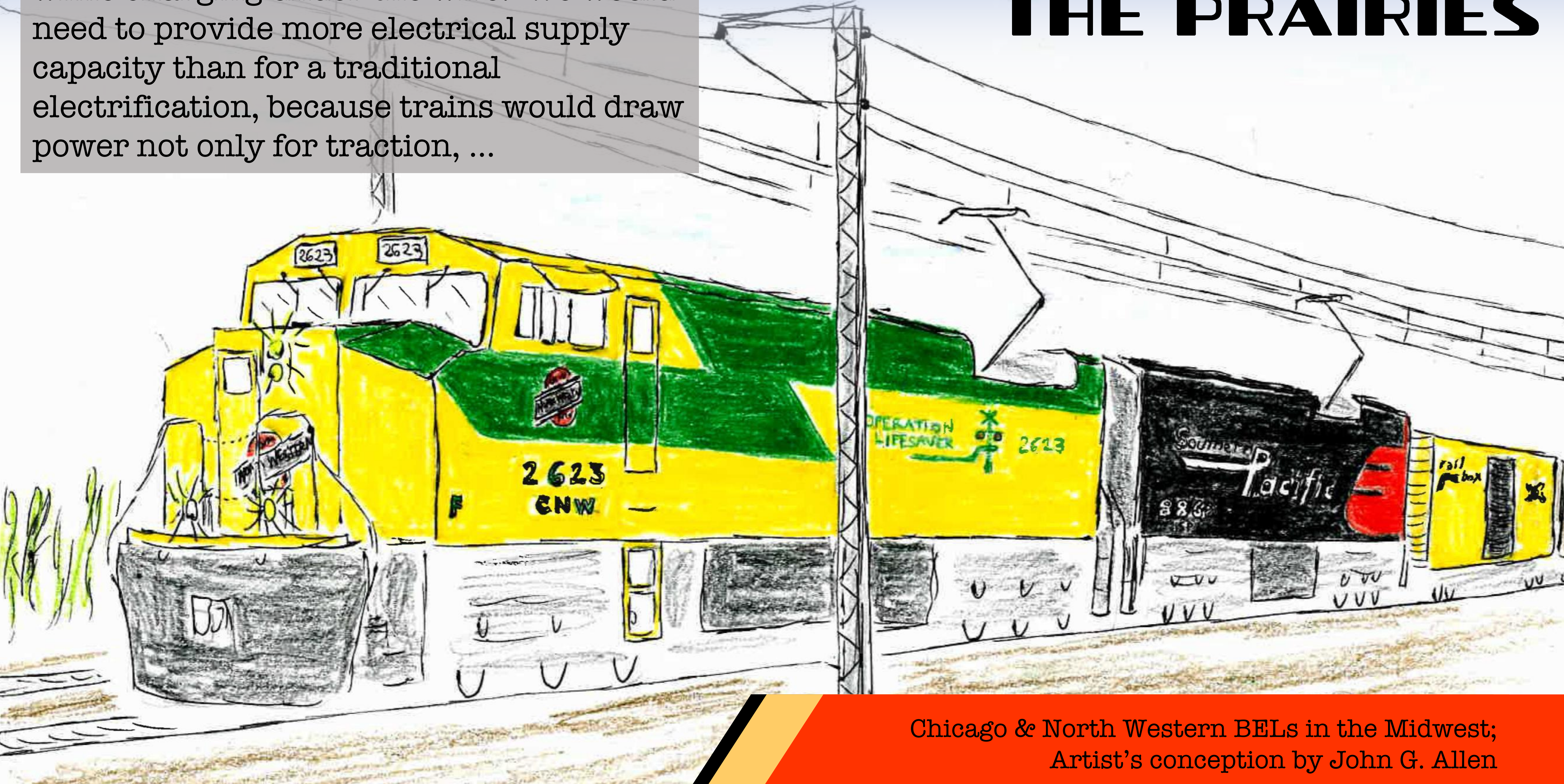
BATTERY-ELECTRIC VS. DIESEL



… using the rapidly-emerging technology of battery-electric locomotives. The top row shows how it works now with diesels. Two diesels each with 5,000-gallon tanks get you about a thousand miles with an 8,000 ton train, depending on terrain. With battery-electrics, it's a little more complicated, as charging up the batteries depends on the time spent under the wires, not on distance. But if we imagine a 40-mile-per-hour average speed, we get the general rule of thumb 200 miles under the wire, 200 miles off the wire, and so on, as shown on the bottom row.

CHARGING THROUGH THE PRAIRIES

So we would see battery-electrics running while charging under the wire. We would need to provide more electrical supply capacity than for a traditional electrification, because trains would draw power not only for traction, ...



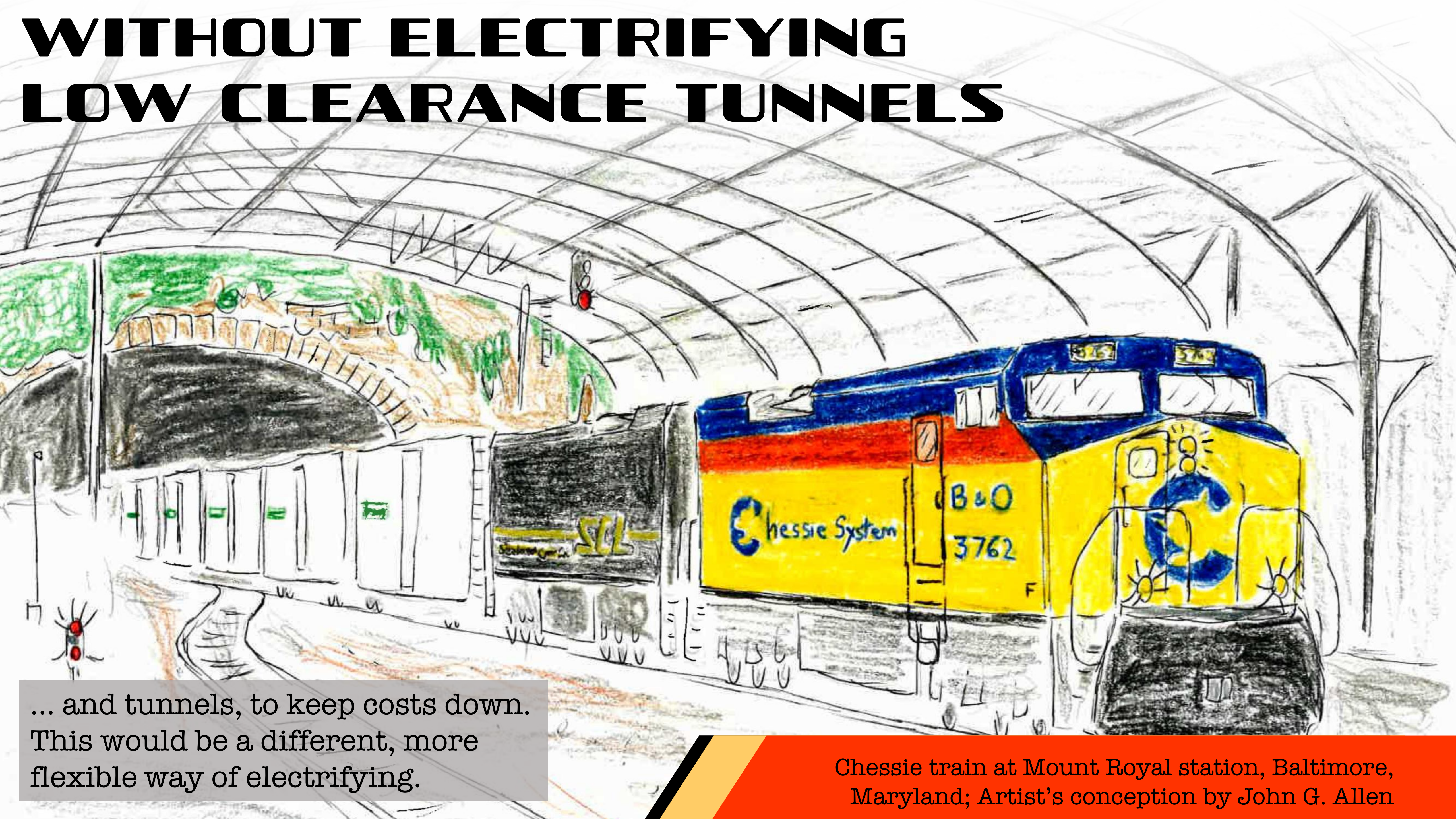
Chicago & North Western BELs in the Midwest;
Artist's conception by John G. Allen

POWERING THROUGH CATENARY GAPS

… but for recharging their batteries to operate outside the electrified zone. Even in electrified zones, we could design short gaps for low-clearance situations such as bridge structures …

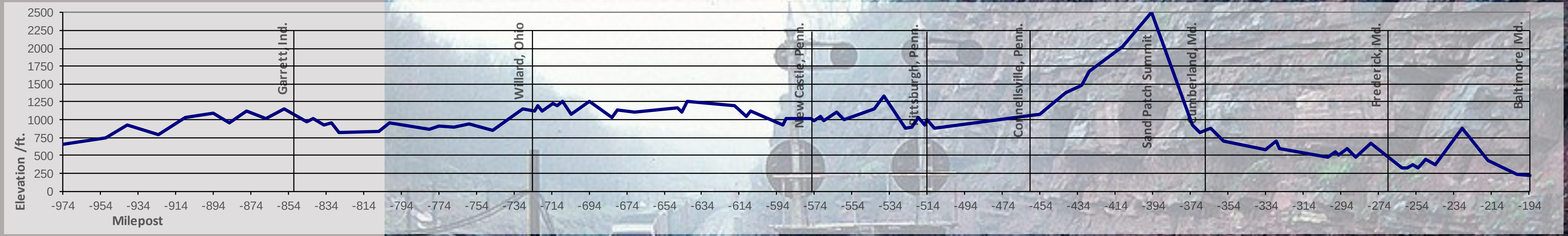
New York Central Cuyahoga River Drawbridge, Cleveland; Artist's conception by John G. Allen

WITHOUT ELECTRIFYING LOW CLEARANCE TUNNELS



... and tunnels, to keep costs down. This would be a different, more flexible way of electrifying.

Chessie train at Mount Royal station, Baltimore, Maryland; Artist's conception by John G. Allen

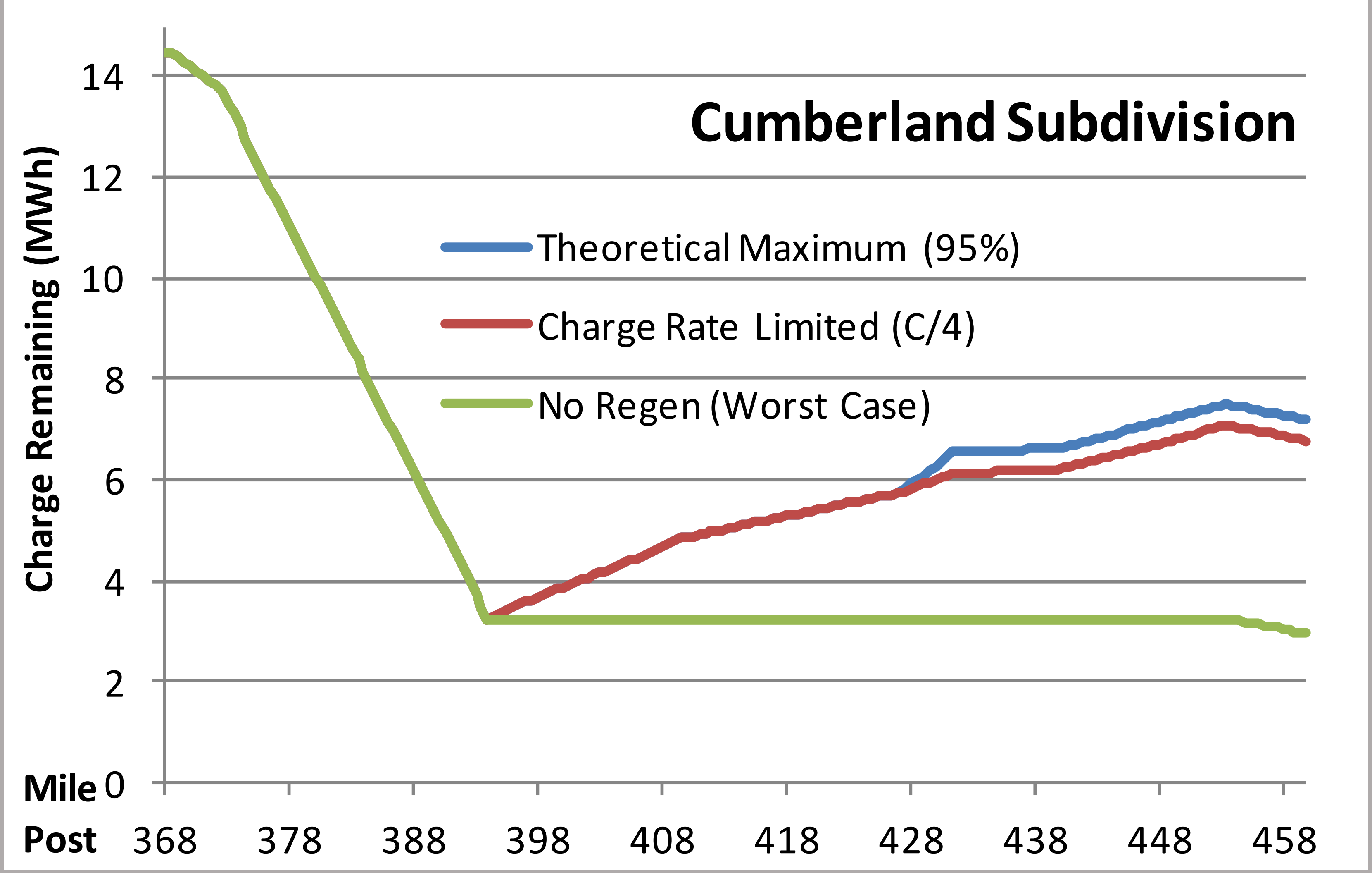


We performed a back-of-the-envelope train performance calculator simulation of how battery-electrics, supplemented with battery tenders, might perform between Baltimore and Chicago via Sand Patch in south-central Pennsylvania, which is one of the most challenging sustained climbs of any major main line on an Eastern railroad. Climbing the steep, sustained east slope in the westbound direction would not be a problem, assuming the train receives a full charge while still in the foothills, and the trains are assigned reasonable energy-to-weight ratios.

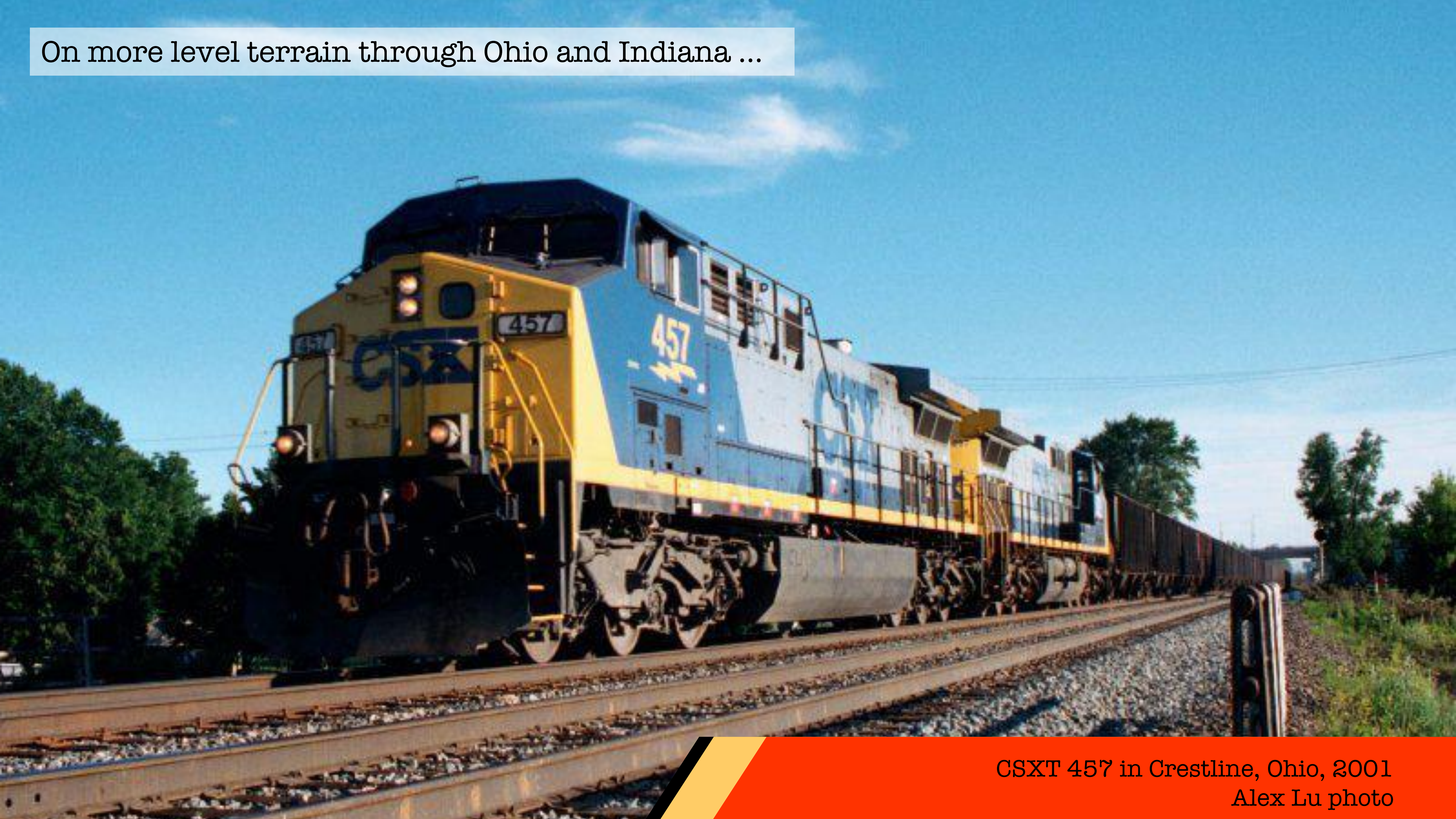
Baltimore and Ohio RR, Sand Patch Summit, 1972
Bruce Fingerhood photo (CC BY 2.0)

CRESTING THE SUMMIT…

This difficult terrain constrains operations in that trains must not run out of energy before cresting the summit, when regeneration kicks in. This chart shows the expected effects of climbing the east face of Sand Patch. Today, the energy dissipated as heat in rheostatic braking is lost, but with battery-electrics it could be used to restore some of the charge to the batteries, allowing railroads to install electrification only in the foothills where it might be easier to build and maintain.

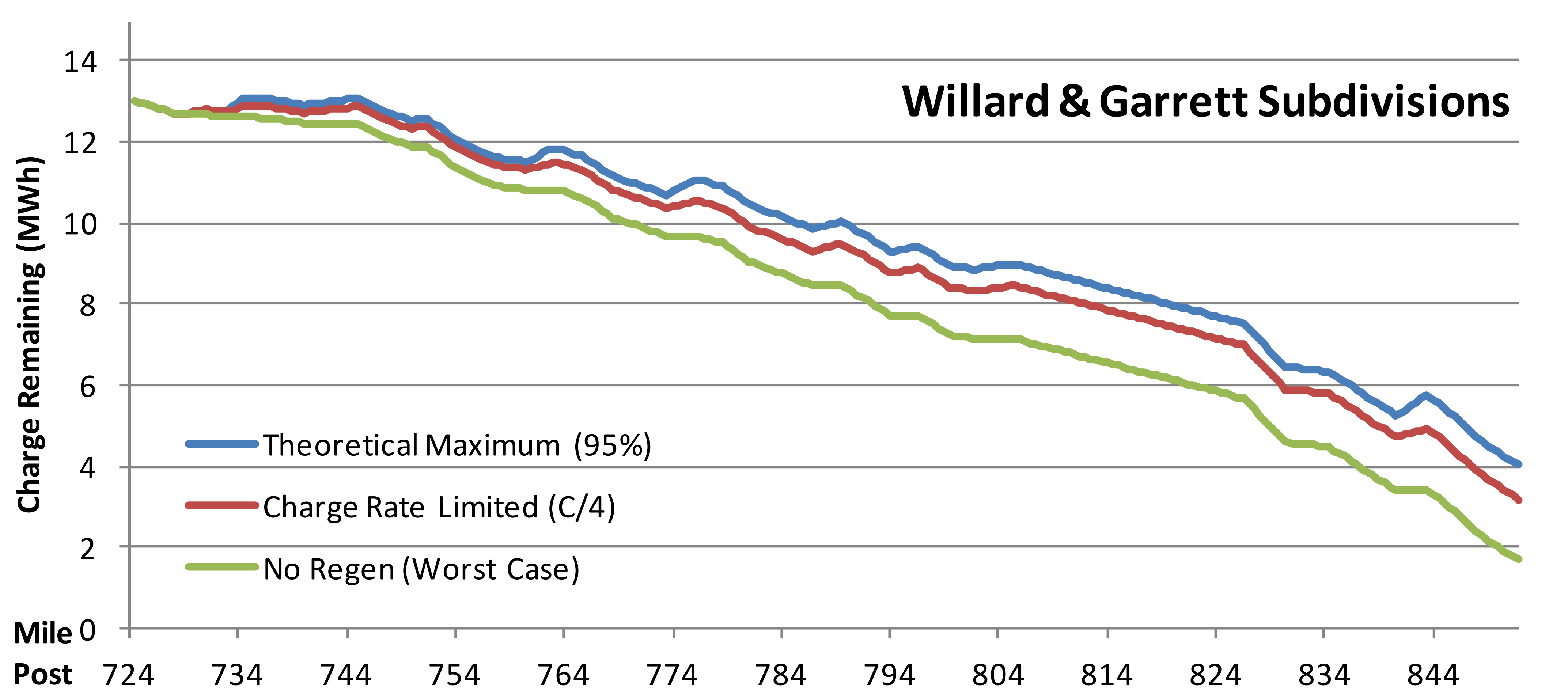


On more level terrain through Ohio and Indiana …



CSXT 457 in Crestline, Ohio, 2001
Alex Lu photo

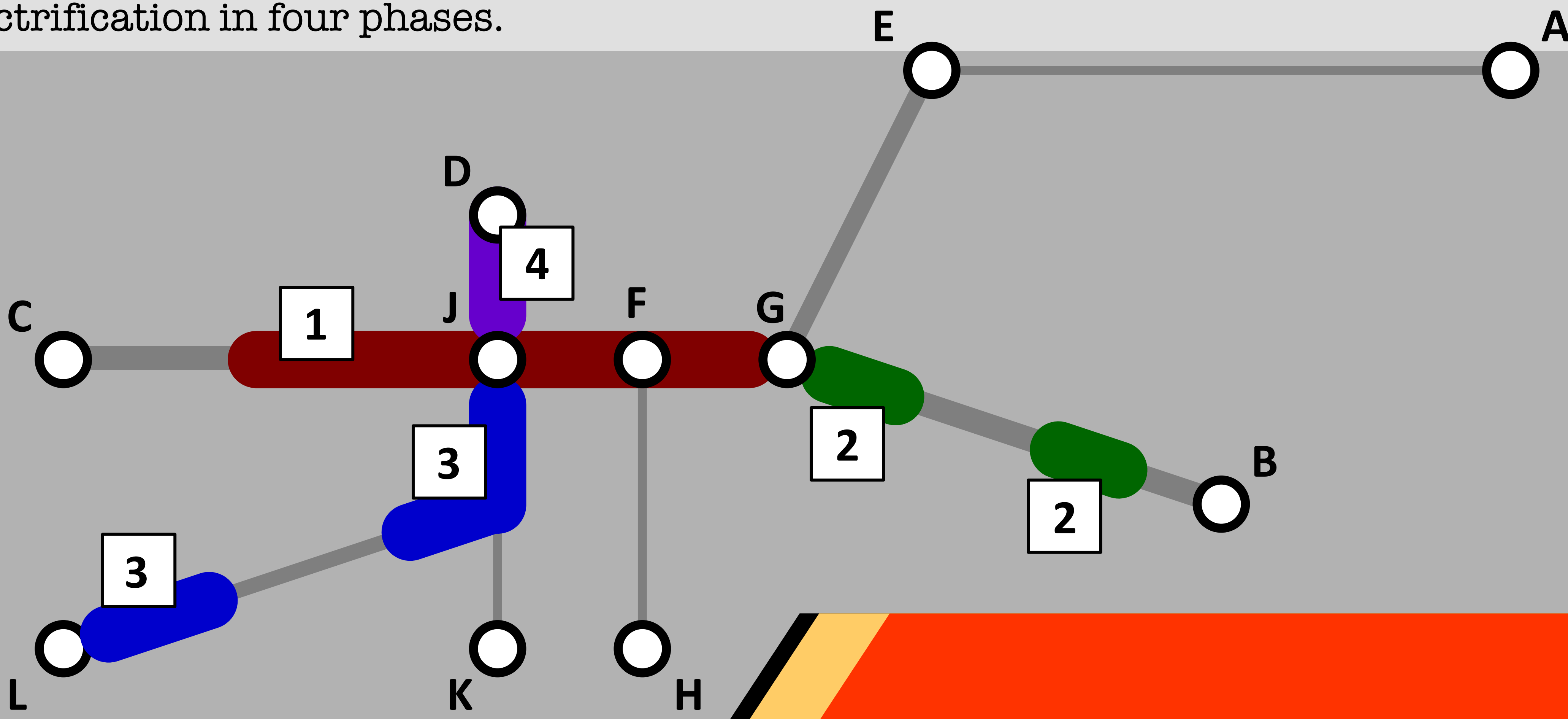
...AND IN THE MIDWEST



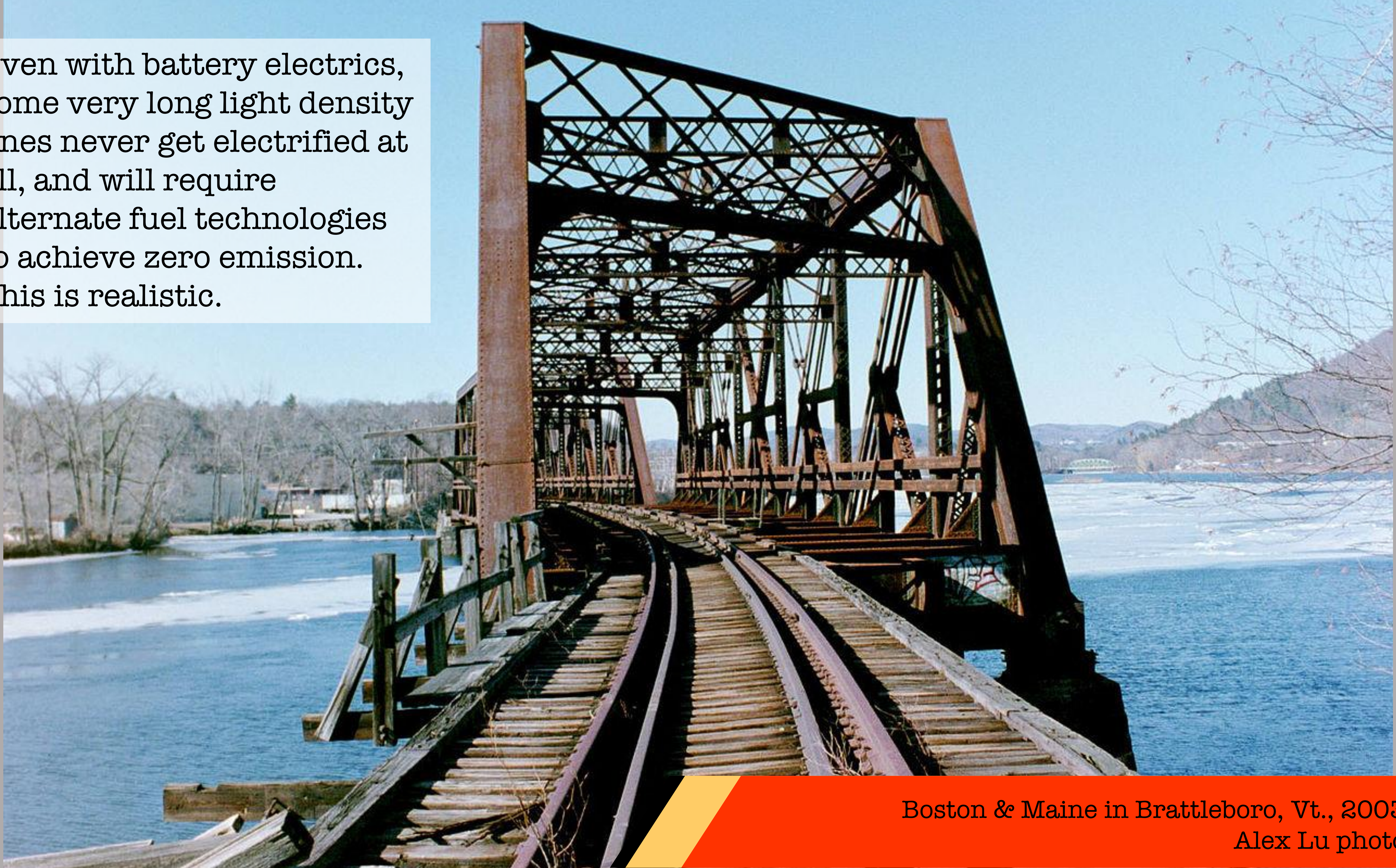
... we see less difference between the charge remaining with and without regeneration.

CASE STUDY – INTERMITTENT

To understand the economic case for intermittent electrification, we set up a hypothetical Class One railroad network, to see how much money we could save (and how much emissions we could remove) compared to electrifying only a contiguous electric zone with the highest traffic density. For the battery-electric based network, we would build the electrification in four phases.



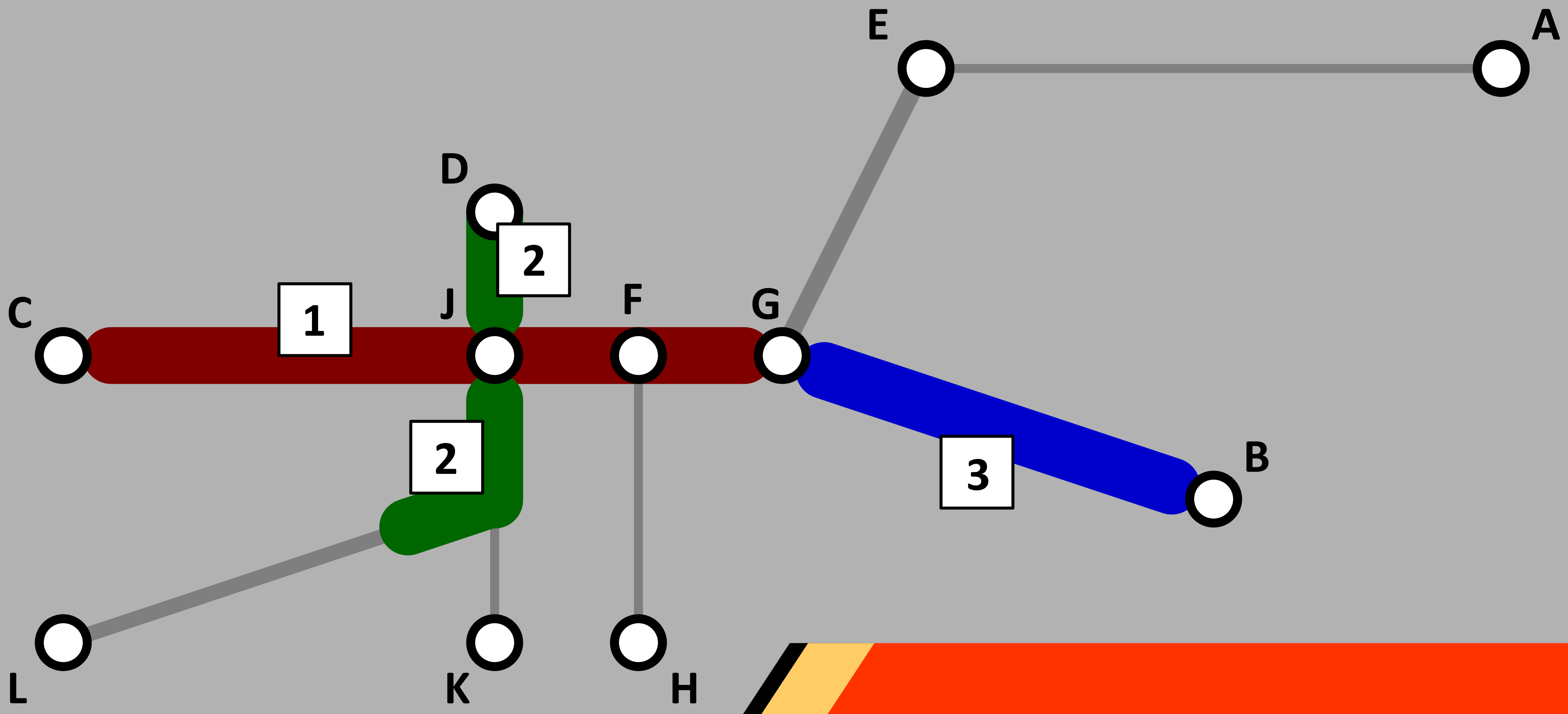
Even with battery electrics, some very long light density lines never get electrified at all, and will require alternate fuel technologies to achieve zero emission. This is realistic.



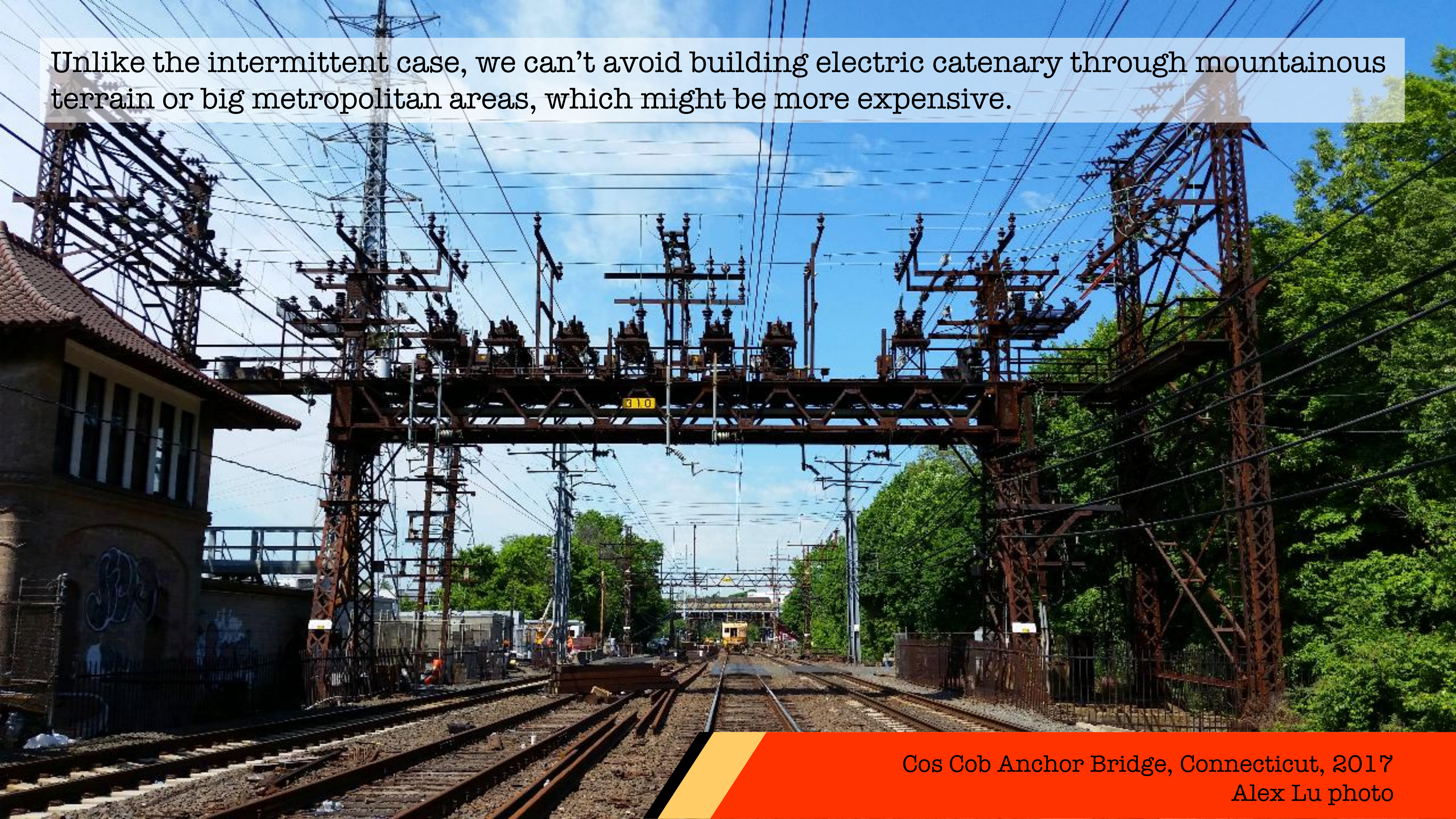
Boston & Maine in Brattleboro, Vt., 2003
Alex Lu photo

CASE STUDY – CONTINUOUS

Here is how we would do it with conventional electrification, in three phases, and with engine changes whenever locomotives get to the electric district.

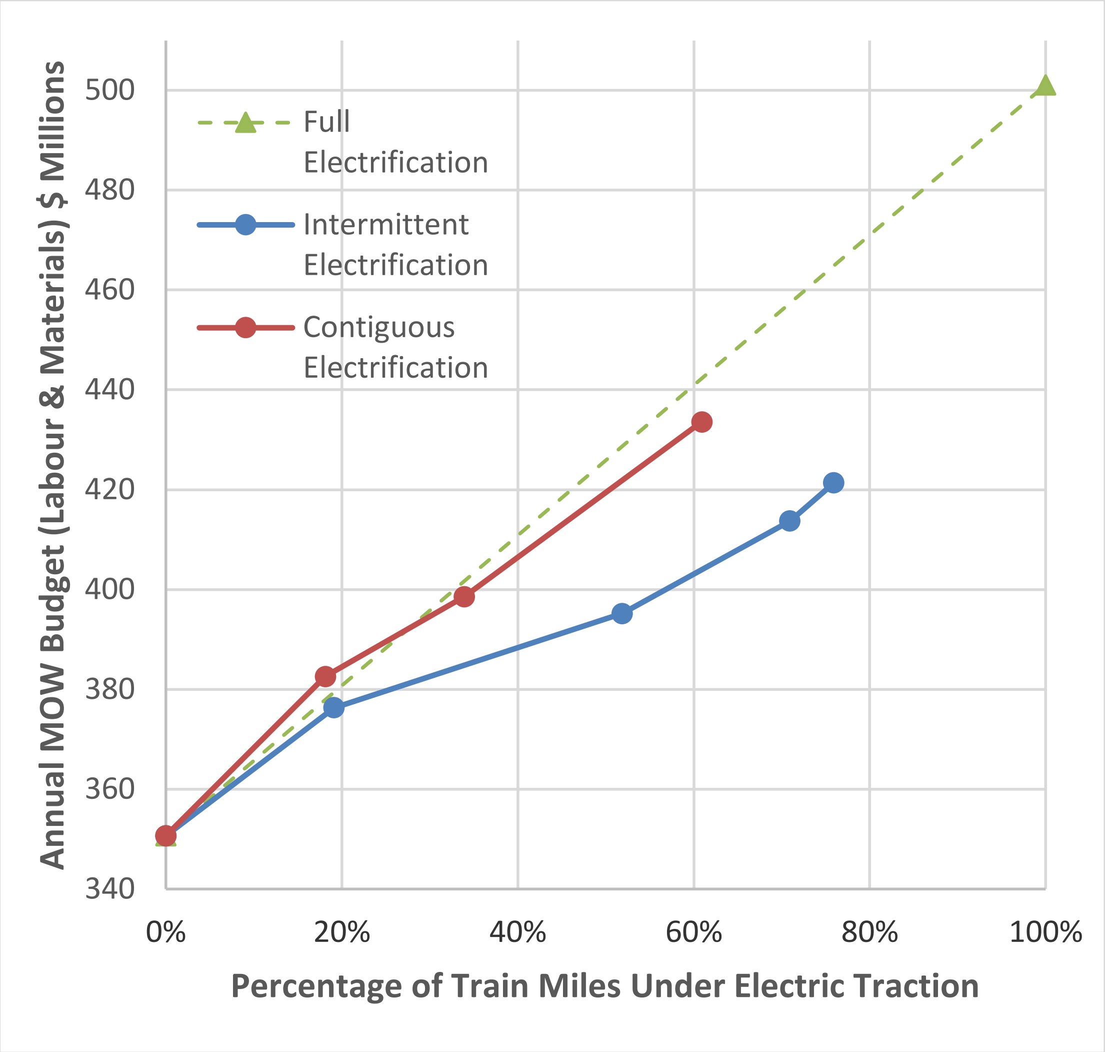


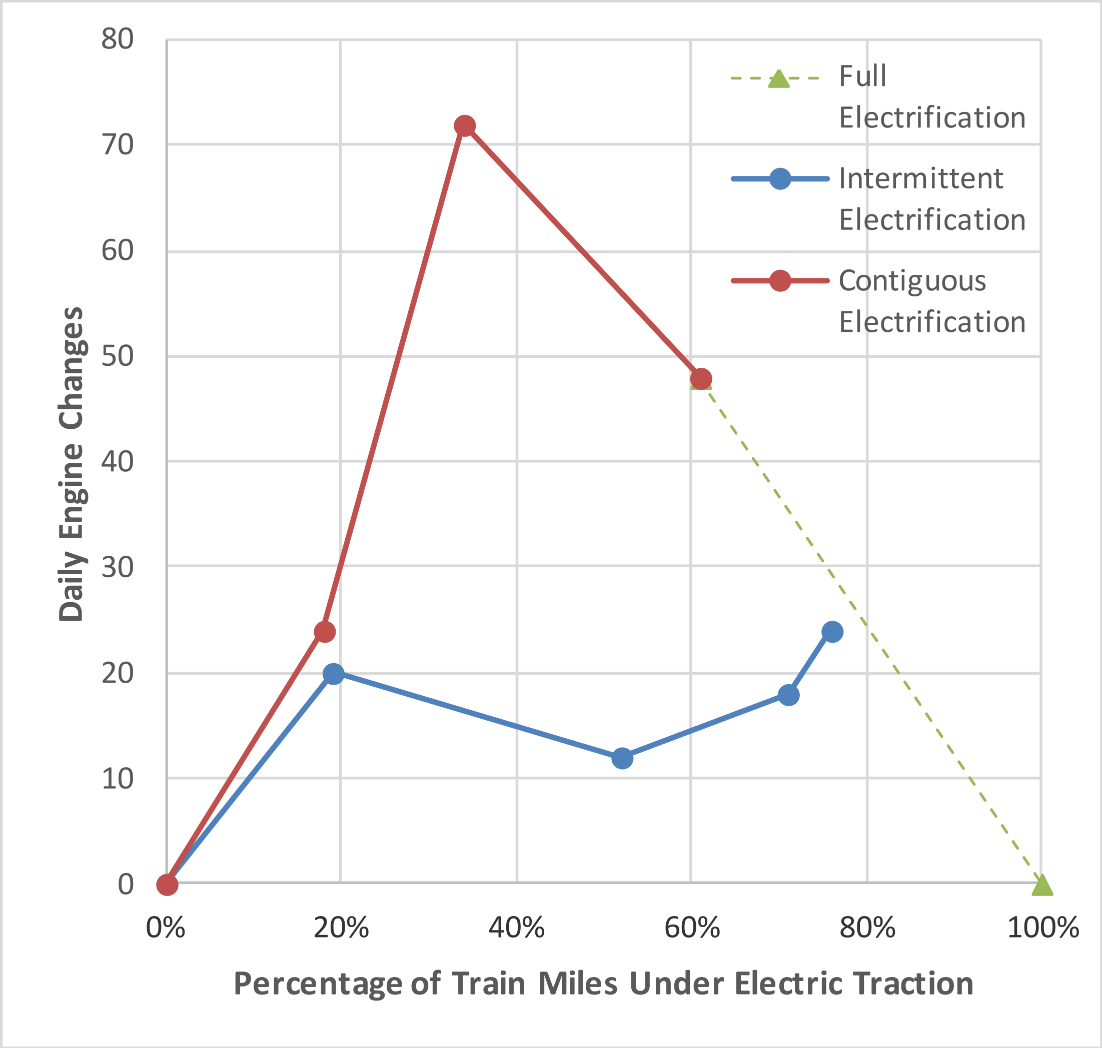
Unlike the intermittent case, we can’t avoid building electric catenary through mountainous terrain or big metropolitan areas, which might be more expensive.



Cos Cob Anchor Bridge, Connecticut, 2017
Alex Lu photo

MAINTENANCE AND COMPLEXITY





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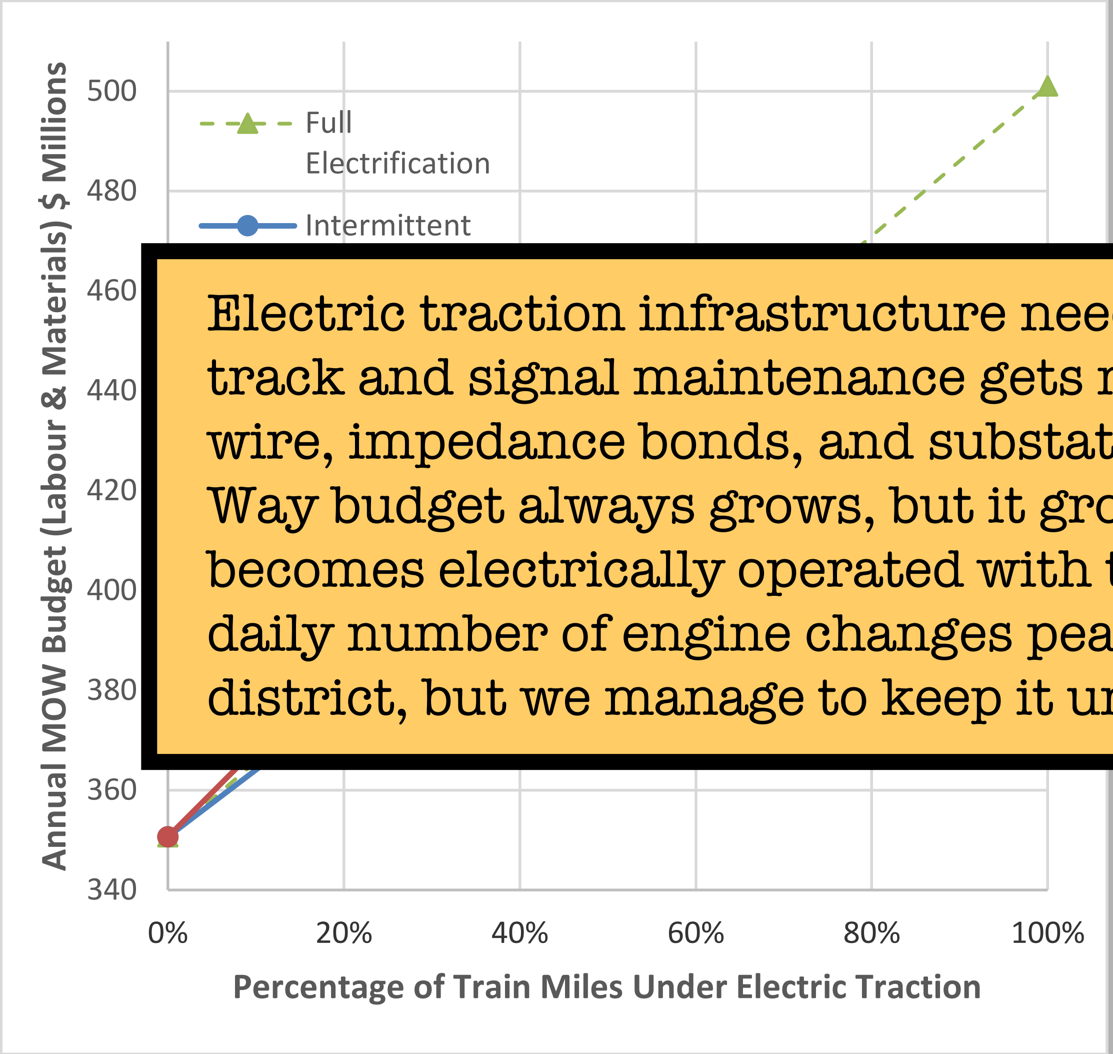
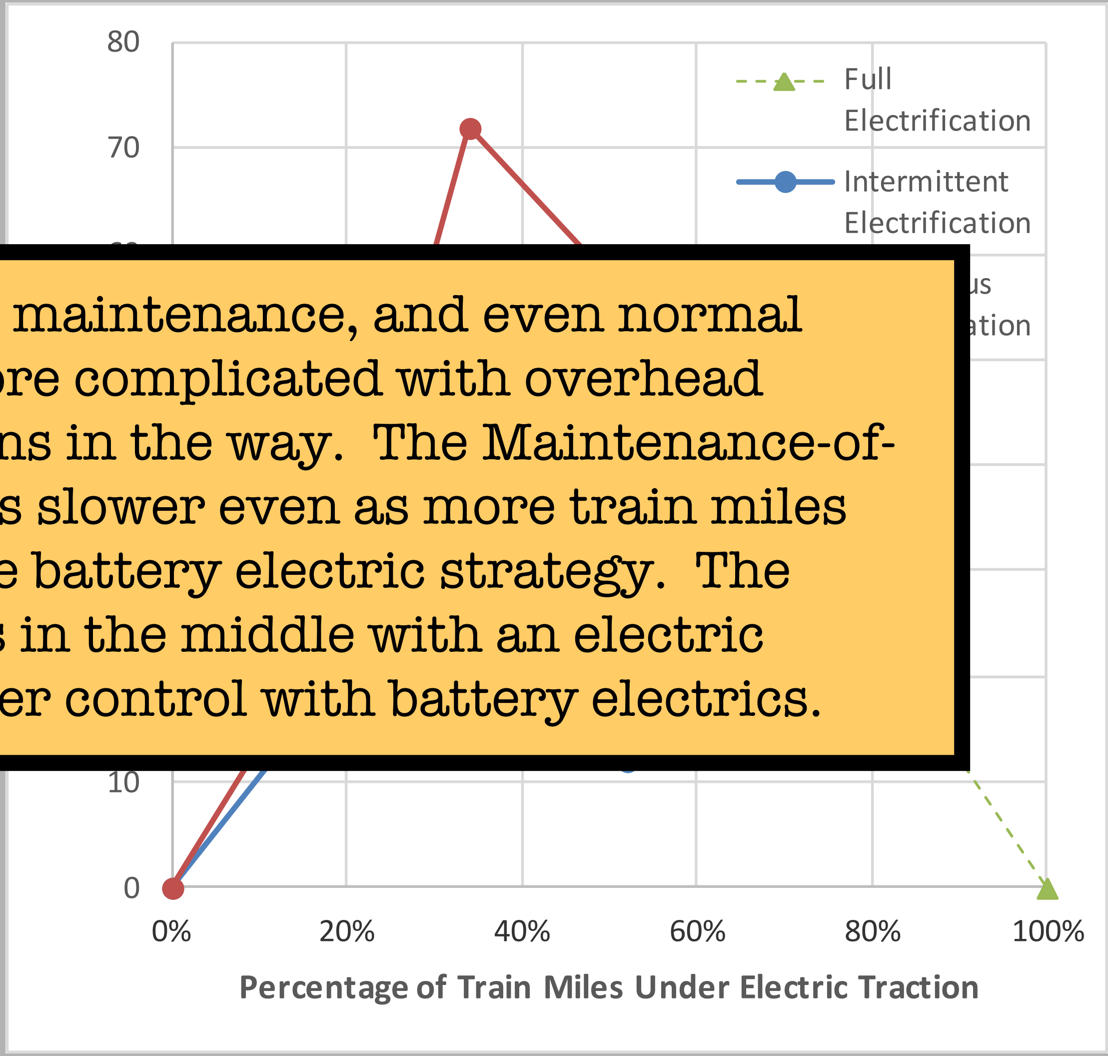
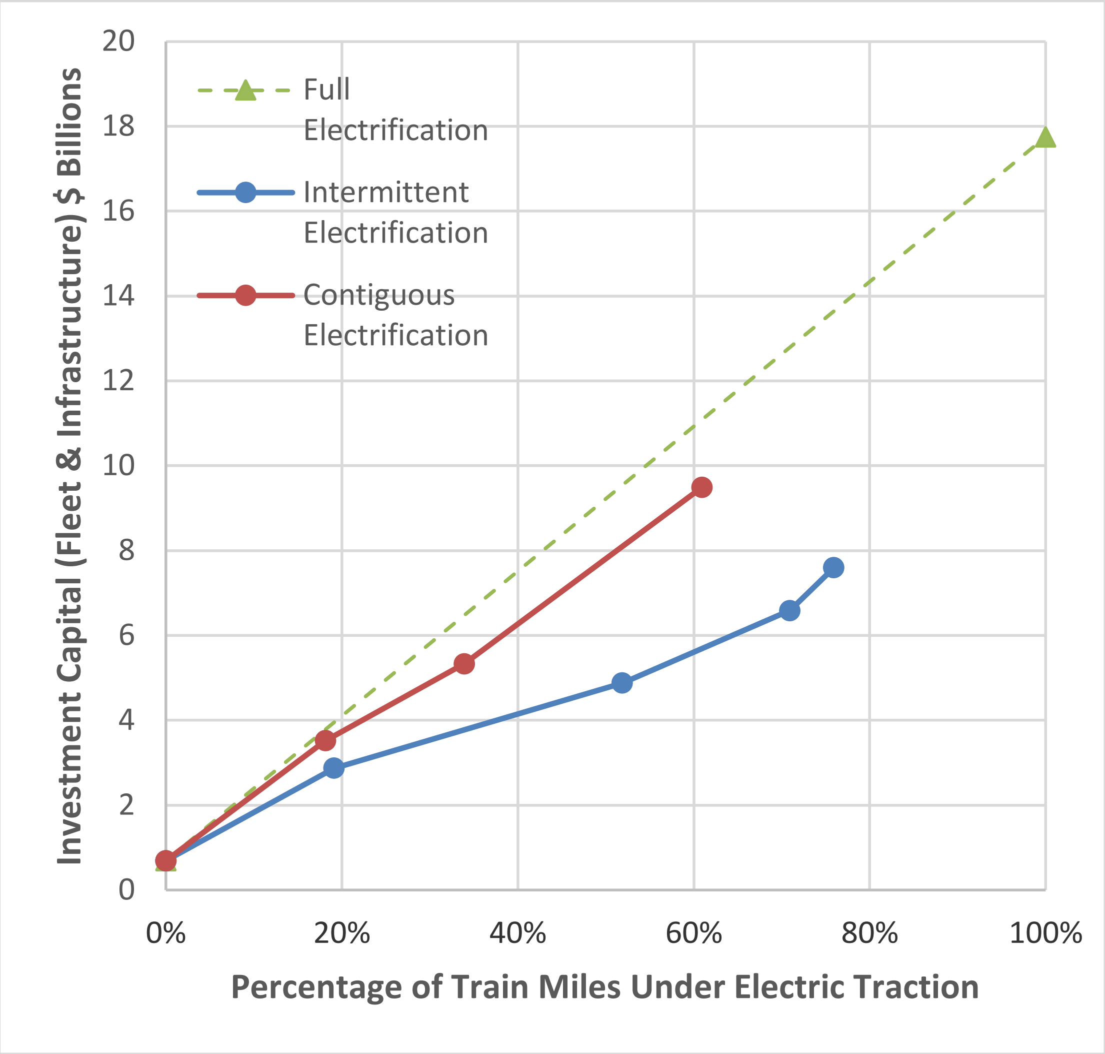
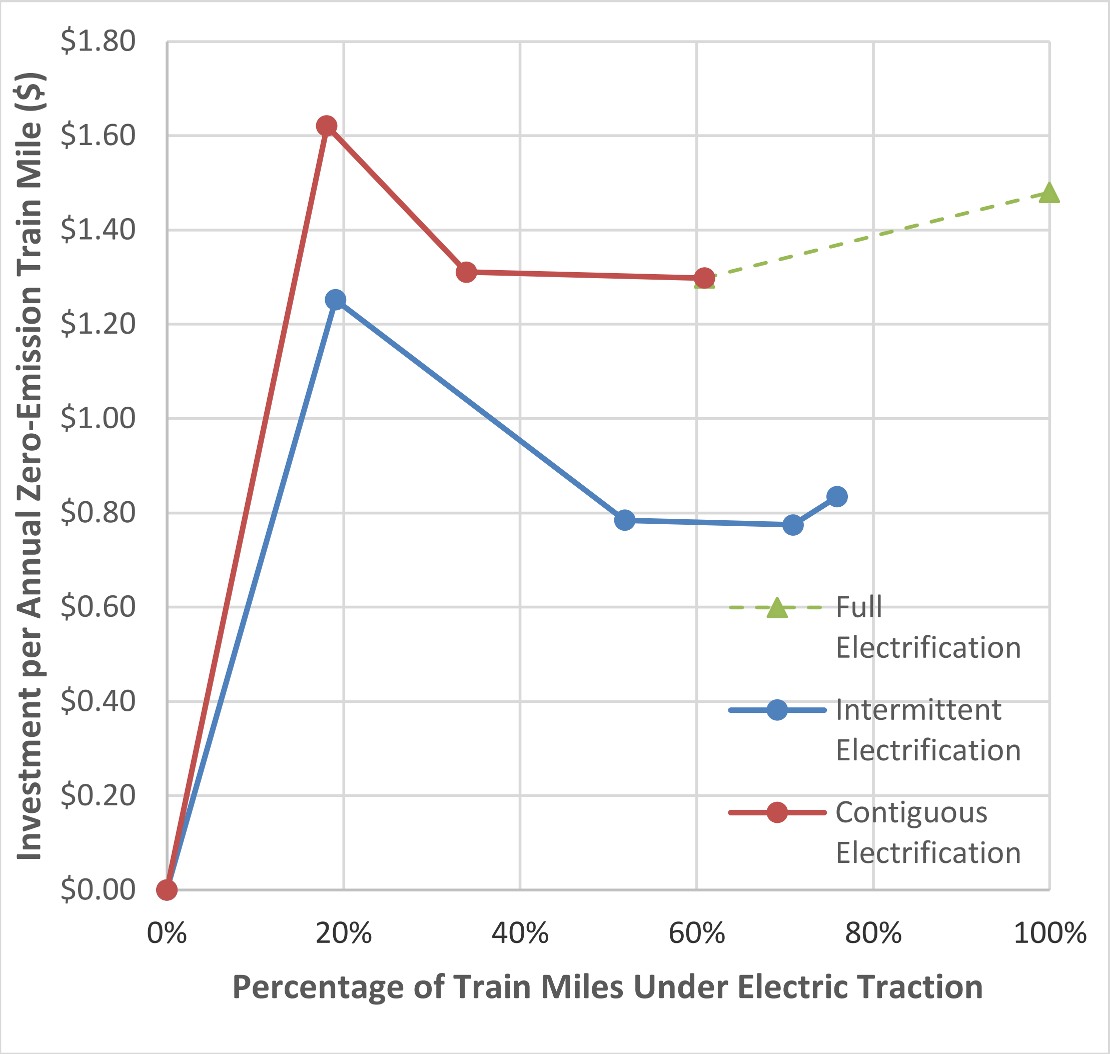




Electric traction infrastructure needs maintenance, and even normal track and signal maintenance gets more complicated with overhead wire, impedance bonds, and substations in the way. The Maintenance-of-Way budget always grows, but it grows slower even as more train miles becomes electrically operated with the battery electric strategy. The daily number of engine changes peaks in the middle with an electric district, but we manage to keep it under control with battery electrics.

CAPITAL AND COST-EFFECTIVENESS





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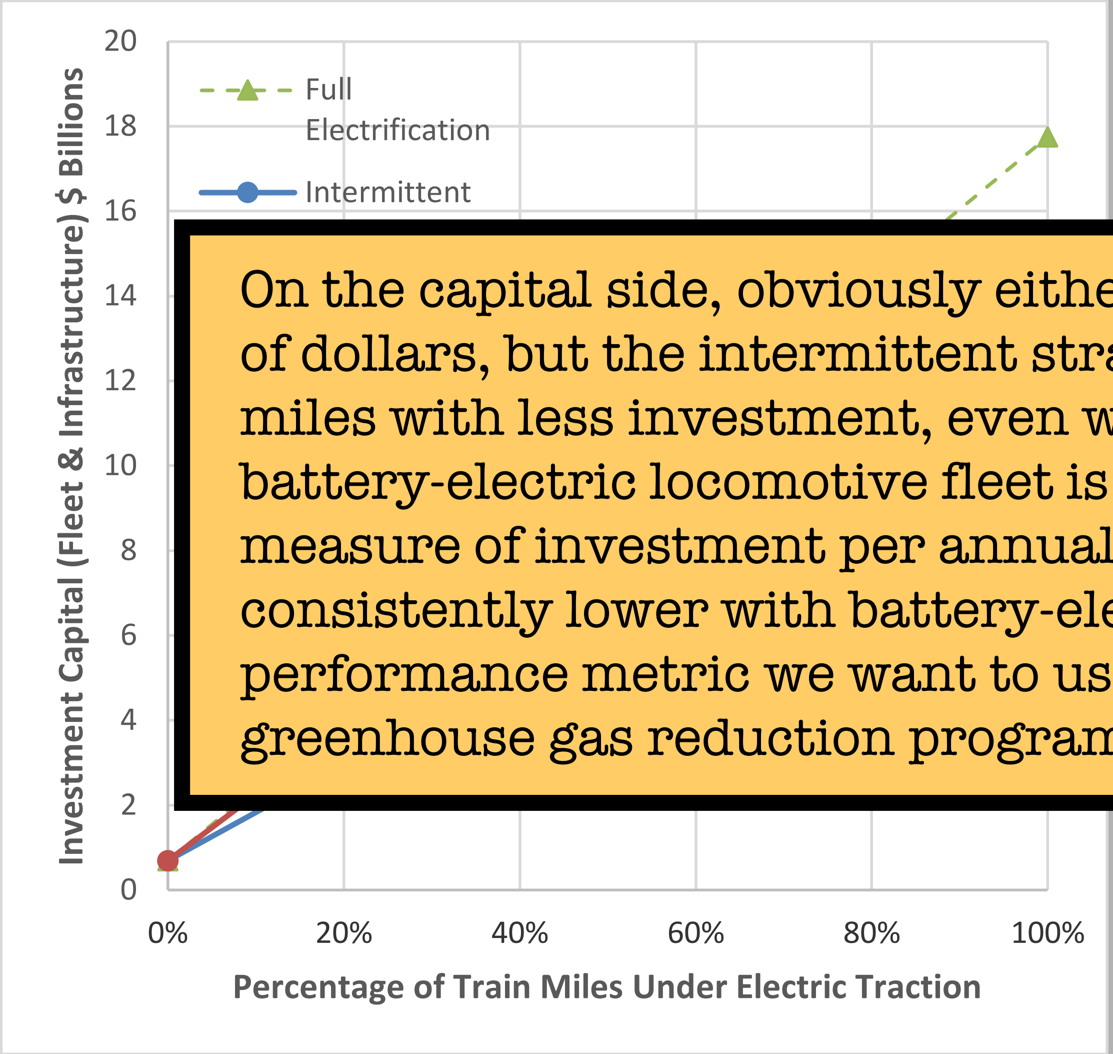
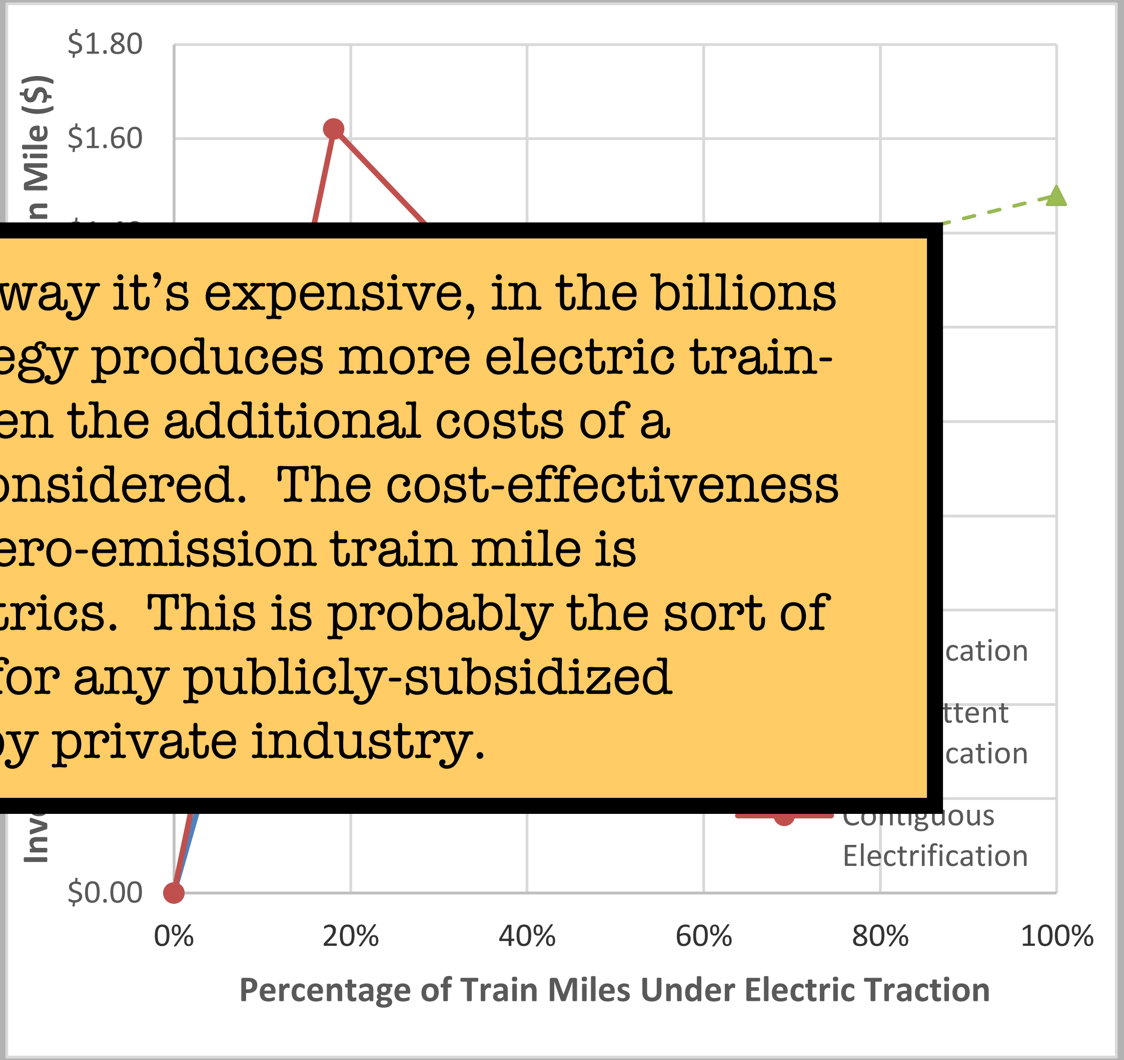
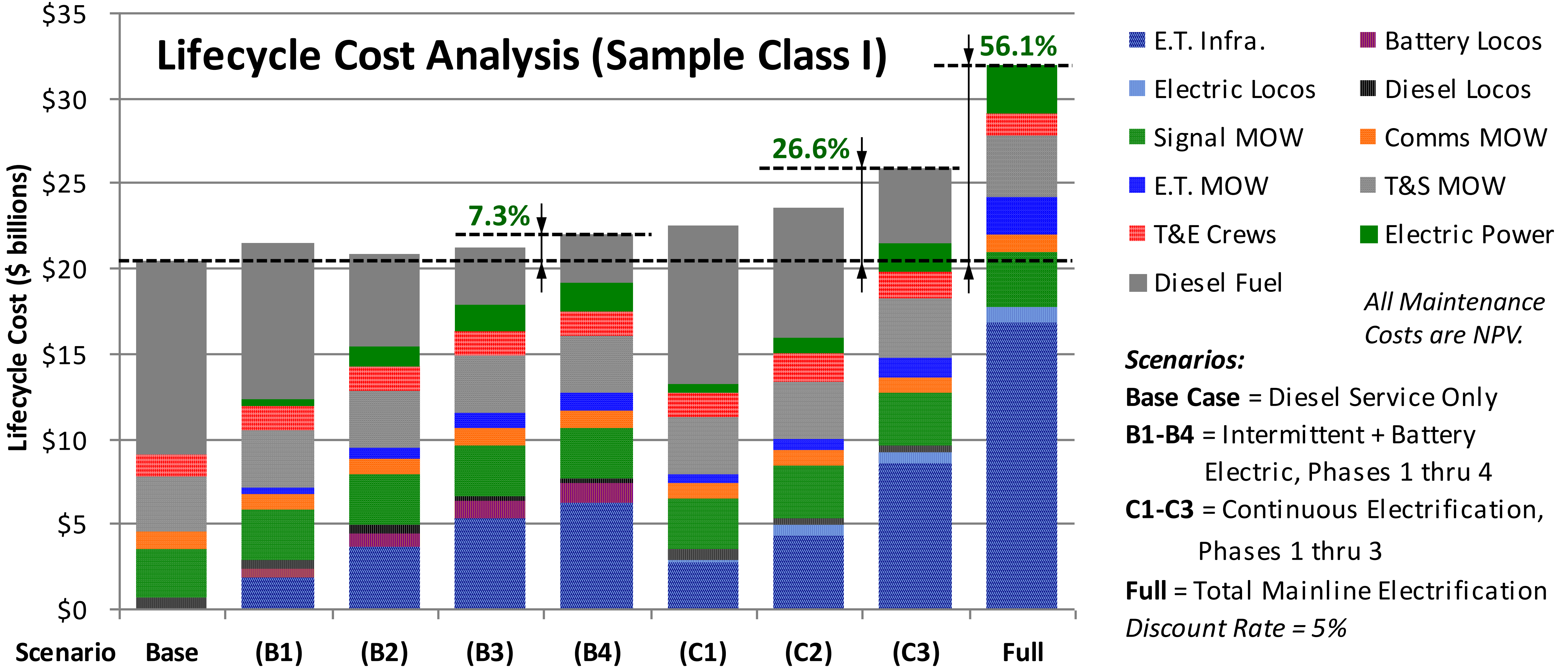




On the capital side, obviously either way it's expensive, in the billions of dollars, but the intermittent strategy produces more electric train-miles with less investment, even when the additional costs of a battery-electric locomotive fleet is considered. The cost-effectiveness measure of investment per annual zero-emission train mile is consistently lower with battery-electrics. This is probably the sort of performance metric we want to use for any publicly-subsidized greenhouse gas reduction program by private industry.

LIFE-CYCLE COST ANALYSIS



All Maintenance Costs are NPV.

Scenarios:

Base Case = Diesel Service Only

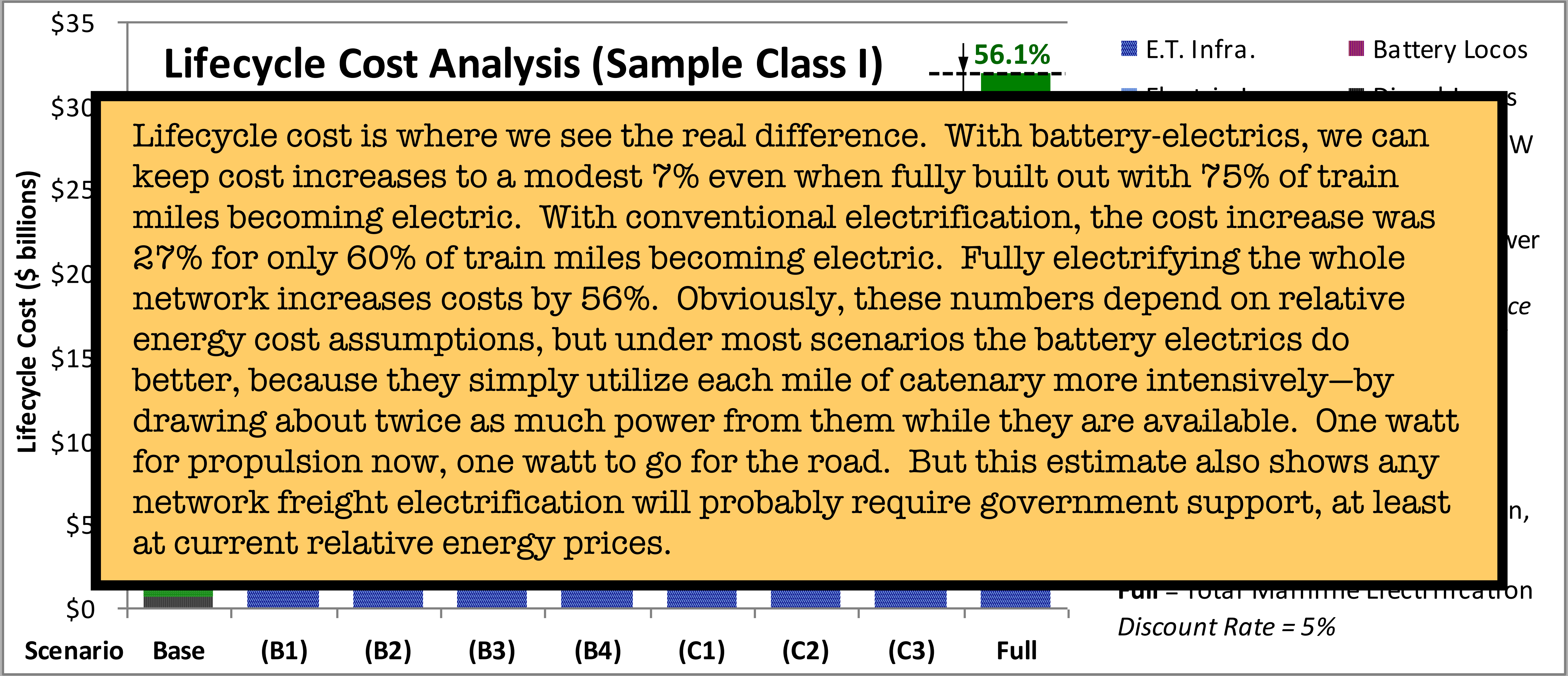
B1-B4 = Intermittent + Battery Electric, Phases 1 thru 4

C1-C3 = Continuous Electrification, Phases 1 thru 3

Full = Total Mainline Electrification

Discount Rate = 5%

LIFE-CYCLE COST ANALYSIS



Lifecycle cost is where we see the real difference. With battery-electrics, we can keep cost increases to a modest 7% even when fully built out with 75% of train miles becoming electric. With conventional electrification, the cost increase was 27% for only 60% of train miles becoming electric. Fully electrifying the whole network increases costs by 56%. Obviously, these numbers depend on relative energy cost assumptions, but under most scenarios the battery electrics do better, because they simply utilize each mile of catenary more intensively—by drawing about twice as much power from them while they are available. One watt for propulsion now, one watt to go for the road. But this estimate also shows any network freight electrification will probably require government support, at least at current relative energy prices.

PRACTICAL ISSUES

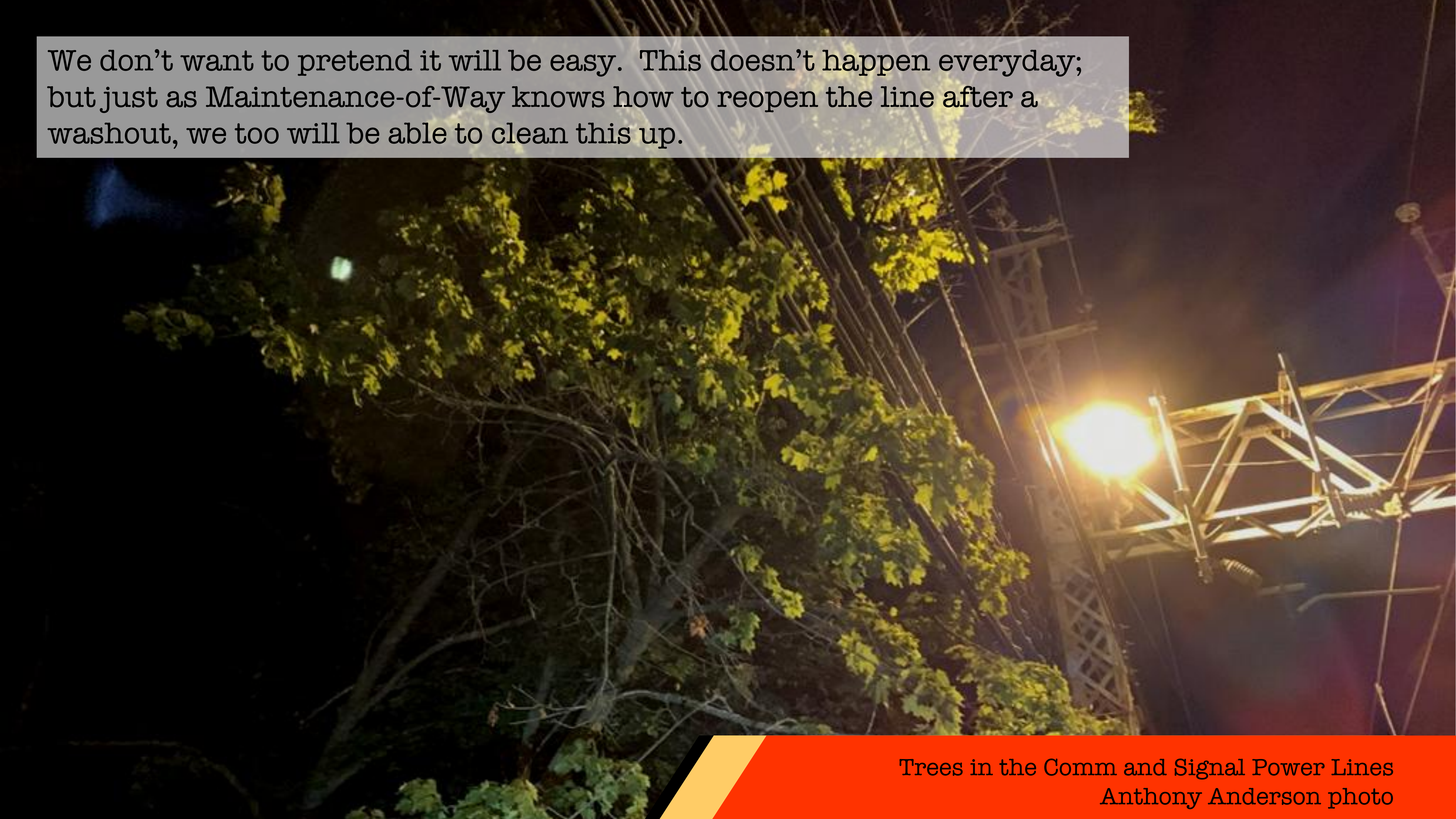
- Proving high-capacity battery-electric locomotives
- Clearances for double-stack trains
- Non-electrified routes for high/wide loads
- Effects of extreme climate in North America
- Impacts on signal systems and maintenance practices

North American freight railroads have essentially no experience with electrification. Various practical issues need to be addressed – proving high-capacity battery-electrics in operation, providing alternate routes for high and wide loads such as aircraft fuselages and electrical transformers, mitigating the effects of North America's often extreme climate on the infrastructure, and mitigating the effects of electrification on signal systems and right-of-way maintenance practices.

India and China already have near-AAR Plate H clearances for electrically-operated double-stack trains.

Indian Western Railways operates a electric double-stack container train from Palanpur to Botad in Gujarat, June 10, 2020; Piyush Goyal photo (India Government Open Data License via indianrailways.gov.in)

We don’t want to pretend it will be easy. This doesn’t happen everyday; but just as Maintenance-of-Way knows how to reopen the line after a washout, we too will be able to clean this up.

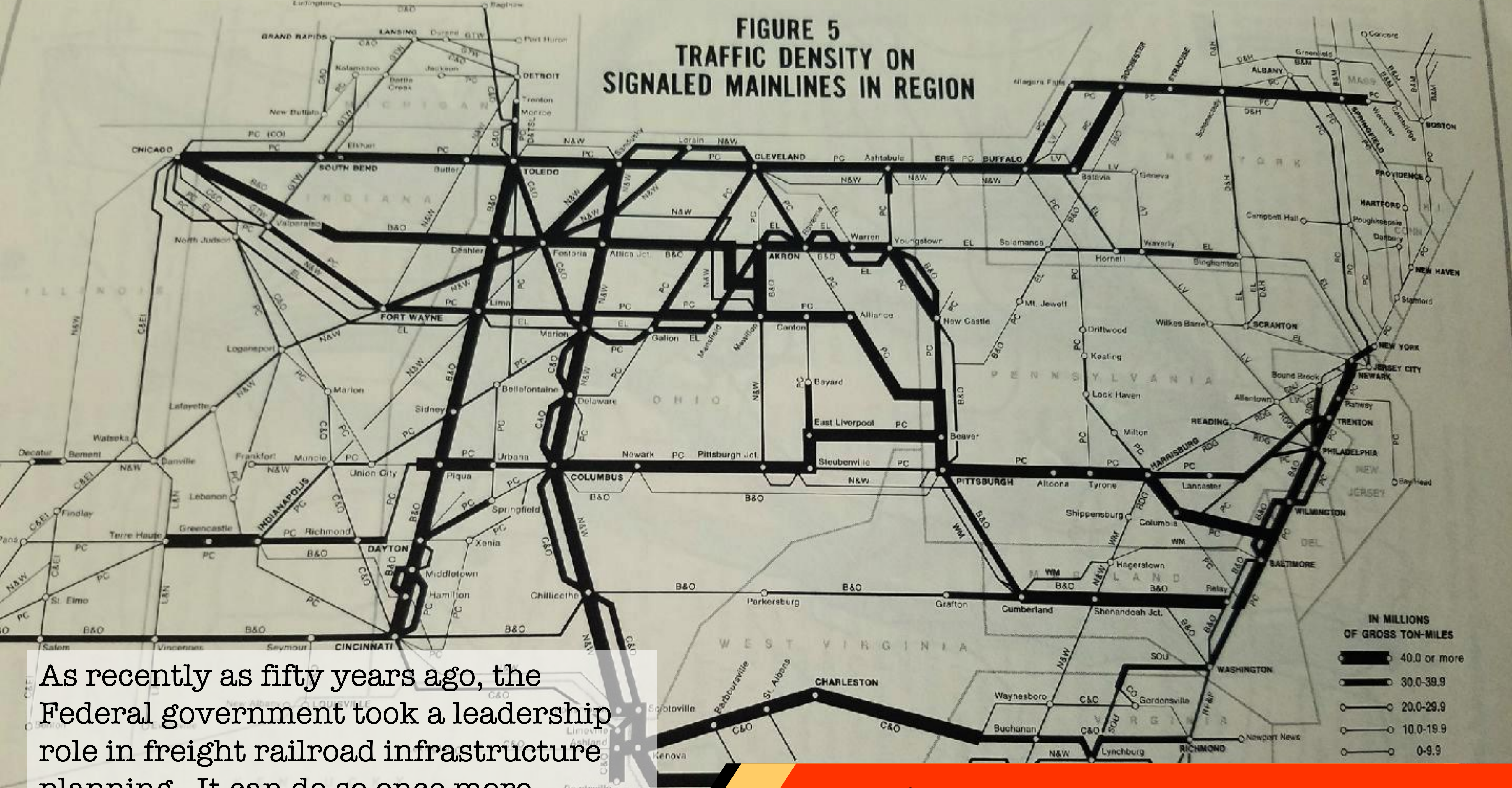


Trees in the Comm and Signal Power Lines
Anthony Anderson photo

NEXT STEPS

- Federal assistance: demonstration programs
- Commodity flow analysis: where to build?
- Business case analysis: what's in it for me?
- Joint network, capacity, and infrastructure planning by railroads with electric utilities

What needs to happen now is a whole lot of planning. Seed money needs to be provided to develop experience and build prototypes. Commodity forecasts will tell us which freight flows would remain important. Business cases will need to find ways to show positive benefits for each stakeholder. And railroads and electric utilities need to get together to do some "joined up thinking"—identify electrification power demands, secure emission-free power sources, and identify transmission capacity gaps.



As recently as fifty years ago, the Federal government took a leadership role in freight railroad infrastructure planning. It can do so once more.

Rail Service in the Northeast and Midwest Region
U.S. Department of Transportation (1973)

INSTITUTIONAL MECHANISMS

- Tax credits
- Joint ventures
- Infrastructure improvement grants
- Cap-and-trade
- "Cash for clunkers" for diesel locomotives

And even partial electrification costs a lot of money. If carbon-neutral transportation is an important policy goal, then governments should be prepared to finance this new way of electrifying with tax credits, encouraging joint ventures, infrastructure improvement grants, cap-and-trade mechanisms…

… and maybe even a “cash for clunkers” program to replace diesels with non-emitting locomotives.

Dead Line at Rutherford Yard, Penn.
Tom Beckett/CRHS photo (CC BY-NC-SA)

CONCLUSIONS

- Discontinuous electrification is workable with battery-electric locomotives
- Technology is rapidly developing and should be ready for service within a few years
- Alternating about every 200 miles between electrified and non-electrified

So, to sum up, the rapidly-developing technology of battery-electrics will make discontinuous electrification on freight railroads a real possibility. Our calculations show that with about 200 miles on, 200 miles off, railroads should be able to take advantage of this potentially carbon-neutral approach for main line operations.

BATTERY ELECTRICS: ARE WE READY?

The new technology is coming. Are the industry and its partners ready? Thank you.

Santa Fe stack train operating with distributed power BELs; Artist's conception by John G. Allen