Zero-emission trains on non-electrified Czech railways

Hydrogen Days 2024

Prague

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Line Skeidsvoll

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Outline

Introduction

Technologies and their Analysis

Cases

- R22: Kolín–Šluknov
- U28: Rumburk–Děčin via Bad Schandau

Conclusions

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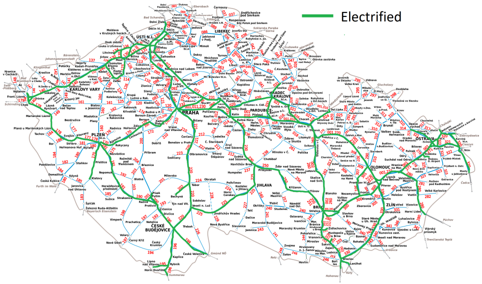
Motivation

- Rail electrification varies among countries:

Czechia	33 %
Norway	68 %
EU	56 %
US	1 %

- Overhead Line Equipment (OLE) is expensive
  — Low-traffic lines run on diesel
- Replace diesel with clean alternatives
- Hydrogen more available—not just to trains!
  — Multi-user refuelling stations



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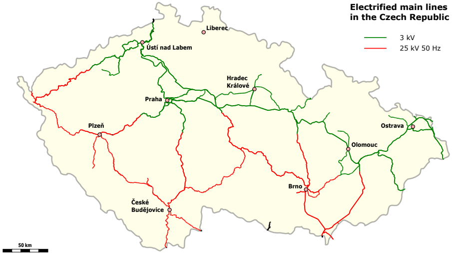

(The plan is to convert all DC to AC)

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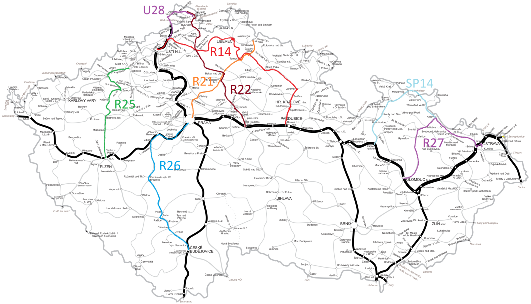
Lines Analysed in this Study

R14, R21, R22, R25, R26, R27, SP14 & U28

- Only local passenger service
- All partially electrified
  - Most DC, some AC (R26, U28)
  - R21, R22, SP14: only a few km
- Longest non-electrified segments:
  - Děčin-Liberec-Jaroměř, 210 km
  - Others: $\gtrsim$100 km
  - Except R26, U28
- Batteries may compete with hydrogen
- All lines can handle weight of new trains



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Zero-Emission Alternatives to Diesel

Multiple Units (MUs) with 2 cars each

DMU Diesel Multiple Units (CZ845, CZ843, Desiro 642)

EMU Traditional alternative is OLE (Škoda RegioPanter)

HMU Hydrogen train modelled after Alstom iLint

HEMU Same as iLint, but with pantograph (hypothetical)

BEMU Battery train, after Siemens Mireo+B

Partial OLE Same as BEMU, but with short OLE sections

- Estimates from Czech Ministry of Transportation

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Single-Train Simulations

Examples for R21 Prague–Tanvald

- Data:
  - Line gradients and speed limits
  - Train weight and tractive effort curves
  - Maximum acceleration and braking

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- Data:
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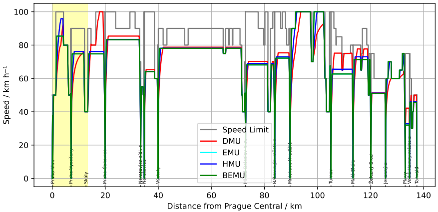
  - Feasible acceleration
  - Speed profile, including stops
  - Reduce speed to respect schedule



Single-Train Simulations

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  - Line gradients and speed limits
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  - Maximum acceleration and braking
- Calculate:
  - Rolling and air resistance
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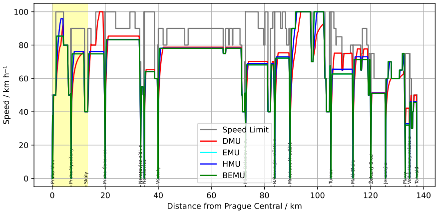
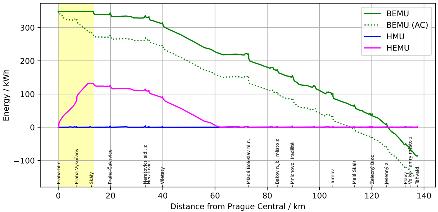
- Output:
  - Propulsion & auxiliary energy
  - Battery state of charge (20 %–80 % window)





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Key Performance Indicators

Assumed interest rate $r = 4\,\%$

- Equivalent Annual Cost (EAC) [€/year]
  - Same ranking as NPV

$$I = NPV = \sum_{i=1}^{n} \frac{A}{(1+r)^i}$$

$$EAC = OPEX + \sum_{j} A_j$$

- Benefit-Cost Ratio (BCR) $[-]$

$$BCR_i = EAC_{\text{Diesel}} / EAC_i$$

- Payback Period (PBP) [years]
  - When discounted cash flows reach 0
- Upfront investment (UFI) [€]
  - Interesting for decision makers
- Cost per km [€/km]
  - EAC / total km run by all trains
- Critical allocation of OLE (CA) [%]
  - Track infrastructure can be shared
  - CA is how much of OLE costs can be accepted by one line
  - CA=25 %: someone else must pay 75 %

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Techno-Economic Analysis Variants

Differential approach

- Account for components separately
  - Fuel cells
  - Batteries
  - Hydrogen tanks
- Assume same cost of base MU
- Closer to technology potential
- More verifiable in literature

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Lumped approach

- Use market estimates for whole MUs
- Closer to “real” prices
- Less verifiable (confidentiality)
- Comparable to Alstom-Hesse deal
  - 500 M€ / 27 MUs / 25 years
- Can account for used DMUs

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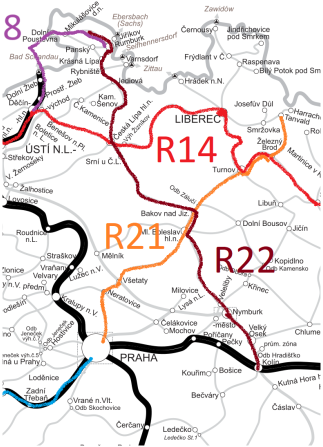
R22: Kolín–Šluknov

- DC-electrified until Nymburk (25 km)
- From Nymburk, 140 km until Šluknov
- Short section in common with R21
- Intersection with R14 at Česká Lípa
- Uphill between Česká Lípa and Jedlová (258 m–545 m over 20 km, or 14 ‰)
- 4 MUs serving the line



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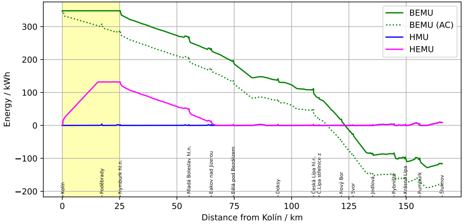
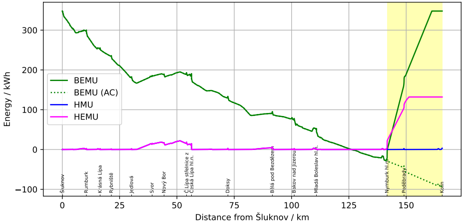
Energy Analysis

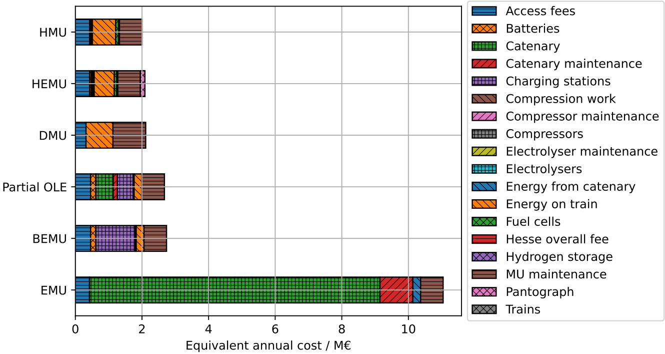
- BEMUs cannot proceed beyond Nový Bor
  - Will need bigger batteries
- Scheduled trains turnaround at 4 stations:
  - Šluknov: full charging station
  - Rumburk: barely time to proceed to Šluknov to recharge
  - Svor: other full charging station
  - Nový Bor: no time for charging
- Chargers at non-electrified stations are very expensive (≈10 M€)
- Partial OLE at Česká Lípa better for BEMUs
  - 1 feeder, 18 km OLE, works with Mireo+B





Cost Analysis

- H(E)MUs ahead of diesel
  - Cost of green hydrogen: 8.5 €/kg
- Partial OLE better than pure BEMU
- Pure BEMU is not fully feasible
  - Nový Bor immediate turnaround
- Full OLE (EMU) is too expensive
  - CA against HMU only 7 %



Differential approach

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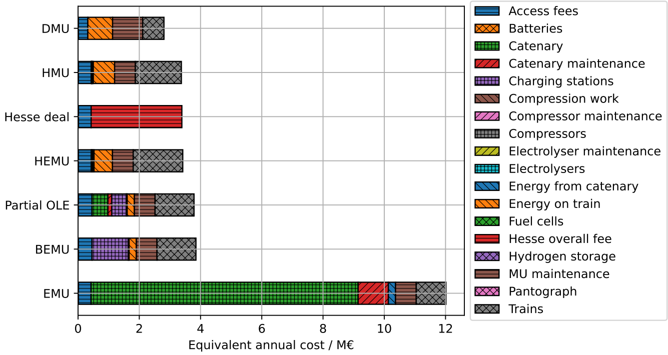
- Lumped approach:
  - Cheaper used DMUs
  - Hesse deal is well aligned



Lumped approach

U28: Rumburk–Děčin via Bad Schandau

- Cross-border National Park Railway

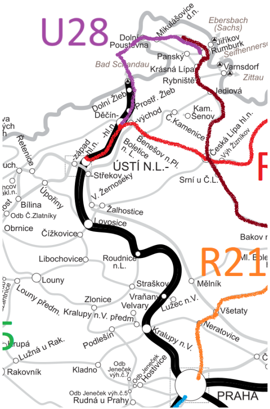
0 km Not electrified from Rumburk

28 km Crosses into Germany at Sebnitz

43 km AC-electrified (**15 kV**) from Bad Schandau

55 km DC-electrified from Czech border (Dolní Žleb)

- Total length 66 km
- Rumburk–Šluknov in common with R22
- Uphill between Bad Schandau and Sebnitz (126 m–313 m over 15 km, or 12 ‰)
- 3 MUs serving the line



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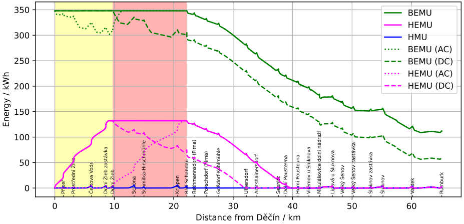
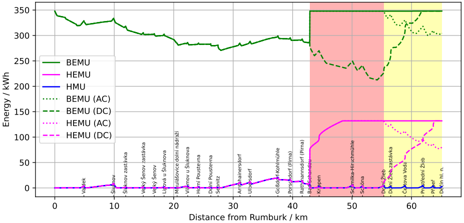
Energy Analysis

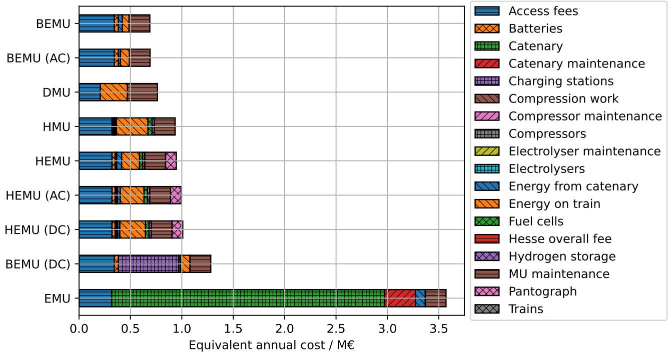
- BEMUs can traverse the line both ways
- **AC** BEMUs need no charger in Rumburk
  - Bad Schandau–Rumburk & back feasible on single charge
  - Dolní Žleb to Děčin and back is easier
  - AC BEMUs need *no extra infrastructure*
- **DC** BEMUs do need a charger in Rumburk
  - Longer section with no DC, Dolní Žleb–Rumburk & back
- Chargers at non-electrified stations are very expensive (≈10 M€)





Cost Analysis

- BEMU (AC or combined) is best, ahead of diesel
- Hydrogen options follow
- DC BEMUs are actually next worst
  - Expensive infrastructure, 3 MUs
- Full OLE (EMU) is too expensive
  - Ignored it would use AC & DC



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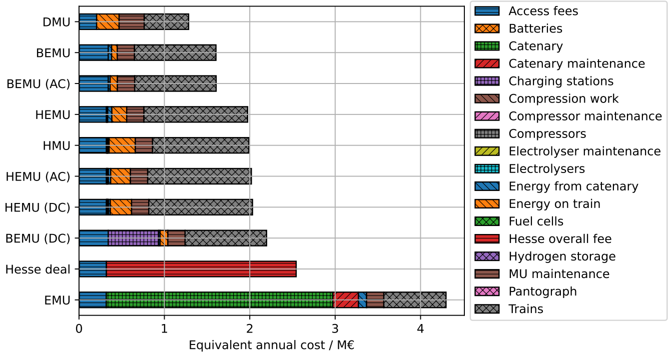

Lumped approach

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Guidelines and Recommendations

- Hydrogen requires less infrastructure
- Batteries are more efficient
- Hydrogen has the advantage if:
  - The line is too long for one charge
  - One or both termini are not electrified
  - Top-up chargers are required along the journey
- Batteries have the advantage if:
  - Pre-existing infrastructure can be exploited
  - No additional chargers are required
- DC BEMUs may have to be replaced in a few years

Line	Technology
R14	HMU
R21	HMU
R22	HMU
U28	BEMU (AC)
R25	BEMU (DC)
R26	BEMU (AC)
R27	BEMU (DC)
SP14	HMU

On Hydrogen Cost

Potential for reduction from project's assumptions

- Batteries' advantage is higher efficiency
- Same kWh price for electrolysis & (B)EMUs
- Resulting hydrogen cost is high, >8 €/kg
- Several ways to reduce it:
  - Import of cheaper hydrogen
  - Run HEMUs with hydrogen as range extender
  - Exploitation of by-product hydrogen
  - Savings on power tariffs (€/kW)
  - Double electrolyser & use cheaper electricity half the day
  - Provide reserve services to power grid
- Significant potential, would need own study

Item	Cost €/kg
Electrolysers	0.3
El. maintenance	0.17
El. energy	7.74
Compressors	0.13
Comp. maintenance	0.06
Comp. energy	0.16
Total	**8.55**

Cost items for hydrogen from electrolysis in Czechia.

Final Considerations

- Biodiesel is an effective way to achieve climate neutrality (not zero emission)
- Local authorities usually cover OPEX, central government infrastructure CAPEX
  - Local authorities may push OLE even if it is most expensive
  - It is however cheapest *for them*
  - Central government should share the savings with local authorities

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Thank you for your attention!

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Technology for a
better society