PARTIAL ELECTRIFICATION STRATEGIES FOR DIESEL COMMUTER RAIL'S CLIMATE CHALLENGE

John G. Allen
Alex Lu
Stuart F. Trout
John P. Aurelius

TRB, January 2023

http://lexciestuff.net/bel/

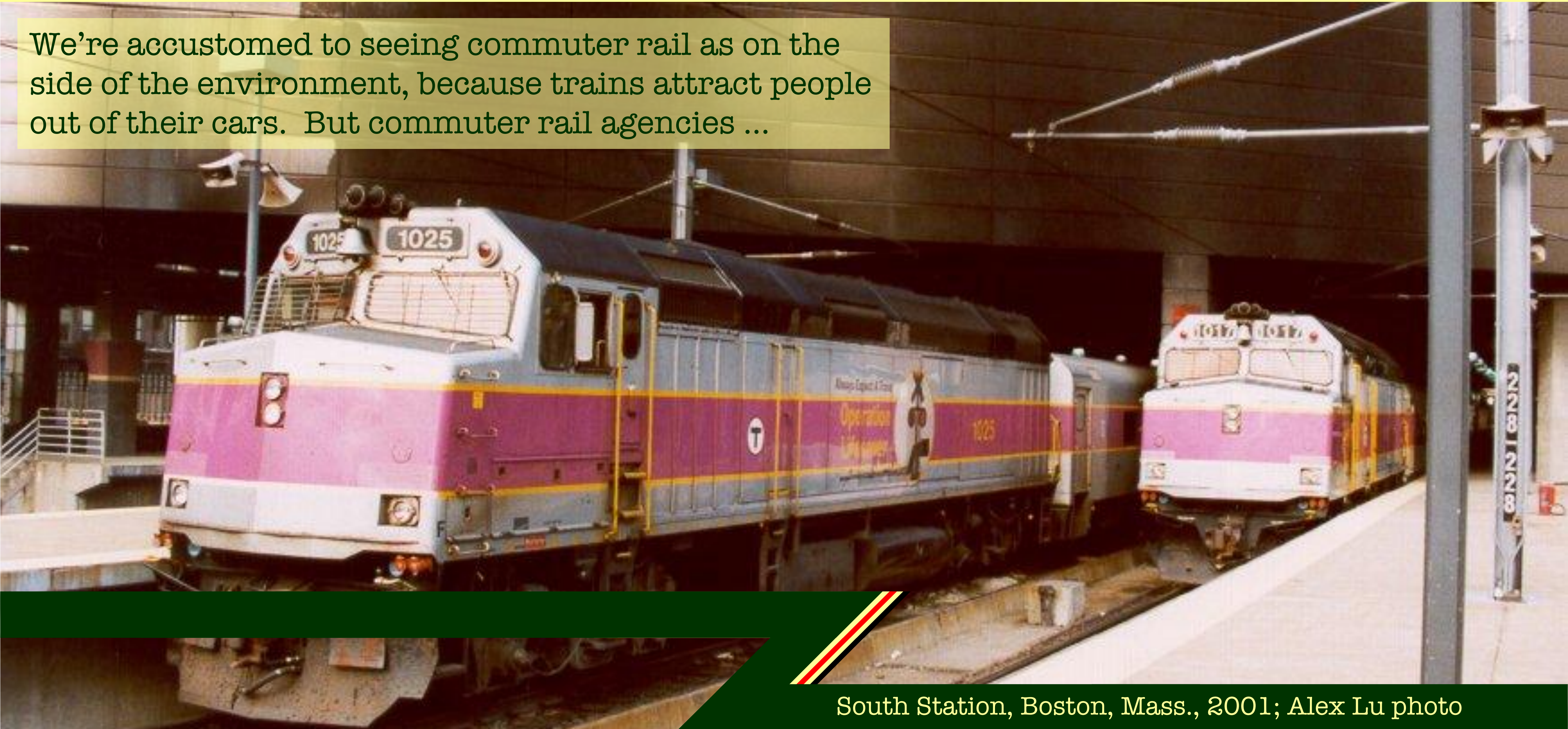
ATTITUDES CHANGING ABOUT FOSSIL FUEL

We see all around us—societal attitudes about fossil fuel are changing. What seemed the norm in recent memory is now coming under critical scrutiny.

LaVergne, Ill., 1999; David Wilson photo (CC BY 2.0)

COMMUTER RAIL: ENVIRONMENTAL GOOD GUYS ?

We're accustomed to seeing commuter rail as on the side of the environment, because trains attract people out of their cars. But commuter rail agencies …



South Station, Boston, Mass., 2001; Alex Lu photo

BUT DIESELS EMIT GREENHOUSE GASES

… are seeing that they have to do more, because diesel locomotives emit greenhouse gases and contribute to climate change.

Chicago Union Station, 2001; Alex Lu photo

SEARCH FOR ALTERNATIVES IS UNDER WAY

So the search is on for alternative propulsion technologies, because the diesel era is pulling out of the station.

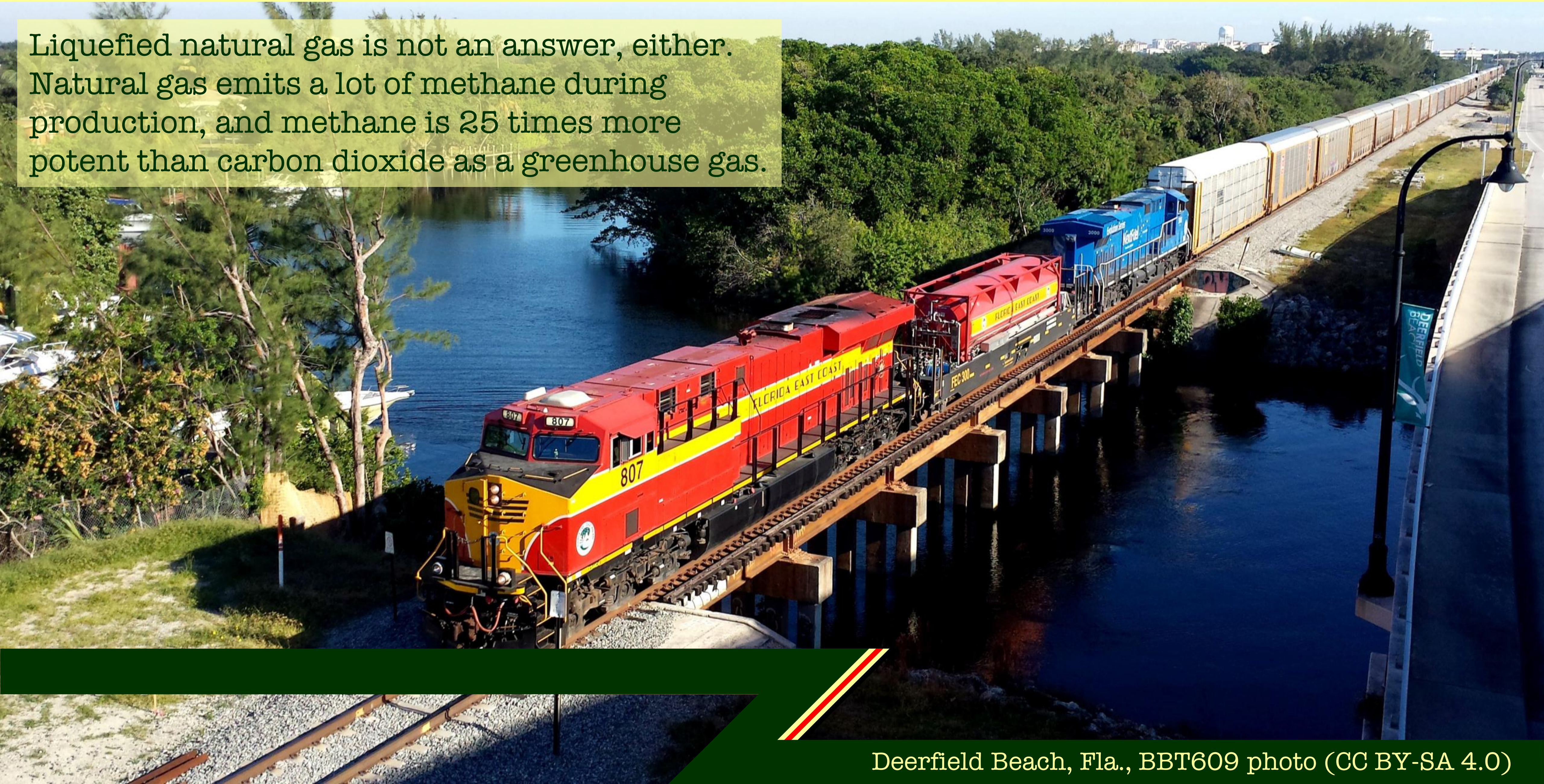
Beverly–107th St., Metra Rock Island, 1998; J. G. Allen photo

GENSETS ?

Although gensets reduce overall emissions at low power, they can consume more fuel at high power and still emit greenhouse gases.

LIQUEFIED NATURAL GAS ?

Liquefied natural gas is not an answer, either. Natural gas emits a lot of methane during production, and methane is 25 times more potent than carbon dioxide as a greenhouse gas.



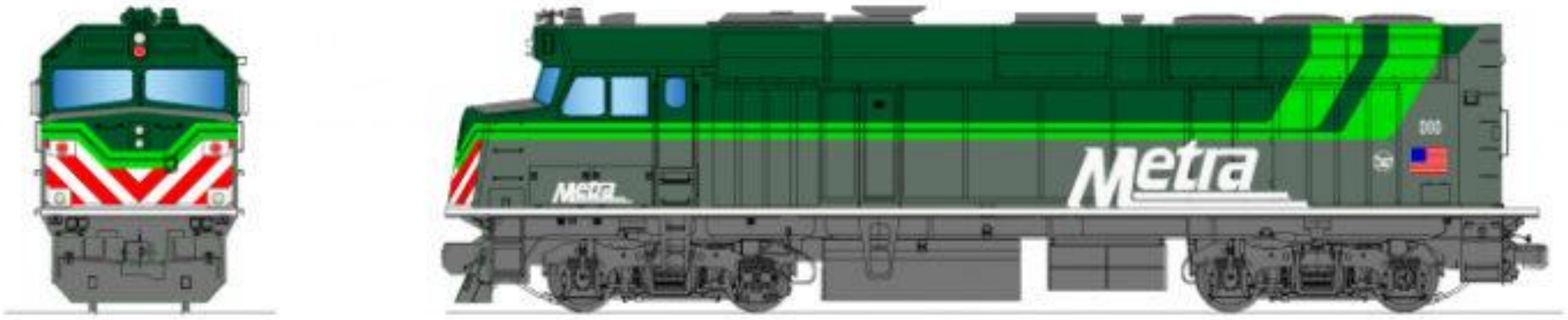
Deerfield Beach, Fla., BBT609 photo (CC BY-SA 4.0)

RENEWABLE DIESEL ?

Some properties now use Renewable Diesel 99, which captures non-fossil-fuel carbon during manufacturing. But it emits carbon dioxide when used, just like regular diesel, and therefore does not actually reduce emissions. At best, this is a net-zero option.

Irvine, Calif., 2010; Brian Zimmerman photo (CC BY 3.0)

BATTERY LOCOMOTIVES ?



Commuter rail agencies are exploring battery power, as with Metra's R.F.P. for converting three diesel locomotives to battery prototypes. Battery locomotives are not fully deployable today, but should be in a few years as development continues.

Artist's Conception, Metra

ELECTRIFICATION ?

Electrification looks like a promising way to go. But it has very high capital costs, and, as with batteries, or hydrogen, may simply be moving emissions from trains to power plants unless the power itself is being generated from non-emitting sources.

Denver A-Line, 2016; Eric Johnson photo (CC BY-SA 3.0)

TRADITIONAL ELECTRIFICATION

Traditional, end-to-end electrification starts with the decision to electrify a particular corridor or zone, so the railroad …

Saga Bridge, Connecticut, 2021; Alex Lu photo

BUILD WHATEVER IT TAKES ?

... then builds whatever infrastructure is needed. We stand this logic on its head, and ask ...

Bryn Mawr, Penn, 2010; Mike Brotzman photo (CC BY-SA 3.0)

MAXIMIZING ELECTRICAL REACH

… how far can one or more substations reach? What is the minimum amount of electrification that we need? What makes this approach possible …

Caltrain Substation 1, 2020; Pi.14159265 photo (CC BY-SA 4.0)

BATTERY-ELECTRICS: DUAL-MODES WITHOUT DIESEL

... is the development of battery-electric locomotives, which will be the dual-mode locomotives of tomorrow. Our calculations suggest that we can replace ...

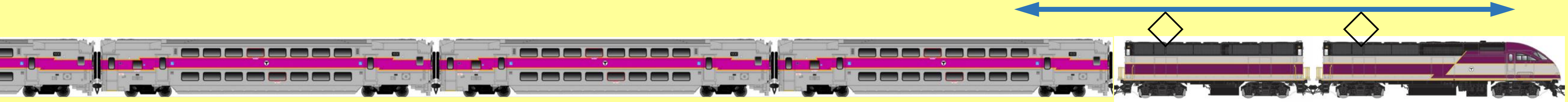
Convent Station, N.J., 2021; Fan Railer photo (CC BY-SA 4.0)

REPLACING DIESELS WITH BATTERY-ELECTRIC ENGINES*

up to seven coaches
about 600-mile range

3,600 hp
diesel-electric

electrify only inner suburban segment (about 25 route miles or 90 minutes charging time each trip)



up to seven coaches
about 60-mile range off-wire

4.8 MWh**
cabless booster

4.8 MWh**
battery locomotive

... a standard 3,600-horsepower diesel-electric with two 4.8 megawatt-hour battery-electrics. This configuration should provide equivalent functionality, if we balance the on-wire and off-wire operations so that the units are sufficiently charged when they leave the electrified zone.

** 4.8 MWh (battery capacity)/1.2 MW (charging)/1.5 MW (traction)/0.4 MW (HEP)

* Platform length issues may arise at very constrained terminal locations.

B.E.L. SUPPORT REQUIREMENTS

- 25kv Electrification (about half the route mileage):
  - Road supply rating for both movement and charging (5 MW/train?)
  - Downtown yard to provide capacity for charging (2.5 MW/train?)
- Battery Locomotives and Tender:
  - Fully charged power units (9.6 MWh?) should be able to operate the full unelectrified zone, return to electrified zone, and still have about 50% charge
- Workshops:
  - Shops need to be able to service battery locomotives
- Shore Power:
  - Shore power at outlying yards must support degraded HEP loads (25 kW/car?), unless the operating plan deadheads locomotives back to the electrified zone

With about half the route-mileage electrified, fully-charged units will be able to operate a round-trip on the unelectrified segment and have sufficient charge to return to the electrified zone, plus a reserve for disruption management. The shops, of course, will have to be able to service battery power.

SHORE POWER

Shore power is needed for weekend layovers at the outer ends, unless we deadhead the locomotives back to the electrified zone.

Port Jervis, N.Y., 2011; Alex Lu photo

STRATEGIES FOR COMMUTER RAIL ELECTRIFICATION

Take Advantage of Commuter Rail's Star Network Topology

Boston Northside Case Study

Use Battery Electric Locomotives to Extend the Reach of Electrification

Boston Northside Case Study

Extend Service Beyond Existing Electrifications with Battery Electric Locomotives

Philadelphia Case Study

Create Trans-Regional Services Spanning Electrified Zones Using Battery Electric Locomotives

Mid-Atlantic Case Study

Take Advantage of Co-located Infrastructure

Chicago North and West Case Study

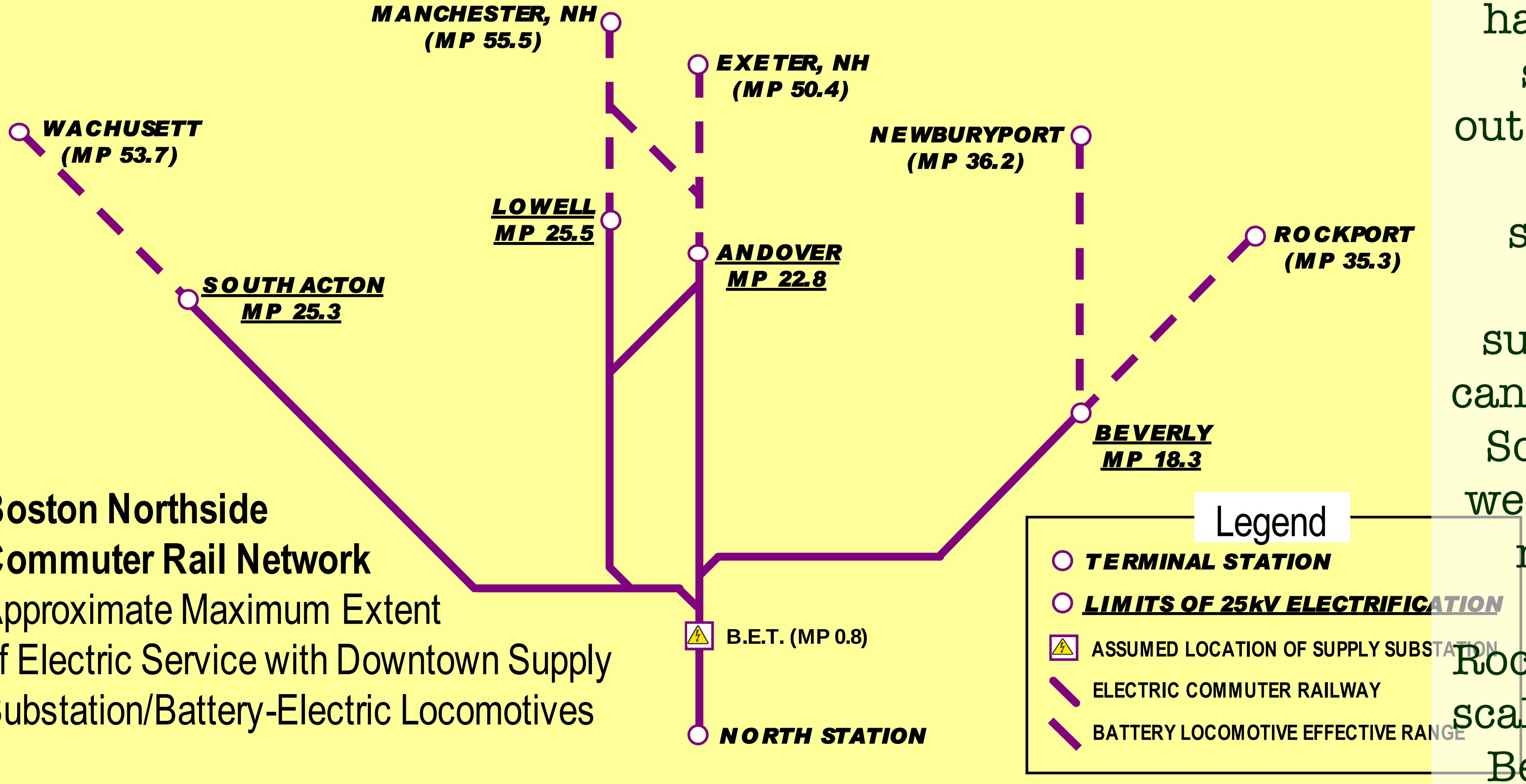
Charging Pads

This makes sense in certain very specific situations.

STRATEGIES FOR COMMUTER RAIL ELECTRIFICATION

Based on these concepts, we devised several strategies that take advantage of the fact that a 25 kV alternating current supply substation has a range of about 25 miles in any direction. For Boston's northside lines, we suggest a basic electrification and how battery-electrics can extend the reach of that electrification. For Philadelphia, we consider how battery-electrics can extend electric service beyond the existing catenary. For Chicago, we look at how co-locating electrification infrastructure off railroad property and using battery-electrics can reduce the cost of electrifying. Finally, charging pads may be useful in limited situations. We examine one such possibility in Minnesota. In all these case studies, we assume that jurisdictional, financial, and ownership issues will be resolved. Our effort is to explore what we expect to be physically workable with battery-electrics.

BOSTON NORTH CASE STUDY



Boston Northside Commuter Rail Network
Approximate Maximum Extent of Electric Service with Downtown Supply Substation/Battery-Electric Locomotives

In Boston, we see what happens when a downtown supply substation pushes out 25 kV AC about 25 miles in any direction. This substation, in conjunction with autotransformer substations along the lines, can power electric service to South Acton and Lowell, as we see on the map. There is not quite enough range to reach Newburyport, Rockport or Haverhill, so we scaled back electrification to Beverly and Andover, with battery-electrics covering the remainder.

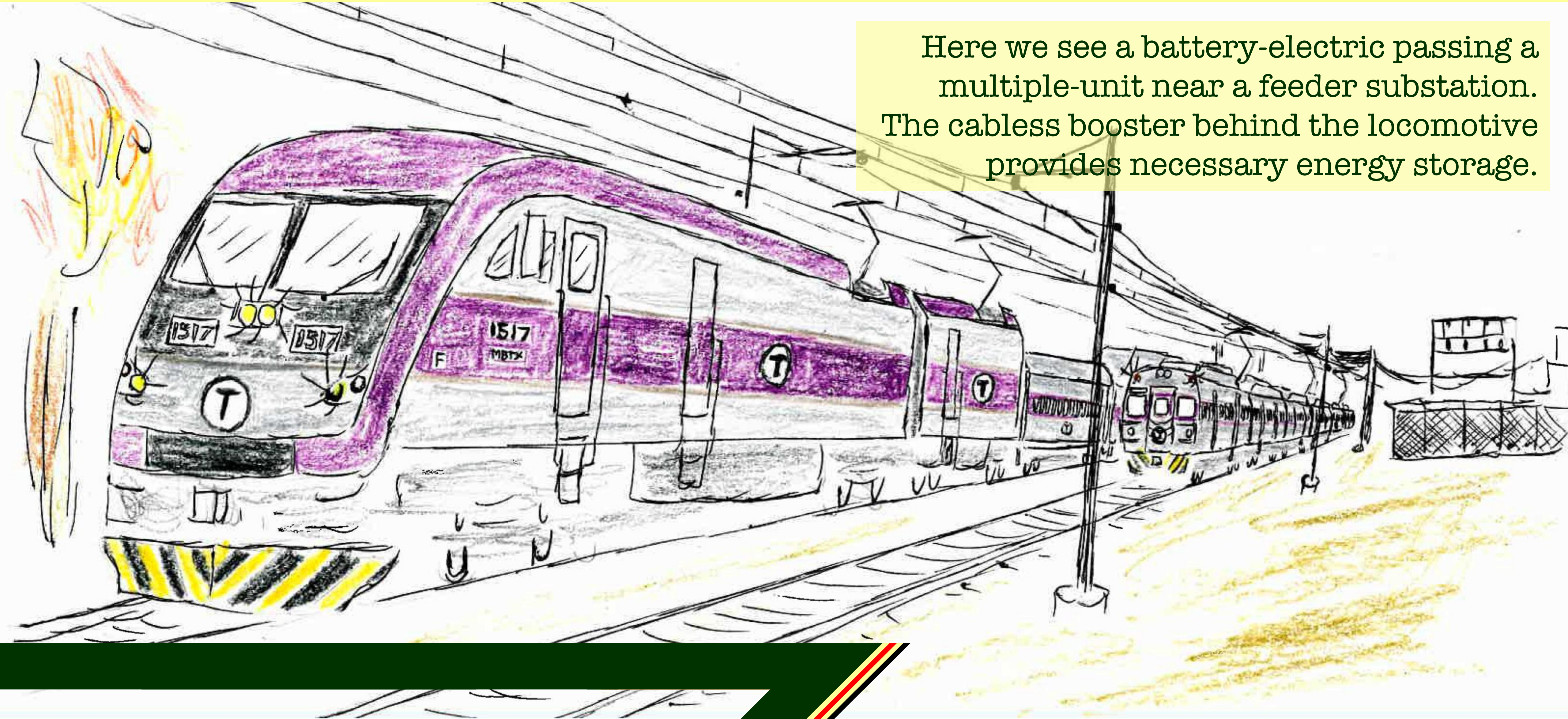
SERVING NEW HAMPSHIRE ?

Battery-electrics also allow us to operate other lines about 50 miles out from Boston—which could restore commuter service to southern New Hampshire.

Boston & Maine, 1969; Roger Puta photo

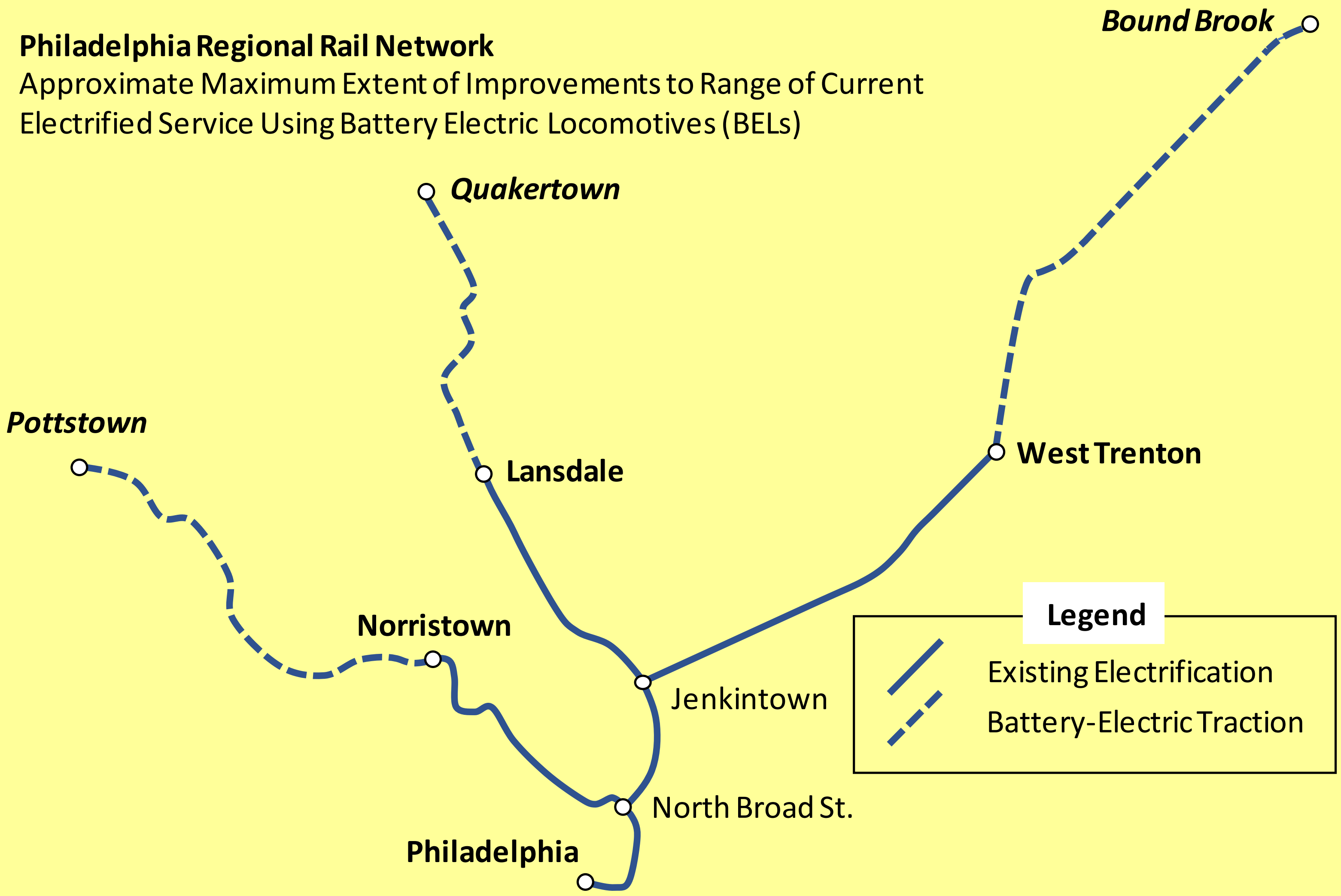
BOSTON NORTH SIDE

Here we see a battery-electric passing a multiple-unit near a feeder substation. The cabless booster behind the locomotive provides necessary energy storage.



Artist's Conception, John G. Allen

PHILADELPHIA CASE STUDY



For Philadelphia, we examined another ability of battery-electrics: to extend the range of existing electrifications. We can operate off-wire on the former Reading side to Pottstown, Quakertown, and Bound Brook ...

POTTSTOWN? BOUND BROOK?

… which had diesel service until the early 1980s. It may be necessary to upgrade the power supplies on the Reading side to meet the needs of locomotives coming inbound off the wire and needing to recharge.

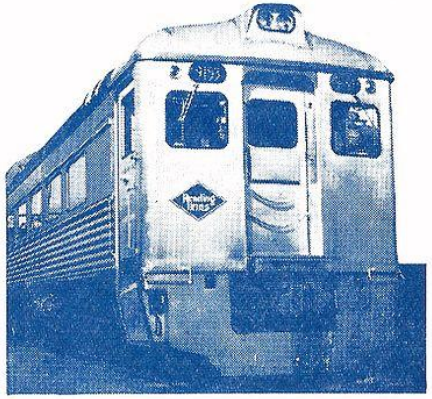
POTTSVILLE—READING PHILADELPHIA

and intermediate stations

READING LINES

EFFECTIVE FEBRUARY 6, 1972

SCHEDULES IN PREVAILING LOCAL TIME



FAST—MODERN

AIR CONDITIONED

T.T. 1 … Printed in U.S.A.

POTTSVILLE & READING TO PHILADELPHIA

MONDAYS THRU FRIDAYS EXCEPT HOLIDAYS

Miles	Fare Zone	Stations	♥ 2	♥ 4	56 6 ⊕	58 8 ⊕	60 10 ⊕	86	88
			AM	AM	AM	AM	PM	PM	PM
.0	15	Pottsville Lv.	......	......	7.18	10.46	1.42	4.48	8.13
4.5	14	Schuylkill Haven	......	......	7.26	10.54	1.50	4.56	8.21
10.1	14	Auburn	......	......	7.34	11.02	1.58	5.03	8.28
18.3	13	Hamburg	......	......	7.47	11.15	2.10	5.14	8.39
23.4	13	Shoemakersville	......	......	7.54	– –	– –	– –	– –
25.0	12	Mohrsville	......	......	7.56	– –	2.19	5.23	– –
27.3	12	Leesport	......	......	8.01	– –	2.23	5.27	– –
35.5	11	Reading (Franklin St.) Ar.	......	......	8.14	11.40	2.36	5.38	9.02
		Reading (Franklin St.) Lv.	5.51	6.49	8.17	11.43	2.39	5.38	9.02
44.1	10	Birdsboro	6.03	7.01	8.29	11.55	2.51	5.50	– –
46.5	10	Monocacy	6.07	– –	– –	– –	– –	– –	– –
53.1	8	Pottstown	6.15	7.12	8.40	12.06	3.02	6.01	9.24
59.2	7	Linfield	6.23	7.20	– –	– –	– –	– –	– –
61.6	7	Royersford	6.28	7.25	8.52	12.18	3.14	6.13	9.36
65.9	6	Phoenixville (Valley Forge Gen'l Hosp. ⊙)	6.36	7.33	9.00	12.26	3.22	6.21	9.44
69.9	5	Valley Forge	6.42	– –	– –	– –	– –	– –	– –
76.4	4	Norristown (De Kalb St.)	6.51	7.46	9.12	12.38	3.34	6.33	9.56
		PHILADELPHIA							
90.7	1	North Broad Street Ar.	7.14	8.11	9.34	1.00	3.56	6.55	10.18
93.6	1	Reading Terminal	7.20	8.18	9.40	1.06	4.02	7.01	10.24
			AM	AM	AM	PM	PM	PM	PM

Bargain tickets good on this train.

PHILADELPHIA TO READING & POTTSVILLE

MONDAYS THRU FRIDAYS EXCEPT HOLIDAYS

Miles	Fare Zone	Stations	♥ 1–51 ⊕	3 53 ⊕	5 55 ⊕	♥ 7	♥ 87	11	89
			AM	AM	PM	PM	PM	PM	PM
		PHILADELPHIA							
.0	1	Reading Terminal Lv.	6.23	10.00	1.00	4.37	5.28	7.00	9.30
2.9	1	North Broad Street	6.30	10.06	1.06	4.43	5.34	7.06	9.36
17.2	4	Norristown (De Kalb St.)	7.04	10.33	1.29	5.07	5.56	7.28	9.59
23.7	5	Valley Forge	– –	– –	– –	5.15	– –	7.36	– –
27.7	6	Phoenixville (Valley Forge Gen'l Hosp. ⊙)	7.16	10.45	1.41	5.21	6.08	7.42	10.11
32.0	7	Royersford	7.24	10.53	1.49	5.29	6.16	7.50	10.19
34.4	7	Linfield	7.29	– –	– –	5.34	– –	– –	– –
40.5	8	Pottstown	7.37	11.05	2.01	5.44	6.28	8.02	10.31
47.1	10	Monocacy	– –	– –	– –	– –	– –	u8.10	– –
49.5	10	Birdsboro	7.48	11.16	2.12	5.55	6.39	8.14	u10.42
58.1	11	Reading (Franklin St.) Ar.	8.01	11.29	2.25	6.09	6.52	8.27	10.55
		Reading (Franklin St.) Lv.	8.19	11.45	2.41	......	6.52	......	10.55
66.3	12	Leesport	– –	– –	– –	......	7.11	......	11.11
68.6	12	Mohrsville	8.35	– –	– –	......	7.15	......	– –
70.2	13	Shoemakersville	– –	– –	– –	......	7.18	......	– –
75.3	13	Hamburg	8.44	12.10	3.06	......	7.25	......	11.23
83.5	14	Auburn	8.56	12.22	3.18	......	7.37	......	11.34
89.1	14	Schuylkill Haven	9.03	12.29	3.25	......	7.44	......	11.41
93.6	15	Pottsville Ar.	9.11	12.37	3.33	......	7.52	......	11.49
			AM	PM	PM	PM	PM	PM	PM

SATURDAY, SUNDAY AND HOLIDAY TRAINS SHOWN ON OTHER SIDE

NEWARK, N. J. to BELLE MEAD—PHILADELPHIA

(With connections from New York)

Effective September 30, 1974

SCHEDULES IN PREVAILING LOCAL TIME

STATIONS	Mondays-Fridays Except Holidays: 5619 CRUSADER	Mondays-Fridays Except Holidays: 5621 WALL STREET	Washington's Birthday and Good Friday: 5621 WALL STREET
	★ PM	★ PM	★ PM
NEW YORK (Penna. Sta.) Lv.	4.32	5.19	5.14
Newark (Penn Central Sta.) Ar.	4.48	5.35	5.29
NEW YORK (PATH) (World Trade Center) Lv.	4.25	5.19	5.19
Newark (PATH) Ar.	4.43	5.38	5.38
Newark (Penn Central Sta.) via C.R.R.N.J. Lv.	4.54	5.45	5.45
Cranford "	r 4.51	- -	r 5.40
Westfield "	r 4.57	- -	r 5.44
Plainfield "	r 5.09	r 5.52	r 5.54
Bound Brook "	a 5.28	a 6.18	a 6.16
Belle Mead Lv.	5.40	6.30	6.27
Hopewell "	5.49	6.39	6.36
West Trenton Ar.	6.01	6.50	6.47
Yardley "	b 6.06	b 6.59	b 6.59
Langhorne "	b 6.15	b 7.08	b 7.08
Somerton "	b 6.24	b 7.17	b 7.18
Philmont "	b 6.27	b 7.20	b 7.21
Bethayres "	b 6.30	b 7.22	b 7.23
Jenkintown "	6.23	7.12	7.07
Elkins Park "	6.26	7.15	7.10
Melrose Park "	6.28	7.17	7.12
Wayne Junction "	6.33	7.22	7.18
North Broad Street "	6.37	7.26	7.23
READING TERM. (Phila.) Ar	6.43 PM	7.32 PM	7.29 PM

NO SATURDAY, SUNDAY OR HOLIDAY SERVICE

FOR EXPLANATION OF REFERENCE MARKS SEE OTHER SIDE

Holidays—The term "Holidays" as used in this time table refers to New Year's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving Day, Christmas Day or days celebrated as such.

REFRESHMENT CAR

Serving coffee, Juice and pastry on morning trips and beverages on afternoon trips.

Reading Co.-CRRofNJ-PATH and Penn Central cannot assume responsibility for errors in time tables or for inconvenience resulting from delayed trains or failure to make connections. Schedules are subject to change without notice.

H. J. PALMER
Director of Passenger Services
Reading Term., Phila., Pa. 19107

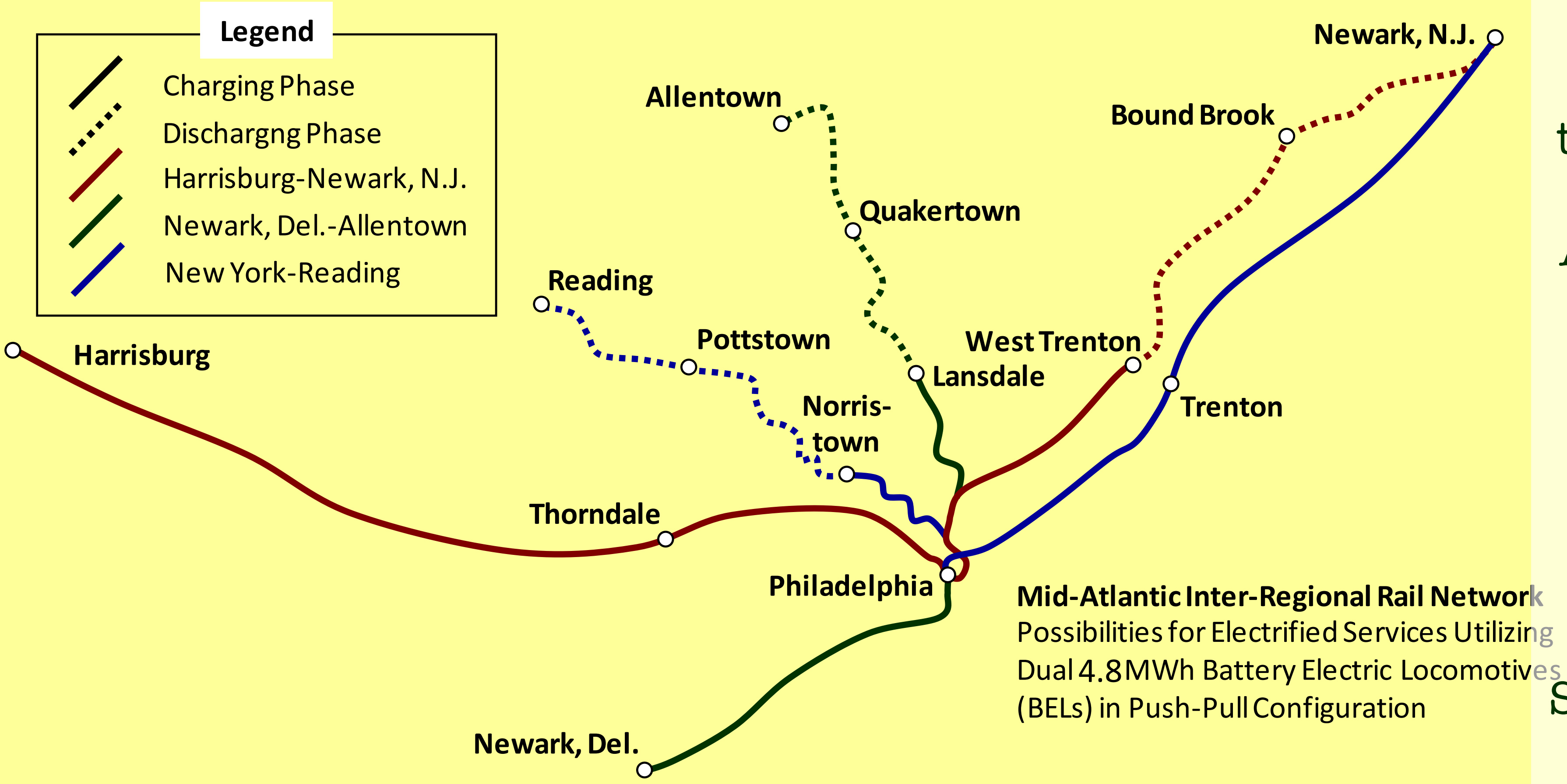
B. C. STAMETS, Manager Psgr. Operations Central R. R. Co., of New Jersey, 1100 Raymond Blvd., Newark, N. J. 07102

Reading Railway System
Central R.R. Co. of New Jersey

T.T. 4 145 ALS LRt. 9-30-74

Reading Lines/Central of N.J., 1972/1974 (rights expired)

MID-ATLANTIC CASE STUDY



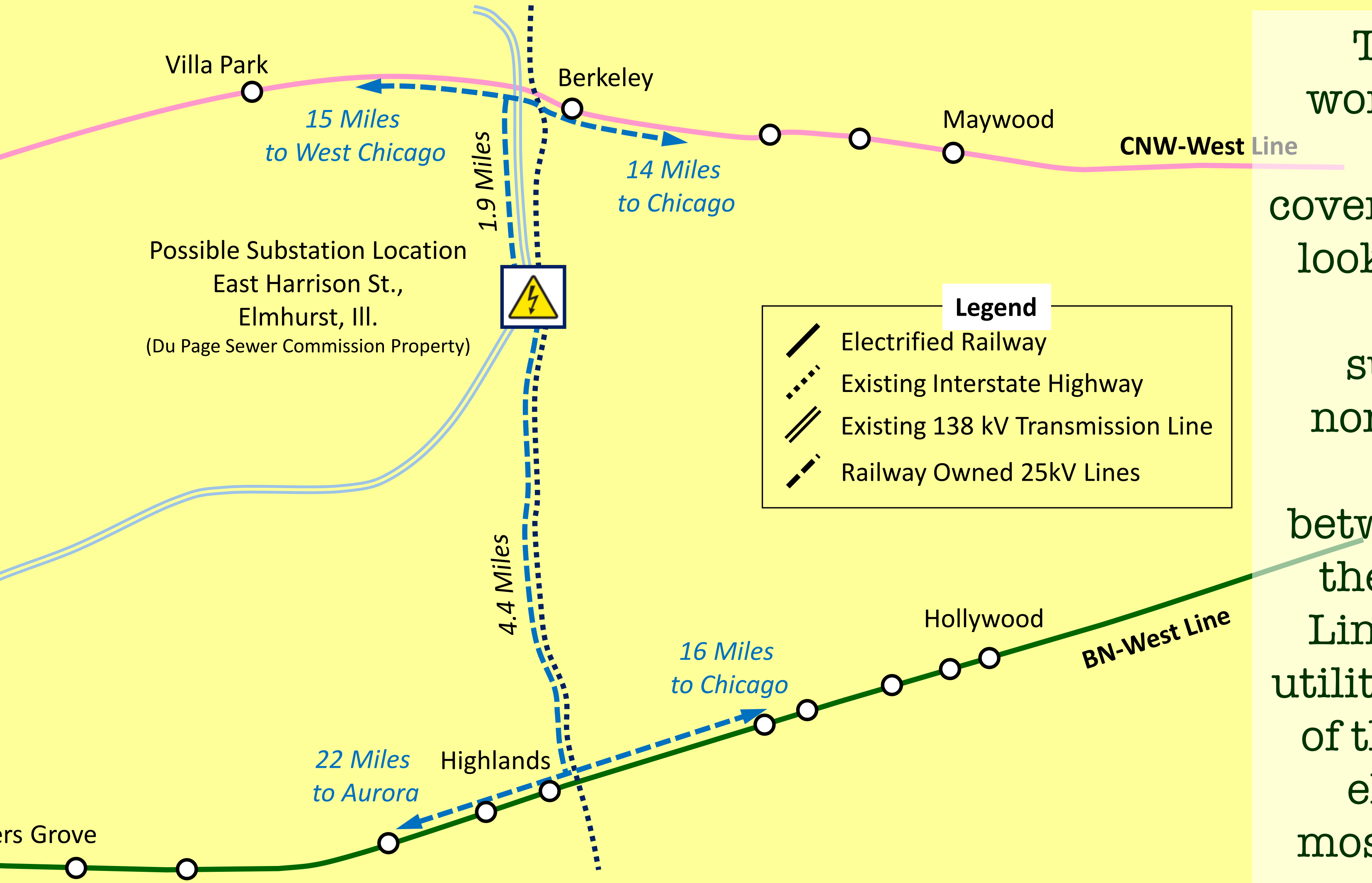
If trains spend enough time under the wire to recharge their batteries, we could take things even further, as with this proposed Mid-Atlantic Inter-Regional Rail system. Note that the line from Quakertown to Allentown has been abandoned and would need to be restored. Reading-side trains could reach the upper level at 30th Street Station via Market East and Suburban Stations, or go off-wire near Wayne Junction to reach Zoo Interlocking and the lower level at 30th Street.

PHILADELPHIA: READING SIDE

We're looking north along the Reading Trunk approaching Wayne Junction. A Mid-Atlantic Regional is coming off the wire to take the freight line to reach the lower level of 30th Street Station. On the right, we have a multiple-unit train. These will continue to provide most of the service.

Artist's Conception, John G. Allen

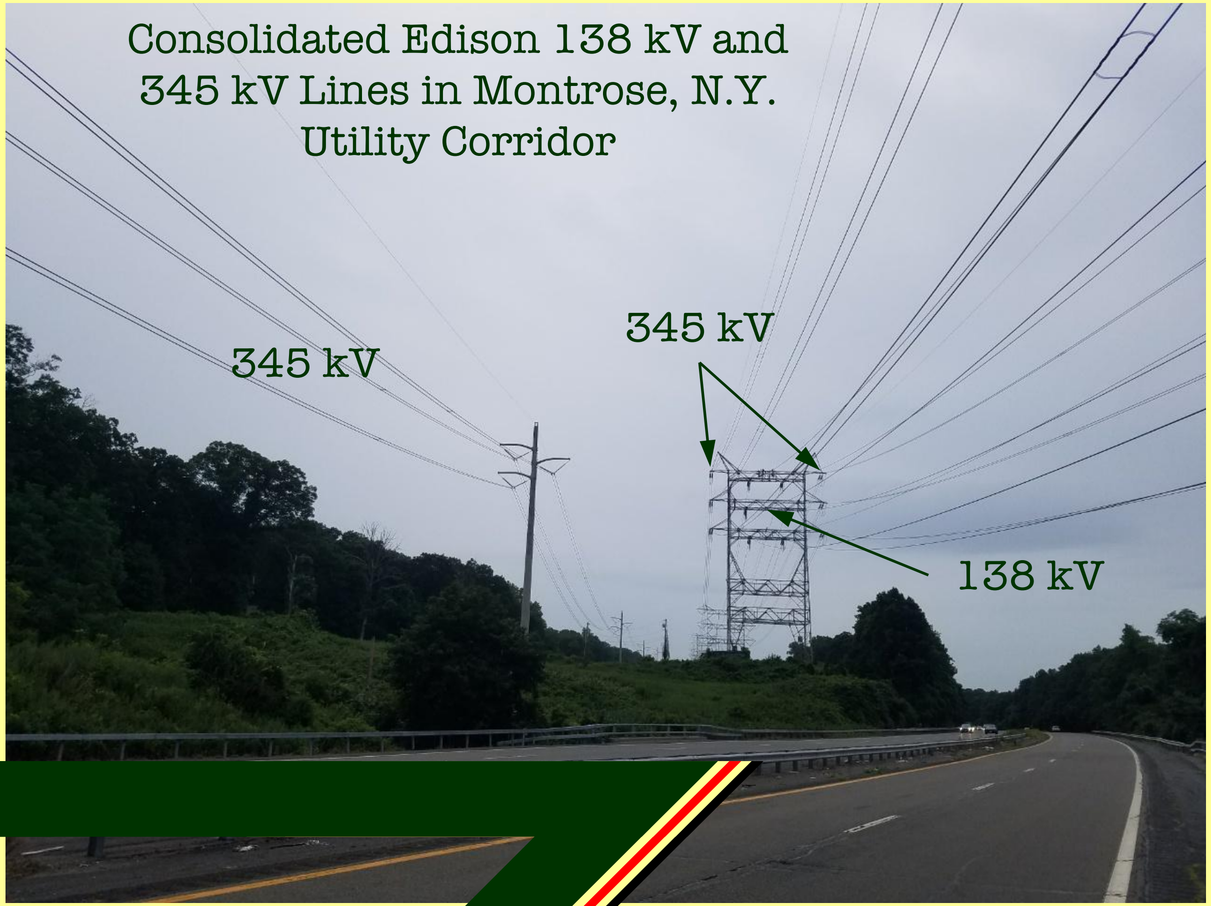
CHICAGO WEST SUBURBS



The downtown substation strategy works well for compact metropolitan areas. But 25 miles simply won't cover enough ground in Chicago, so we looked for another way to electrify as much as possible with a single substation. The key here is finding non-railroad alignments to carry the power. We locate a substation between the Burlington Northern and the Chicago & North Western's West Line, and get it to both railroads on a utility right-of-way. Taking advantage of the roughly 25-mile radius, we can electrify the Burlington—one of the most intensively-traveled lines in the country—in its entirety, and the CNW West Line to the yard at West Chicago.

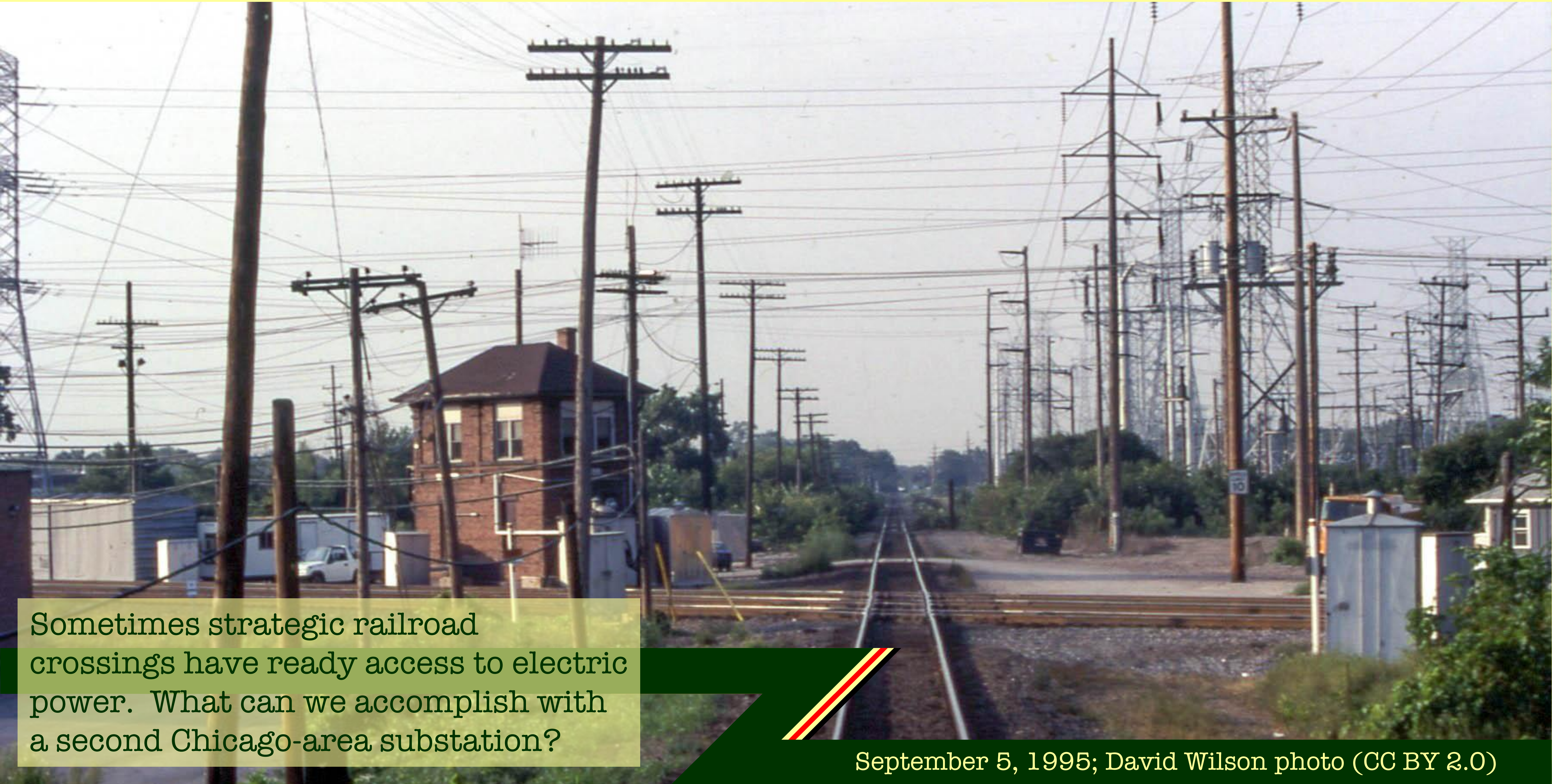
SUBURBAN UTILITY CORRIDORS

A railroad substation can tap a 69 kV or 138 kV line directly if there's capacity. Modern European railway substations now tap the 345 kV or even 500 kV supergrid directly, which has a much greater capacity to absorb power imbalances. A railroad-owned line could connect utility taps to the railroad substation or supply points along the high-voltage utility corridor.



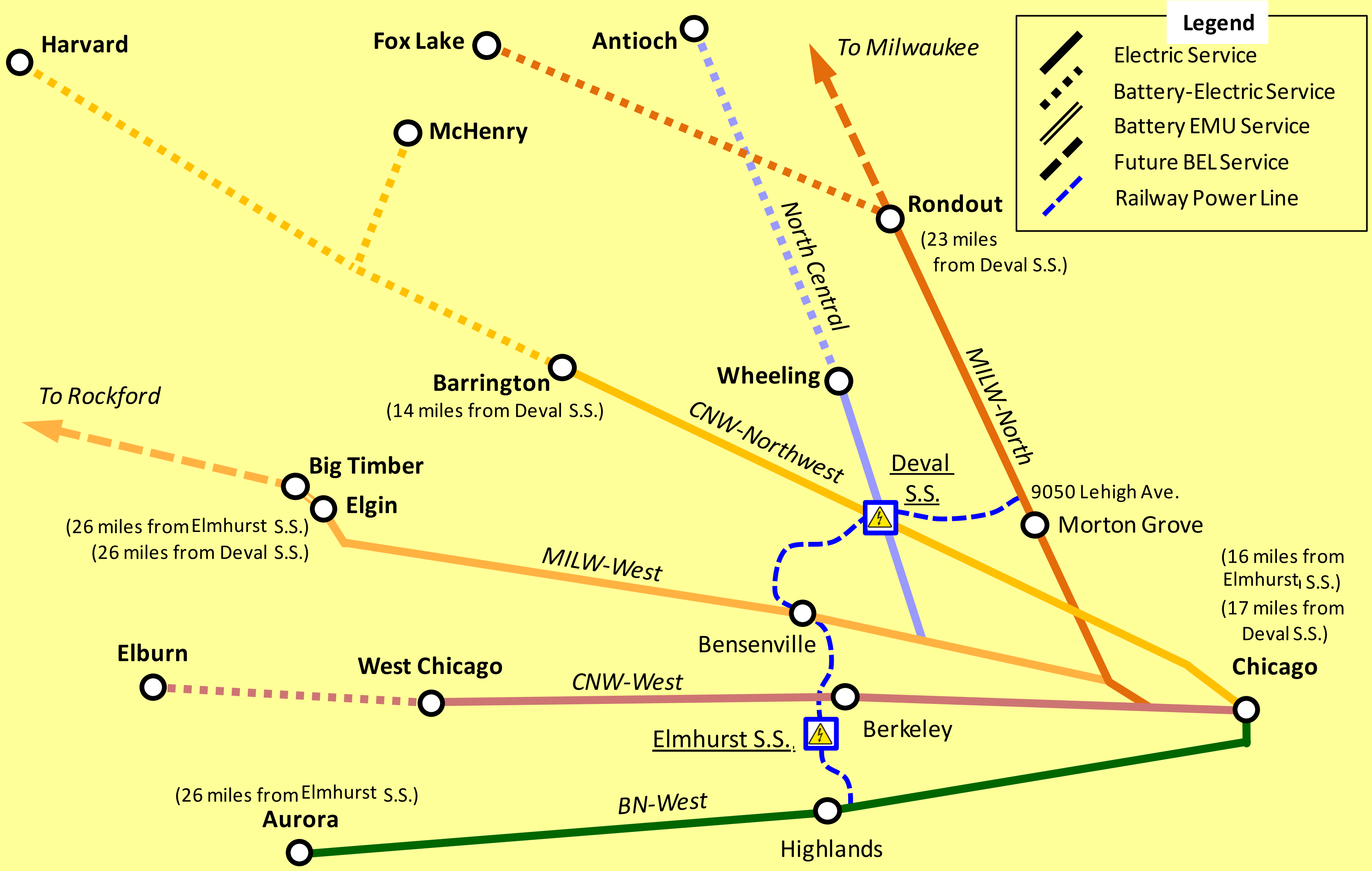
Alex Lu photos

DEVAL CROSSING

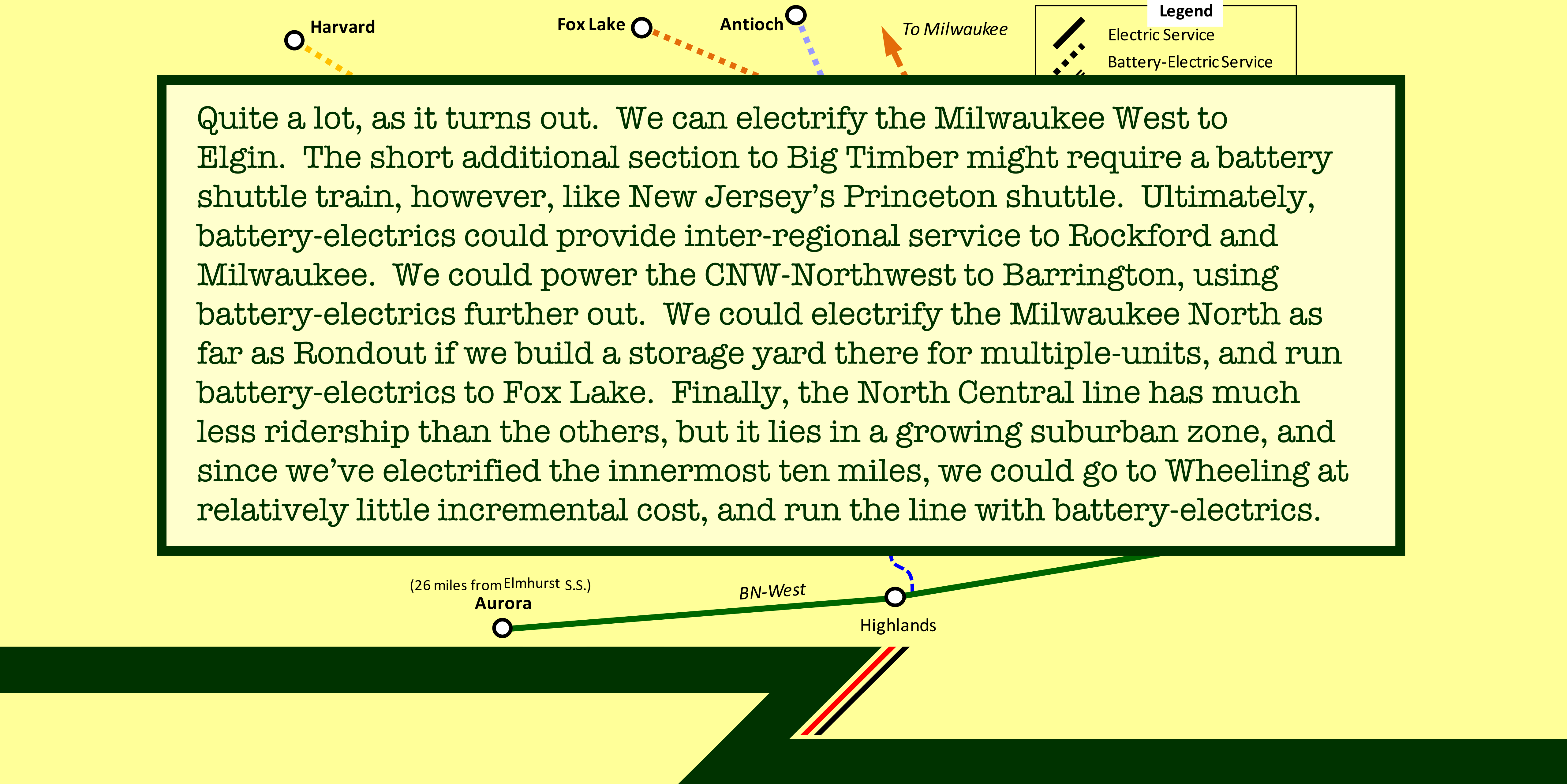


Sometimes strategic railroad crossings have ready access to electric power. What can we accomplish with a second Chicago-area substation?

CHICAGO NORTH AND WEST



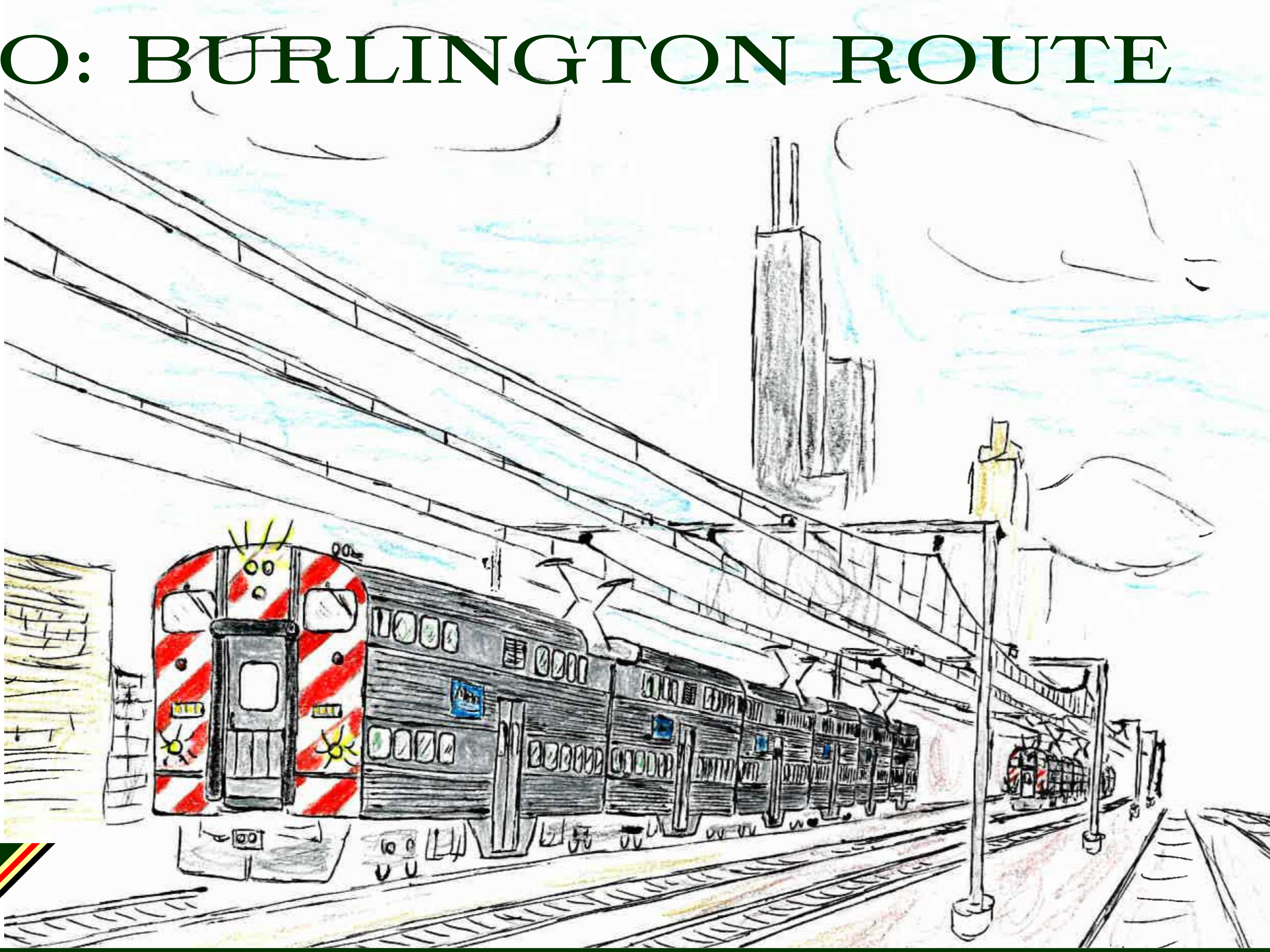
CHICAGO NORTH AND WEST



Quite a lot, as it turns out. We can electrify the Milwaukee West to Elgin. The short additional section to Big Timber might require a battery shuttle train, however, like New Jersey's Princeton shuttle. Ultimately, battery-electrics could provide inter-regional service to Rockford and Milwaukee. We could power the CNW-Northwest to Barrington, using battery-electrics further out. We could electrify the Milwaukee North as far as Rondout if we build a storage yard there for multiple-units, and run battery-electrics to Fox Lake. Finally, the North Central line has much less ridership than the others, but it lies in a growing suburban zone, and since we've electrified the innermost ten miles, we could go to Wheeling at relatively little incremental cost, and run the line with battery-electrics.

CHICAGO: BURLINGTON ROUTE

That's not bad for just two supply substations. We envision the Burlington Northern with multiple units, as shown here. Same with the Milwaukee West.



Artist's Conception, John G. Allen

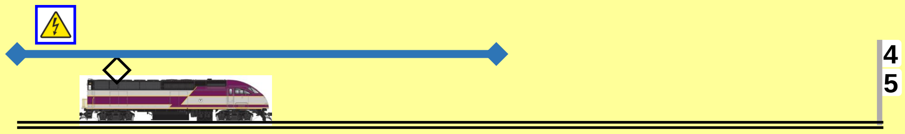
CHICAGO: C&NW NORTHWEST

Elsewhere, we envision a combination of battery-electrics and multiple-units, as we see here on the CNW Northwest Line near downtown Chicago.

Artist's Conception, John G. Allen

CHARGING PADS

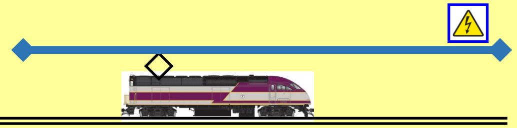
- If downtown-end electrification cannot be extended; or
- If service frequency is sparse and no existing shore power is available



45-mile route, 25 miles electrified, supply substation at MP 1: **no charging pad needed.**

70-mile route, 40 miles electrified, supply substation at MP 21: **no pad needed.**

95-mile route, 50 miles electrified, two supply substations: **no pad needed.**

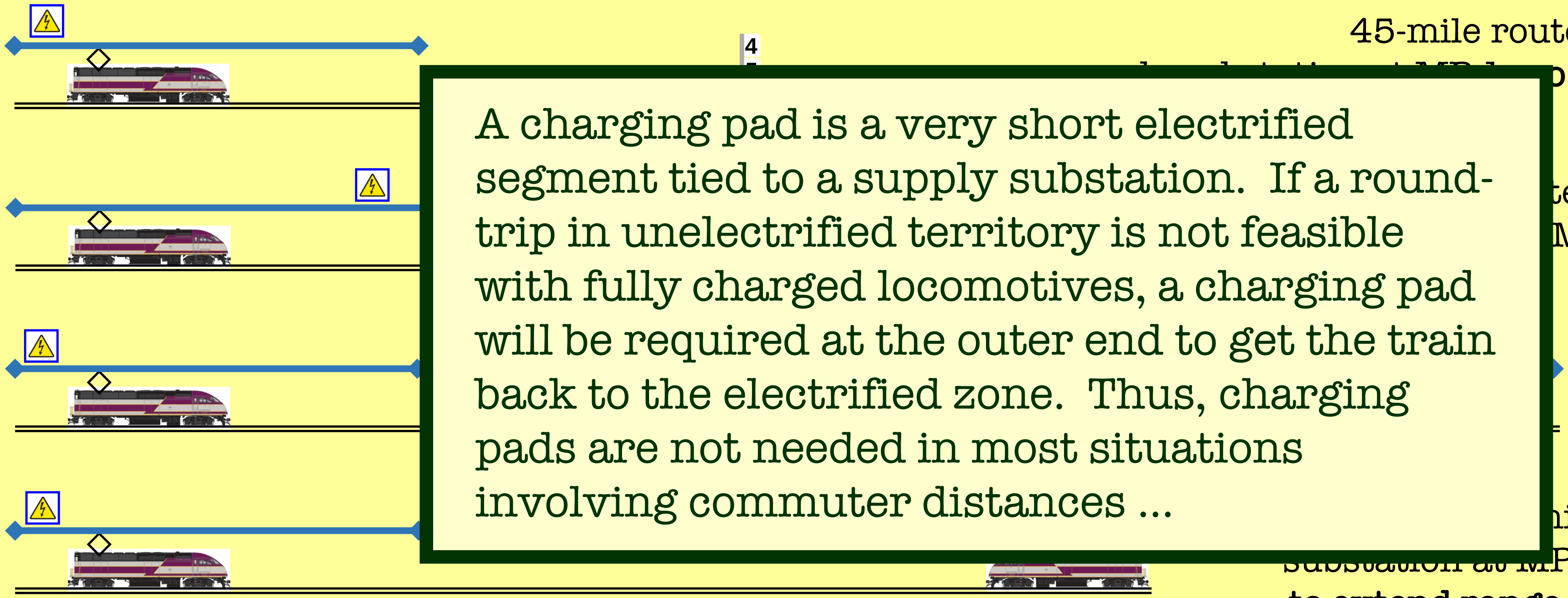


70-mile route, 25 miles electrified, supply substation at MP 1: **need charging pad to extend range of BELs to end of line.**

A charging pad is equivalent to a very short electrified segment tied to an additional substation.

CHARGING PADS

- If downtown-end electrification cannot be extended; or
- If service frequency is sparse and no existing shore power is available



45-mile route, 25 miles electrified,
o **charging pad needed.**

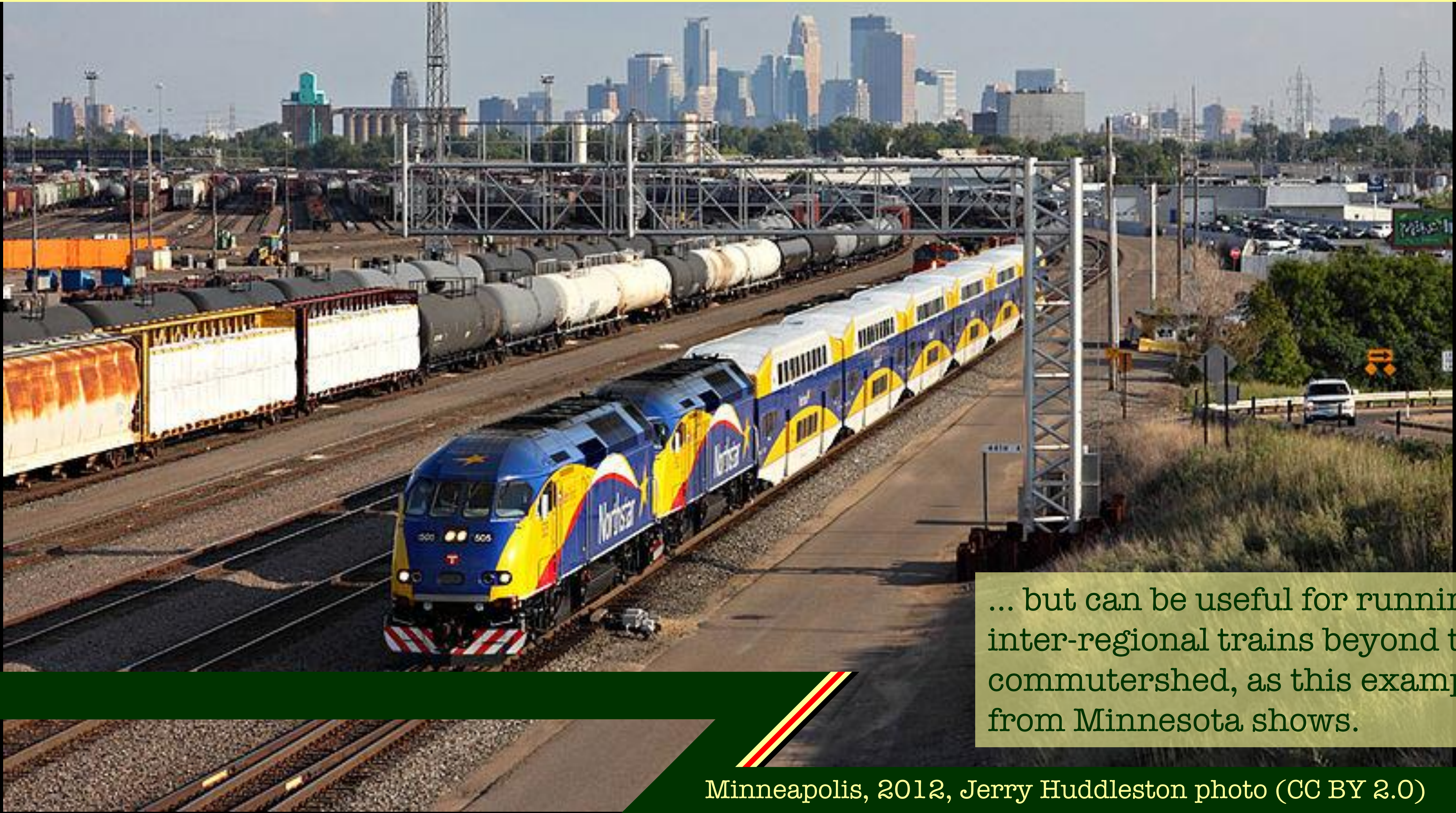
te, 40 miles electrified,
MP 21: **no pad needed.**

A charging pad is a very short electrified segment tied to a supply substation. If a round-trip in unelectrified territory is not feasible with fully charged locomotives, a charging pad will be required at the outer end to get the train back to the electrified zone. Thus, charging pads are not needed in most situations involving commuter distances …

niles electrified, supply
P 1: **need charging pad**
to extend range of BELs to end of line.

A charging pad is equivalent to a very short electrified segment tied to an additional substation.

CHARGING PAD CASE STUDY

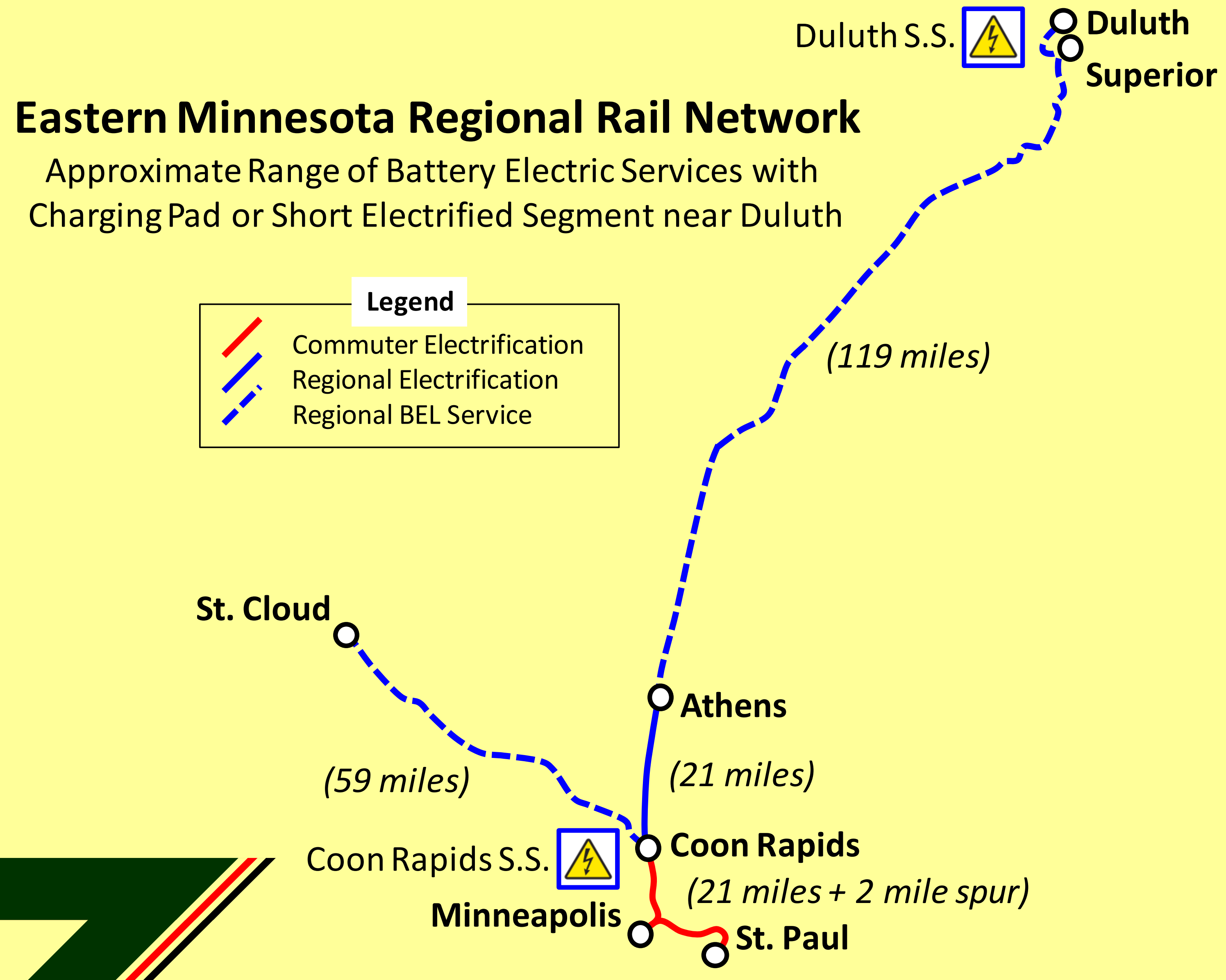


... but can be useful for running inter-regional trains beyond the commutershed, as this example from Minnesota shows.

Minneapolis, 2012, Jerry Huddleston photo (CC BY 2.0)

TWIN CITIES TO DULUTH?

Suppose we build 23 miles of electrification south from a substation in the northern suburbs. It would allow us to get battery-electric commuter trains running between St. Paul and St. Cloud, provided that the set makes every other round trip entirely within the electrified and most heavily traveled part of the line south of Coon Rapids, to allow sufficient time for charging. If we electrify an additional 21 miles on a new, northerly route to Athens, we could get an inter-regional train to Duluth, provided that a charging pad is installed at Duluth to replenish the batteries to get the train back to the Twin Cities metropolitan area.



LEGACY ELECTRIFICATIONS

The main advantage of 25 kV AC is that you can get power about 25 miles in any direction from a supply substation. However, battery-electrics will work with legacy electrifications at lower voltages, although more current will be needed to provide the same power.

Flushing, N.Y., 2008, Adam Moreira photo (CC BY-SA 3.0)

SAMPLE OPERATING PLAN

Set			C	A	B	C	D	E	A	B	D	A	B	C	E	D	A	C
Train #	**Schd Time**	**Miles**	DH 5799	700	702	704	706	708	710	712	714	711	716	718	720	715	722	798
Town E/Yard				**5:30**	**6:05**	**6:35**	**7:05**	**7:35**	**9:00**	**10:35**	**12:35**		**15:05**	**15:35**	**16:05**		**19:05**	**22:35**
Town D	15	10.0		5:45	6:20	6:50	7:20	7:50	9:15	10:50	12:50		15:20	15:50	16:20		19:20	22:50
Town C	13	8.7		5:58	6:33	7:03	7:33	8:03	9:28	11:03	13:03		15:33	16:03	16:33		19:33	23:03
Begin Electrification	10	6.7		6:08	6:43	7:13	7:43	8:13	9:38	11:13	13:13		15:43	16:13	16:43		19:43	23:13
Town B	7	4.7		6:15	6:50	7:20	7:50	8:20	9:45	11:20	13:20		15:50	16:20	16:50		19:50	23:20
Town A	10	6.7		6:25	7:00	7:30	8:00	8:30	9:55	11:30	13:30		16:00	16:30	17:00		20:00	23:30
Downtown	20	13.3		**6:45**	**7:20**	**7:50**	**8:20**	**8:50**	**10:15**	**11:50**	**13:50**		**16:20**	**16:50**	**17:20**		**20:20**	**23:50**
Layover	**5**		4:25	6:50	7:25	7:55	8:25	8:55	10:20	11:55	13:55	15:55	16:25	16:55	17:25	17:55	20:25	23:55
Downtown	**35**		**5:00**	**7:25**	**8:00**	**8:30**	**9:00**	**9:30**		**12:30**		**16:30**	**17:00**	**17:30**	**18:00**	**18:30**	**21:00**	
Town A	20	13.3	5:20	7:45	8:20	8:50	9:20	9:50		12:50		16:50	17:20	17:50	18:20	18:50	21:20	
Town B	10	6.7	5:30	7:55	8:30	9:00	9:30	10:00		13:00		17:00	17:30	18:00	18:30	19:00	21:30	
End Electrification	7	4.7	5:37	8:02	8:37	9:07	9:37	10:07		13:07		17:07	17:37	18:07	18:37	19:07	21:37	
Town C	10	6.7	5:47	8:12	8:47	9:17	9:47	10:17		13:17		17:17	17:47	18:17	18:47	19:17	21:47	
Town D	13	8.7	6:00	8:25	9:00	9:30	10:00	10:30		13:30		17:30	18:00	18:30	19:00	19:30	22:00	
Town E/Yard	**15**	**10.0**	**6:15**	**8:40**	**9:15**	**9:45**	**10:15**	**10:45**		**13:45**		**17:45**	**18:15**	**18:45**	**19:15**	**19:45**	**22:15**	
Next Train #			704	710	712	718	714	720		716		722	702	798	708	706	700	
Repeat Time			6:35	9:00	10:35	15:35	12:35	16:05		15:05		19:05	6:05	22:35	7:35	7:05	5:30	
Layover Time			0:20	0:20	1:20	5:50	2:20	5:20		1:20		1:20	11:50	3:50	12:20	11:20	7:15	
CDMI/Toilet						X		X					X			X	X	
Charging Time			6:24	1:54	1:54	1:54	1:54	1:54		1:54		7:29	1:54	1:54	1:54	5:54	1:54	

We created a sample operating plan to test the parameters of battery-electric service on a hypothetical 50-mile line, half of which is electrified.

Manipulations: Downtown step-up; C/D/E or A/B swaps at outlying yard; A, C, D recharge cycles.

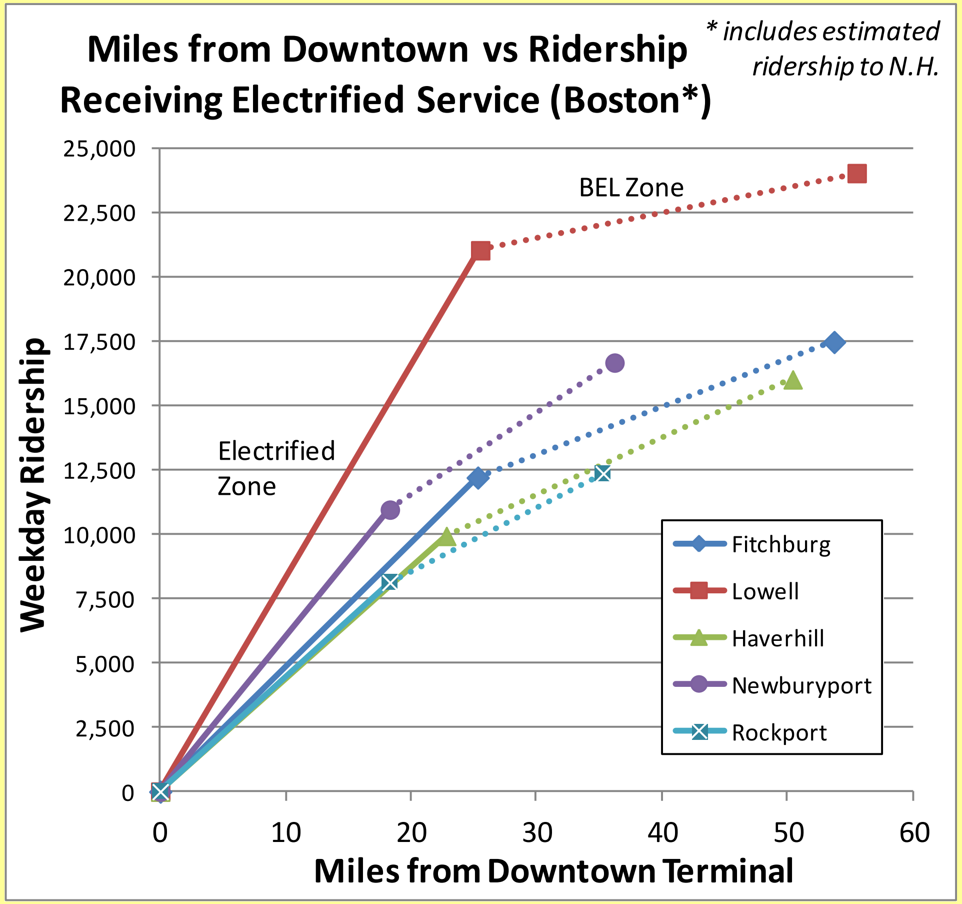
BATTERY CHARGE FORECAST

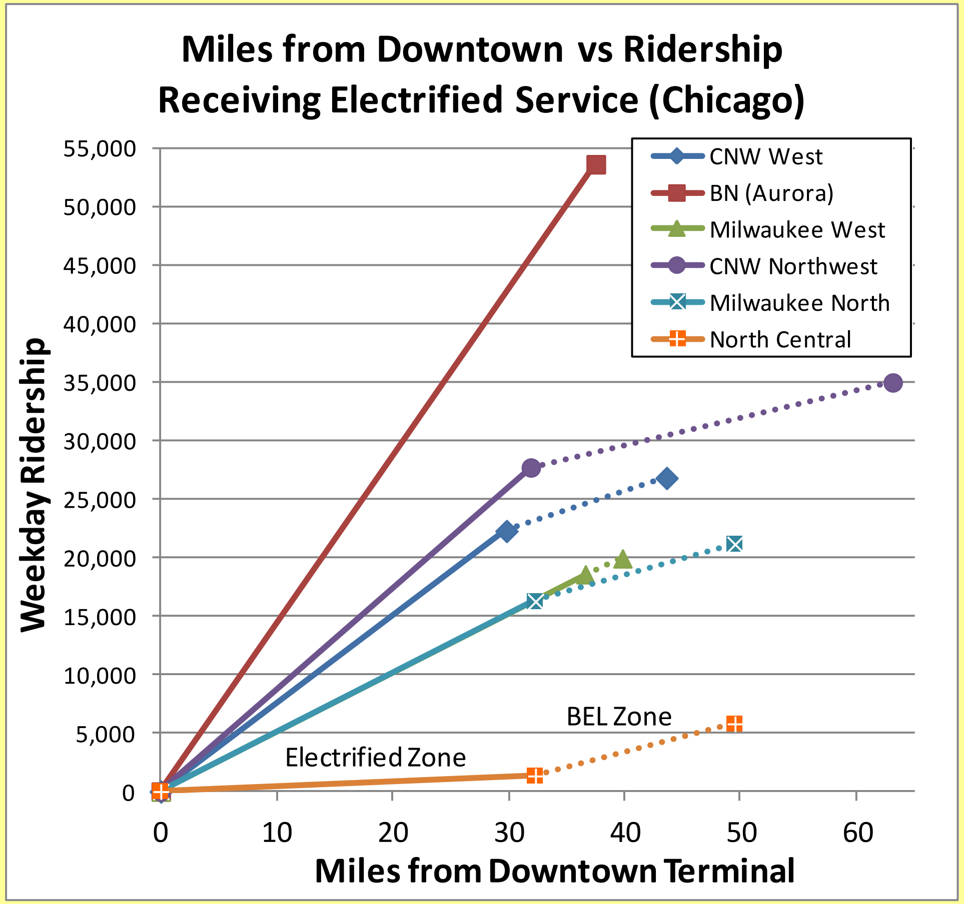
Set			C	A	B	C	D	E	A	B	D	A	B	C	E	D	A	C
Train #	Schd Time	Miles	DH 5799	700	702	704	706	708	710	712	714	711	716	718	720	715	722	798
Town E/Yard				70%	56%	90%	58%	55%	90%	87%	80%		87%	74%	75%		87%	80%
Town D	15	10.0		66%	53%	86%	54%	51%	86%	83%	77%		83%	70%	72%		83%	76%
Town C	13	8.7		63%	50%	83%	51%	48%	83%	80%	73%		80%	67%	69%		80%	73%
Begin Electrification	10	6.7		**61%**	**47%**	**81%**	**49%**	**46%**	**81%**	**78%**	**71%**		**78%**	**65%**	**66%**		**78%**	**71%**
Town B	7	4.7		63%	50%	84%	52%	49%	84%	81%	74%		81%	68%	69%		81%	73%
Town A	10	6.7		68%	54%	88%	56%	53%	88%	85%	78%		85%	72%	73%		85%	78%
Downtown	20	13.3		76%	63%	96%	64%	61%	96%	93%	86%		93%	80%	82%		93%	86%
Layover	5		100%	78%	65%	98%	66%	63%	98%	95%	89%	100%	95%	82%	84%	100%	95%	88%
Downtown	35		100%	93%	79%	100%	81%	78%		100%		100%	100%	97%	98%	100%	100%	
Town A	20	13.3	100%	100%	88%	100%	89%	86%		100%		100%	100%	100%	100%	100%	100%	
Town B	10	6.7	100%	100%	92%	100%	93%	90%		100%		100%	100%	100%	100%	100%	100%	
End Electrification	7	4.7	**100%**	**100%**	**100%**	**100%**	**96%**	**100%**		**100%**		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	
Town C	10	6.7	98%	98%	98%	98%	94%	98%		98%		98%	98%	98%	98%	98%	98%	
Town D	13	8.7	94%	94%	94%	94%	91%	94%		94%		94%	94%	94%	94%	94%	94%	
Town E/Yard	15	10.0	91%	91%	91%	91%	87%	91%		91%		91%	91%	91%	91%	91%	91%	
Next Train #																		
Repeat Time			90%	90%	87%	74%	80%	75%		87%		87%	56%	80%	55%	58%	70%	
Layover Time																		
CDMI/To																		
Charging																		

At no point did any trains begin a run with less than 55% charge after laying over for the night, or enter the electrified zone with less than 49%. But for weekends, it would be necessary to deadhead back to the electrified zone, or provide shore power at the outer end.

Power Assumptions: 1.39 MW working average; 0.28 MW HEP only; 2.4 MW charging.

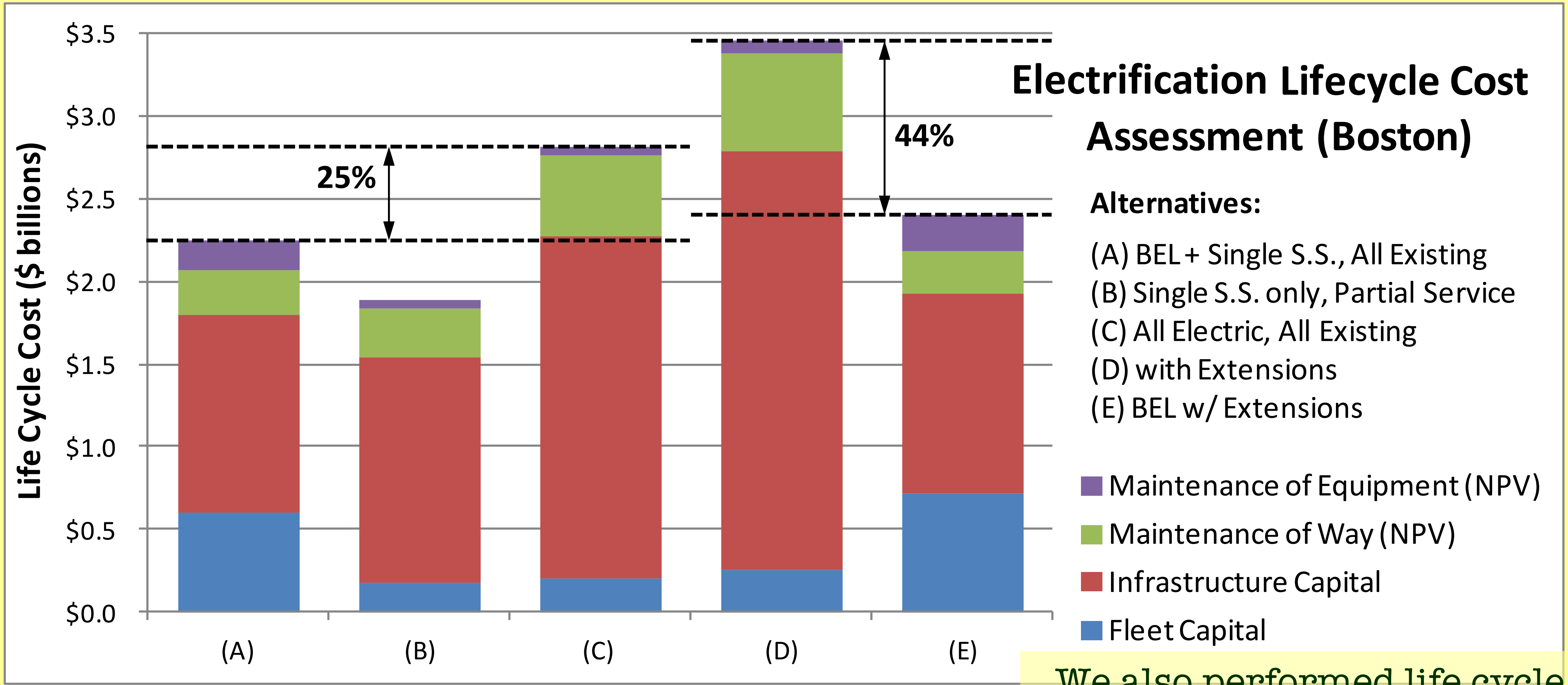
CASE STUDY RESULTS





Even though we propose electrifying only about half the route-mileage, the vast bulk of the ridership will be in the electrified areas – the solid lines – versus the battery-powered zone with the dotted lines.

LIFE CYCLE COST (ESTIMATES)



We also performed life cycle costing for different alternatives in Boston, showing a 25 to 44% cost savings versus full electrification, depending on the extent of battery-electric service.

Note: Cautious cost assumptions; actual BEL technology performance could exceed these.

CONCLUSIONS

- Changing attitudes about fossil fuels are forcing commuter railroads to respond
- Battery-electric locomotives offers a new way of electrification:
  - Electrify with a single supply substation
  - Half-on, half-off electrification
  - Electrification benefits at lower capital cost
- Can also expand reach of existing electrification

So, in conclusion, changing attitudes about fossil fuel are forcing commuter railroads to do something. As battery-electric locomotives develop, a new way of electrification is coming. Instead of electrifying an entire line on a whatever-it-takes basis, we try to electrify as little as possible while replacing diesels with battery-electrics. Half-on, half-off electrification is feasible. Commuter railroads gain the benefits of electrification at lower life cycle costs, and can also expand the reach of existing electrification.

BATTERY-ELECTRICS: IS THE INDUSTRY READY ?

The technology is coming. The question is, are commuter railroads ready? Thank you.

For more information, please visit:
http://lexciestuff.net/bel/

Alex Lu (lexcie@gmail.com)
John G. Allen (jgatransit@2200.com)