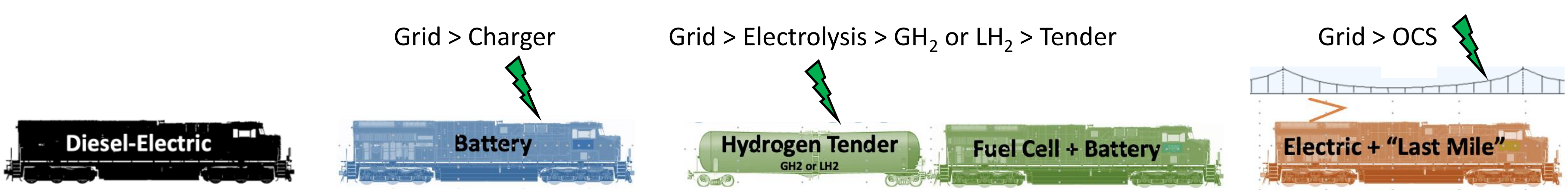
ZE Freight Railroad Propulsion

Risks, Uncertainties & Variabilities

Overview

- Discussing future ZE for freight rail-only
- "Silver bullet" ("winner take all") technology is unlikely (unlike dieselization)
- Multiple ZE technologies likely to be adopted (following semi-ZE transition)
  - Battery locos. (BELs) = short-medium hauls (& yards)
  - H_2 fuel cell locos. (H_2FCLs) = longer hauls (& yards)
  - Electrification = high-density routes ~9% & ~15% energy of Class 1s
- Grid dependency; rolling stock *<u>and</u>* infrastructure need attention, analysis
- Economic analyses: ROI; sensitivity risks & uncertainties; practical trade-offs



Nominal 77 MWh "usable to the rails" energy in 5000 USG fuel

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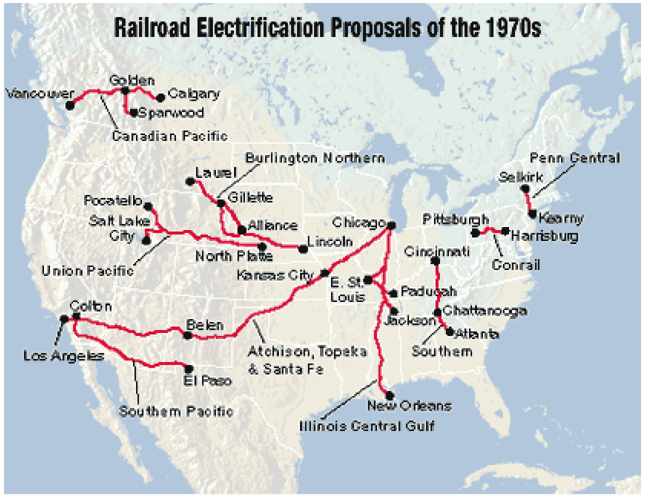
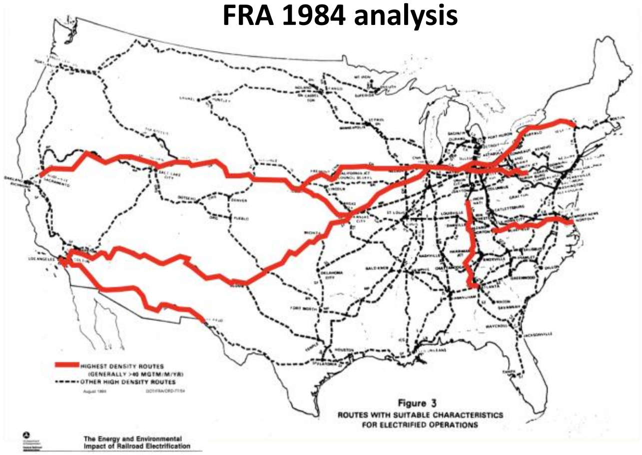
Previous analyses; current traffic densities



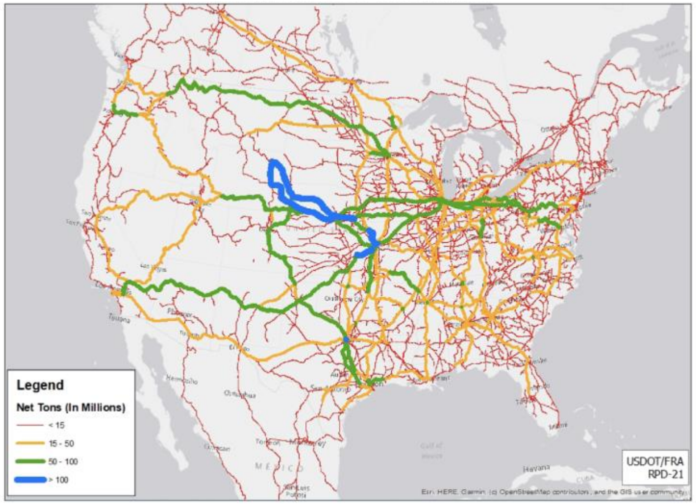
https://www.trains.com/ctr/railroads/railroad-operations/railroad-electrification-proposals/

FRA 1984 analysis



https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/14659/The%20Energy%20and%20Environmental%20Impact%20of%20Railroad%20Electrification%20Aug%201984%20Report%20date%20Sept%201977.pdf

2018 density (waybill samples)



The Waybill is a stratified sample of carload waybills for all U.S. rail traffic submitted by those rail carriers terminating 4,500 or more revenue carloads annually. Image created by Federal Railroad Administration, Office of Railroad Policy and Development (Office of Policy), based on Surface Transportation Board's 2018 Carload Waybill Sample.

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Risk & Uncertainty

Risk and the Real Cost of Electrification

By WILLIAM L. WITHUHN

From the beginning of 1973 through 1975, wholesale prices of diesel fuel almost tripled as a result of embargoes of crude oil from the Middle East. Then between 1976 and 1981 wholesale fuel prices further escalated.[1] As late as 1972, the average price per gallon of diesel fuel to large buyers had been as low as 11 cents. At the end of 1981 that price had reached $1.05. In the ten years through 1980, the total fuel bill to major rail carriers leaped from $409 million to $3.3 billion, a whopping eight-fold increase.[2] The magnitude of the change pushed railroad managers to look for new answers to control their fuel budgets.

In 1980, the Union Pacific Railroad's planning department, commenting on the oil shock of the previous decade, wrote, "We now recognize that occurrence as the end of the era of secure, cheap oil. We now find ourselves surrounded by rising fuel prices and questionable availability. These factors indicate that it is time to reevaluate our motive power energy source."[3]

Across the United States and Canada from the mid-1970s through the early 1980s, major railroads conducted or sponsored feasibility studies of installing electric infrastructure on long trackage segments and converting those segments to electric locomotives so as to cut dependence on oil fuel.[4] Interest in railway electrification in North America probably reached an all-time high. Yet other than the building of two new captive shortlines in

Risk and the Real Cost of Electrification
Author(s): WILLIAM L. WITHUHN
Source: *Railroad History*, AUTUMN 1999, No. 181 (AUTUMN 1999), pp. 80-91
Published by: Railway & Locomotive Historical Society (R&LHS)
Stable URL: https://www.jstor.org/stable/43524019

Why the Santa Fe Isn't Under Wires

By WALLACE W. ABBEY

Three times between the 1940s and the 1970s, the Atchison, Topeka & Santa Fe studied the economic feasibility of electrifying some or all of the most important parts of its railroad. Three times the Santa Fe decided not to risk the big leap. Three times the opportunity to do what many other railroads were talking about doing had to be sacrificed to basic corporate economics.

The Santa Fe's middle management was known for its steam diehards, and one could assume that diesel diehards would show up when talk of electrification began, which they did. On the other hand, top management more easily embraced the notion of electrification—or at least they wanted to know more about the idea. That included Fred G. Gurley, very much a leader in the operation and modernization of the Santa Fe even before he became the president in 1944, and John Shedd Reed, who occupied the top executive chair from 1967 to 1983.[1]

Untested technology was not the question that confronted the company. Railway electrification was well known and proven, dating back to the

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Historical RR concerns re electrification (v H_2 & Batteries)

1. **Does grid have adequate capacity?**
   - **All ZE modes will be grid dependent (H_2, batteries & electrification)**

2. **ROI sensitivities?**
   a. Cost of elec. locos.
   b. Grid access & connections
   c. Construction delays
   d. Cost/availability of materials
   - **ROI sensitivities: same +1**
     - H_2FCL & BEL costs unknown
     - Grid access & connections
     - Construction delays
     - Cost/availability of materials
     - Different grid-to-rail energy efficiencies (input-waste=work)

3. **$ risks of grid power v diesel fuel?**
   - **Cost of grid power & net grid-to-rail energy efficiency**

4. **Are electric locos. available/when?**
   - **U.S. v global sourcing**
     - Electric locos. = existing tech.
     - H_2FCL & BEL = new technologies

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Locos. & Infrastructure: mature v new; simple v complex

Technology	Development (1)	Shops (2)	"Refueling" (3)	Infra. dependencies (4)
Diesel	Mature	Existing	Existing	Minor (flexible refueling)
Battery (BEL)	Experimental	" mod.	TBDesigned	Grid energy; fixed sites
H_2 (H_2FCL)	Experimental	New	TBDesigned	" "; H_2 tenders; " "
Electrified	Mature	" min.	N/A	" "; OCS

(1) "Experimental" is years away from fully-vetted and ready for commercialization
(2) H_2FCL will require shops protected against H_2 ignition, etc (NFPA, etc)
(3) Charger network for BELs; H_2 production network etc plus H_2 fuel tenders
(4) High energy density of liquid diesel fuel is "tough to beat"; diesel = "infrastructure by the gallon"

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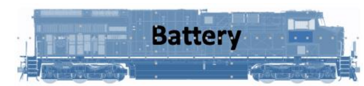
Grid-to-rail traction* energy efficiencies

- **BEL (*shorter op. range than H_2FCL*)** **est. 82% energy to rails**
  - Grid-to-BEL, charge/discharge 90%
  - Loco. eff. (inverters, TMs, etc) 91%



94 MWh > 77 MWh
but needs 3-4 charging cycles

- **H_2FCL (*longer op. range than BEL*)** **est. 33% energy to rails ***
  - Grid-into-electrolysis H_2 75%
  - H_2 compression or liquefaction 80%
  - FC eff. onboard loco. 60%
  - Loco. eff. (inverters, TMs, etc) 91%

233 MWh > 77 MWh

- **Electric** **est. 87% energy to rails**
  - Xformer, power conditioning, etc 96%
  - Loco. eff. (inverters, TMs, etc) 91%

88 MWh > 77 MWh

* *Regenerative Dynamic Braking: BEL and H_2FCL limited by onboard battery capacities; Electric regeneration ~unlimited with return-to-grid capability*

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ZE rail in the UK

TRANSPORT

THE FUTURE FOR
HYDROGEN
TRAINS
IN THE UK

Institution of
MECHANICAL
ENGINEERS

https://www.imeche.org/docs/default-source/1-oscar/reports-policy-statements-and-documents/imeche-hydrogen-trains.pdf?sfvrsn=44848c12_2

OPERATIONS

Typical efficiencies for electrolysis and fuel cells are respectively 68% and 52%. Compressing hydrogen for storage, typically at 350bar, requires 6% of its chemical energy. The overall cycle efficiency from multiplying all these efficiencies is 33%. Hence hydrogen traction requires 3KW of electricity to deliver 1KW of power to the wheel. An electric train has no on-board energy conversion, so needs only 1.2KW.

This low overall cycle efficiency potentially undermines the green credentials of hydrogen trains, as they require 2½ times the electrical energy of a comparable electric train, especially if hydrogen is delivered by the much cheaper CO2-producing reforming process. However, if otherwise surplus overnight (eg wind-turbine) generating capacity is used to produce and store hydrogen, this low efficiency is not an issue, due to the availability of this energy source. Used in this way, hydrogen production also addresses intermittency issues associated with electrical generation from renewables.

“Separate fleets” concern

- **Diesel-electric now continental, ubiquitous**
  - Canada-U.S.-Mexico interoperability, common fuel, infra., etc
  - A “best case” scenario today (unlikely to repeat without a "silver bullet")
  - Dieselization required 20 years R&D + 20 years replacement (1940-60)

- **Diesel v Electric fleets (valid, but same issue with H_2FCL & BEL fleets)**

- **Diesel-electric replacement not a trivial task**
  - ~27,000++ diesel locos. in U.S. + Canada + Mexico
  - Transition, best case based on past ~1,800 units/year
  - Assuming no traffic growth = 15 year conversion
  - Extensive R&D & field testing must precede commercialization
  - Infrastructure for loco. energy, maintenance, etc?

Trade-offs

- **Batteries (BELs)**
  - Moderately-high grid-to-rails energy efficiency
  - Short operating range
  - Tethered to large recharging network
  - More recharging enroute (high grid demand $s for fast charging)

- **Hydrogen (H_2FCLs)**
  - Lowest grid-to-rails energy efficiency
  - Longer operating range with H_2 tender
  - Tethered to H_2 production & transfer (refueling) network
  - H_2 production/storage can be an "energy flywheel"

- **Electrification (Electric under OCS)**
  - Highest grid-to-rails energy efficiency
  - Tethered to large OCS ("last mile battery" can power beyond-OCS)
  - Greatest ability to regenerate Dynamic Braking energy

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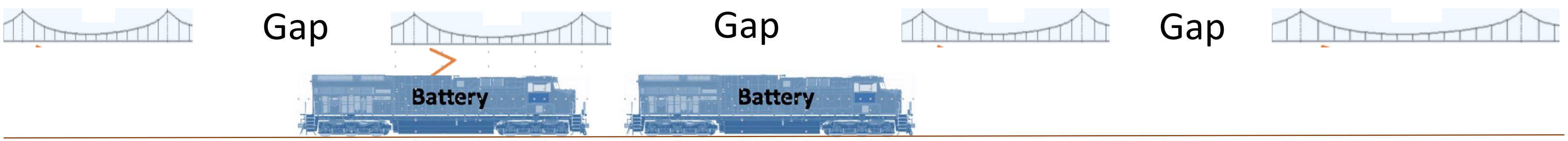
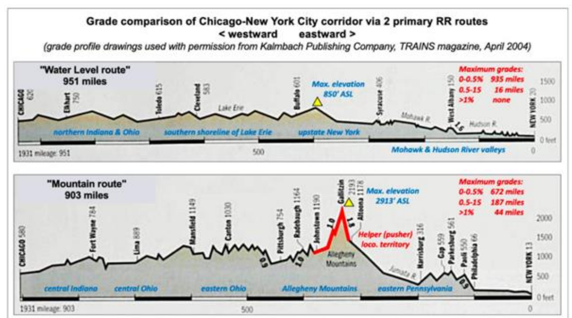
Unconventional alternatives

BEL in-motion recharge from discontinuous OCS

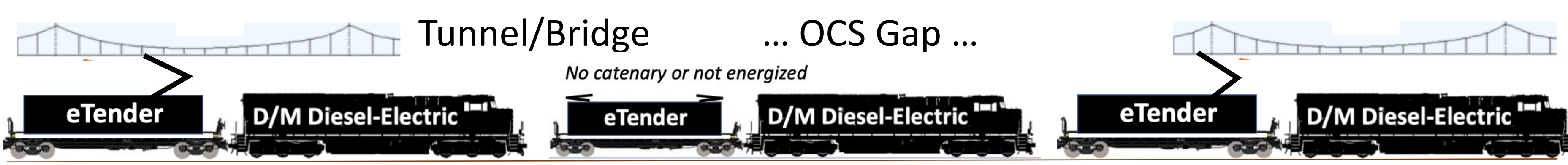


No optimum for variable speed/tonnage/topographies (see 2 routes below)

Same total energy to the rails as Electric but higher demand charges



Dual-Mode (modified) Diesel w/ Power Tender (ZE as OCS is installed/energized)



Accelerated ROI & GHG reductions as OCS is extended

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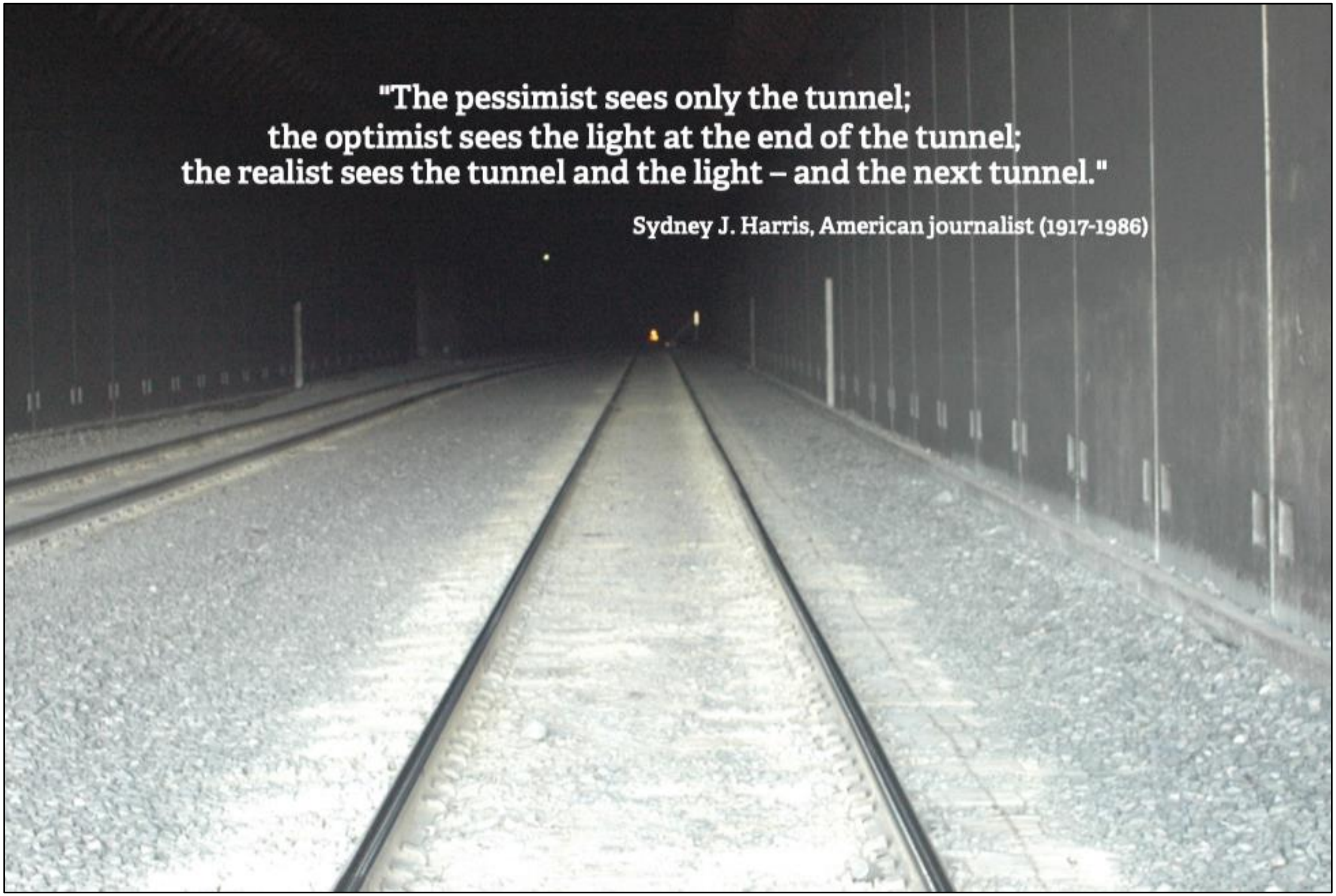
Financial lessons learned: large rail projects in the UK

- Plan work properly
- Avoid optimistic assumptions & underestimated costs
- Institutional knowledge & skills are critical (if unavailable, obtain)
- Standardize for economies of scale (but also …)
- Optimize for reasonable cost reductions
- Rapid start-ups & super-accelerated programs are most risky


"The pessimist sees only the tunnel;
the optimist sees the light at the end of the tunnel;
the realist sees the tunnel and the light – and the next tunnel."
Sydney J. Harris, American journalist (1917-1986)