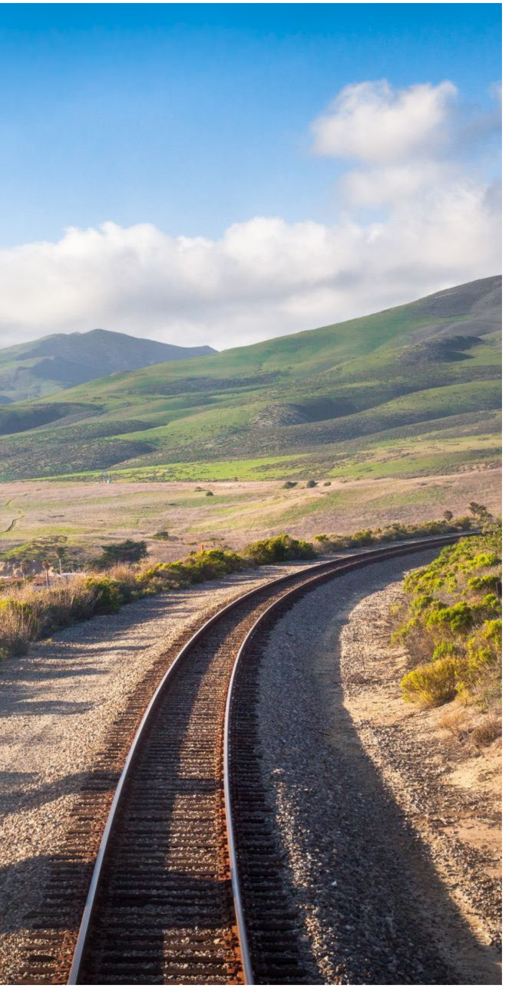
DB

RailPac Annual Meeting

Net-Zero emissions in Rail
& North Americas Cost Problem

November 18 | RailPac Annual Meeting

Agenda



What is Driving Net Zero in Rail?

What Zero Emission Options Exist?

Why All the Hype Around Hydrogen?

Does the US Have a Cost Problem?

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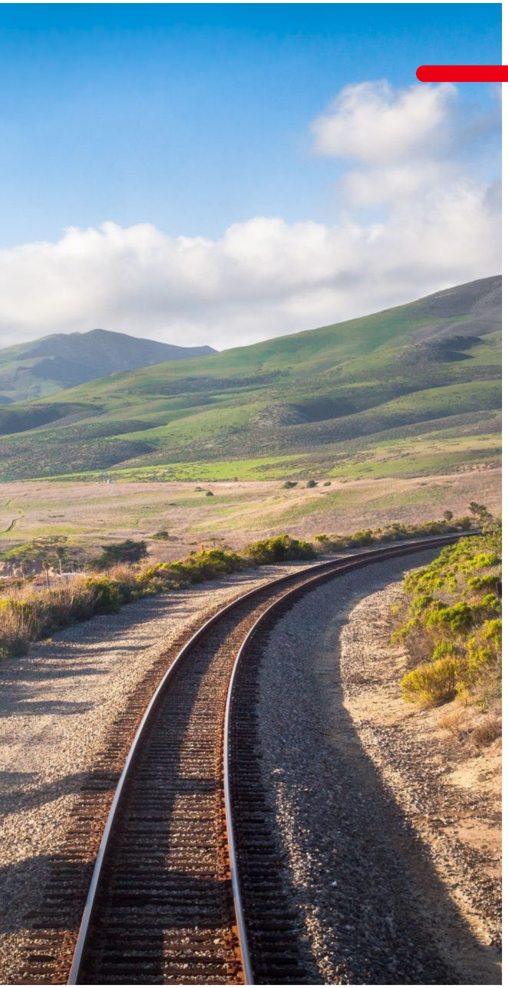


What is Driving Net Zero in Rail?

What Options Exist?

Why All the Hype Around Hydrogen?

Does the US Have a Cost Problem?

The push to Net-Zero GHG emissions for North American railways is driven by three factors

Why North American railways need to transition to net-zero GHG operations

1 To accelerate the fight against climate change

By transporting more passengers and goods via fuel-efficient trains instead of planes and cars/trucks, emissions can be significantly reduced from a holistic perspective

2 To meet rising regulatory & political expectations

With the federal government targeting net-zero emissions by 2050, railway companies must proactively transition their operations to align with these goals and comply with emerging policies

3 To maintain competitive edge as most sustainable mode of travel

As other transportation providers announce their own sustainability plans, railways must lead the way in greening the sector by aggressively cutting emissions across trains, facilities, and infrastructure

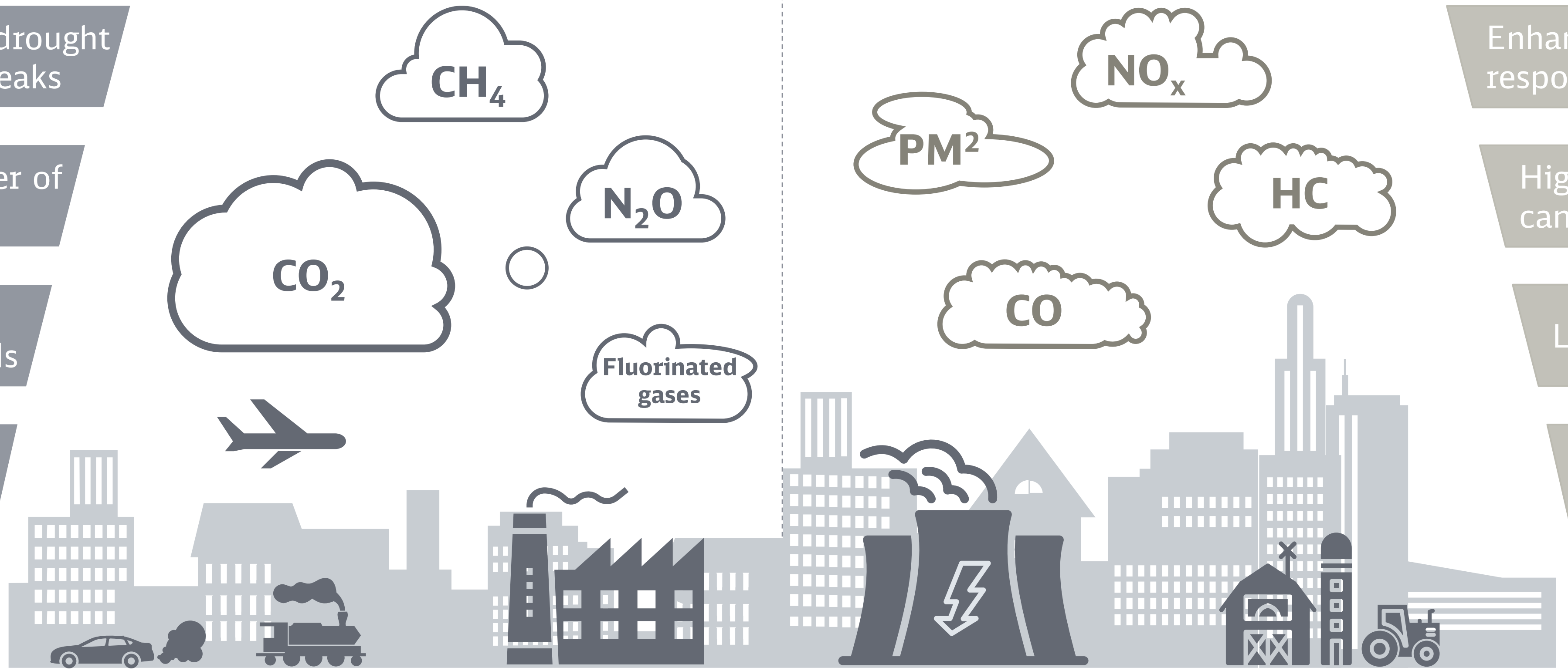
Greenhouse gases (GHGs) and criteria air pollutants (CAPs) pose a high risk for the environment and people's health

Greenhouse gases produced by human activities accelerate climate change[1]...

- Increased heat, drought and insect outbreaks
- Increased number of wildfires
- Reduced agricultural yields
- Declining water supplies
- ...

...whereas **criteria air pollutants** from exhaust gases affect air quality impacting people's health

- Enhanced allergic responses
- Higher risk of cancer
- Lung irritations
- Premature death
- ...



(1) Once Greenhouse gases are released, they can stay in the atmosphere for 100 years or more. (2) PM = Particulate Matter

Source: USGCRP 2017, Fourth Climate Assessment

Various states are pushing towards ambitious GHG reductions and regulations of the transportation sector, especially for road vehicles

GHGs: Summary of state reduction targets and the push to zero-emissions on road vehicles

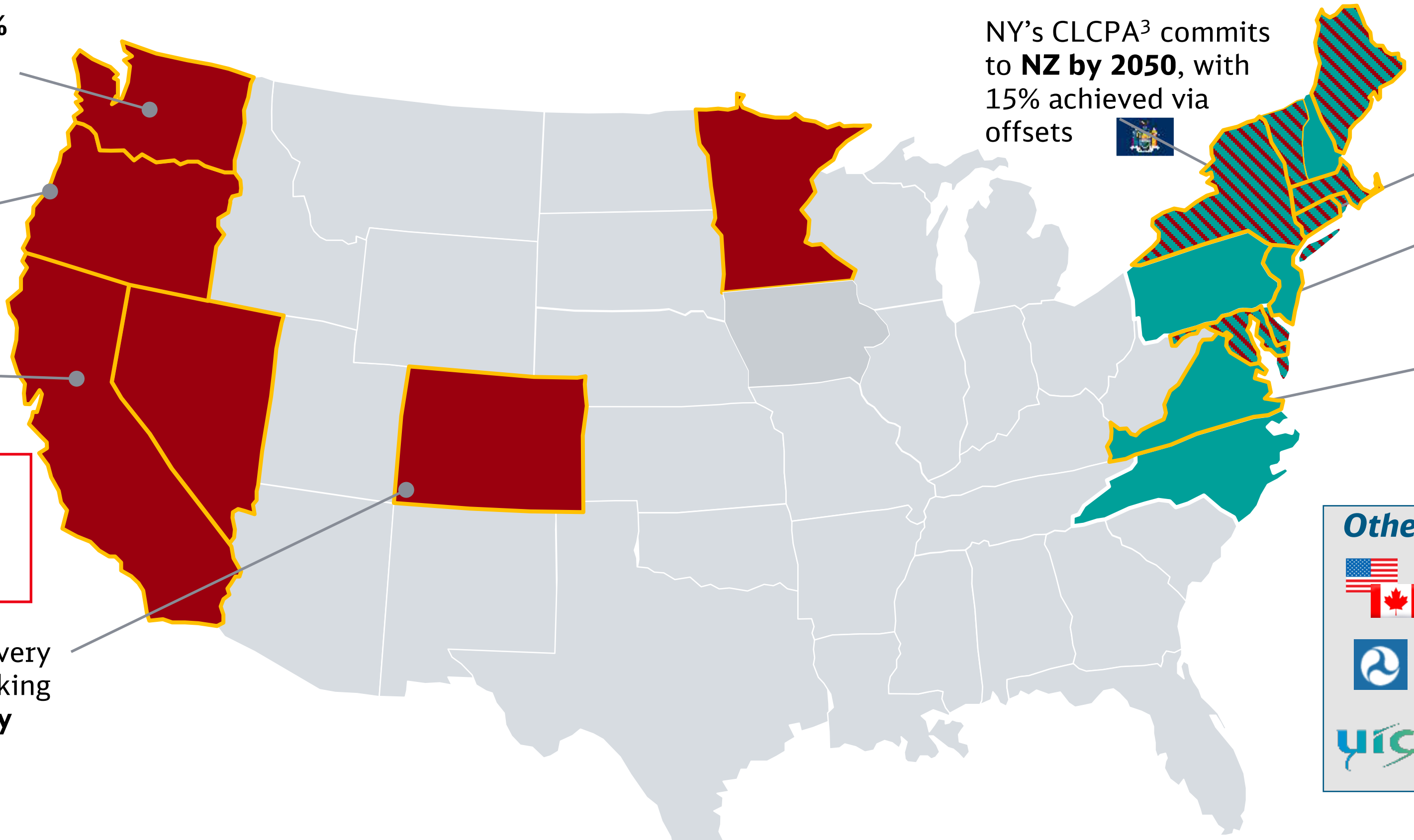
WA aims to **reduce GHG 95% by 2050**[1] and establish a NZ economy; transport is required to do emissions reporting

OR requires **75% GHG reduction by 2050**[1]

CA CARB[2] requires GHG reporting & verification with targets to reduce **GHG 40% 2030**[1]

Additionally, **all locomotives must** be **ZE by 2047** (in-use loco. Regulation), **2035 for multiple units** (EO-N-79-20)

CO requires GHG reporting every two years with forecasts tracking progress to **90% reduction by 2050**[4]



NY's CLCPA[3] commits to **NZ by 2050**, with 15% achieved via offsets

CT requires **80% GHG reduction by 2050**[4]

NJ requires **80% GHG reduction by 2050**[4] and an annual report measuring progress

VA targets **NZ by 2045**, with GHG emissions inventory conducted every 4 years

Other relevant goals:

- **Executive Order** for federal gov. to achieve NZ emissions by 2050
- **Federal Railroad Administration Climate Challenge** to be NZ by 2050
- **UIC Climate Responsibility** targets NZ emissions by 2050

"Section 177" states: ZEVs are to be 100% of sales by 2035

Transport Climate Initiative TCI (to reduce carbon in transport)

State GHG reduction & reporting requirements

No combined reduction & reporting requirements

(1) from 1990 levels (2) CARB: California Air Resources Board (3) CLCPA: Climate Leadership & Community Protection Act (4) from 2005 levels (5) CARB proposed legislation notes that from 2030 onwards, new motive power purchases must be ZE, and that any loco engine with an original engine build date 2035 or newer would be required to be ZE

Source: National Conference of State Legislatures, Climate Group, Executive Department State of California, DB research & analysis

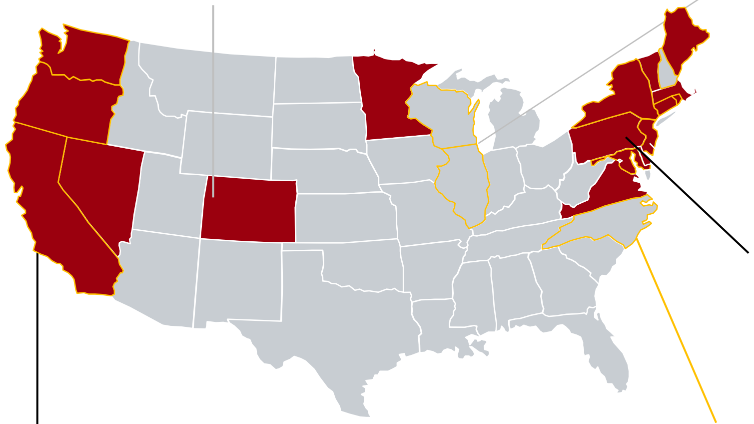
The CAPs landscape on both state and company-level is changing rapidly; there may be an opportunity for rail companies to get ahead of the curve

CAPs[5] policies by state

CARB States | Coalition states

May 2022 CO[3] passed HB-1244 aimed at HAP[2]s; it will develop a monitoring system and by 2026 require emission control regs to reduce priority contaminants

As with all states, IL must submit to EPA an annual Air Monitoring Plan & Network Assessment; otherwise, IL does not display CAPs policies



PA's RFM grant program seeks to improve air quality by reducing NOx produced by nonroad equipment (e.g., freight switcher locos)[9]

As CARB seeks to reduce air pollution and emissions, other states are adopting CARB's Criteria Pollutant regulations, as related to Low & Zero Emission vehicles

CA's EO N-79-20 states that by 2035 all offroad vehicles must be ZE (where feasible)

A coalition of 19 states[6] in May 2022 filed a letter to urge the EPA to impose stronger standards & regulations on NOx emissions & other harmful pollutants on heavy trucks specifically

CAPs approaches by companies

METROLINK.	✓ Specific CAPs goals	Goal to reduce total NOx an average of 44% & PM 64% annually by 2030[8]; intends 100% ZE by 2028
DB	✓ Specific CAPs goals	Goal to reduce combustion-related soot 55% by 2020 – exceeded target (reduced 61%), & aims to cont. progress
Caltrans	✓ Specific CAPs goals	As part of CA Transport Plan 2050, Caltrans aims to be fully ZE by 2035 (including CAPs)
CN	✓ Mention of CAPs in company communication, but not goals	No specific CAPs goals; Tracks CAPs through GRI in Sustainability Data Supplement
UNION PACIFIC	✓ Mention of CAPs in company communication, but not goals	No specific CAPs goals; Notes that CA railyard emission inventories show 70% CAP reduction[7]
CSX	✓ Mention of CAPs in company communication, but not goals	No specific CAPs goals; Notes updating to Wabtec Tier 4 switcher will eliminate 7 tons of NOx per year

✓ Specific CAPs goals ✓ Mention of CAPs in company communication, but not goals ✗ No CAPs goals

(1) Source: Section 177 (2) HAPs: Hazardous Air Pollutants (3) Supporters of HB-1244 note at least 15 other states, incl. TX and KY have taken steps to address air toxins in absence of stricter federal rules (5) CAPs include Ozone, Atmospheric Particulate Matter, Lead, CO, SO_2, and NOx (6) States include: CA, CO, CT, DE, DC, HI, IL, ME, MD, MA, MN, NJ, NY, NC, OR, RI, VT, WA, WI
(7) Compared to 2005 levels (8) From 2023 baseline (9) RFM: Rail Freight Movers grant will repower/replace pre-Tier 4 switchers with EPA/CARB certified diesel/alt fuel/ all electric engines

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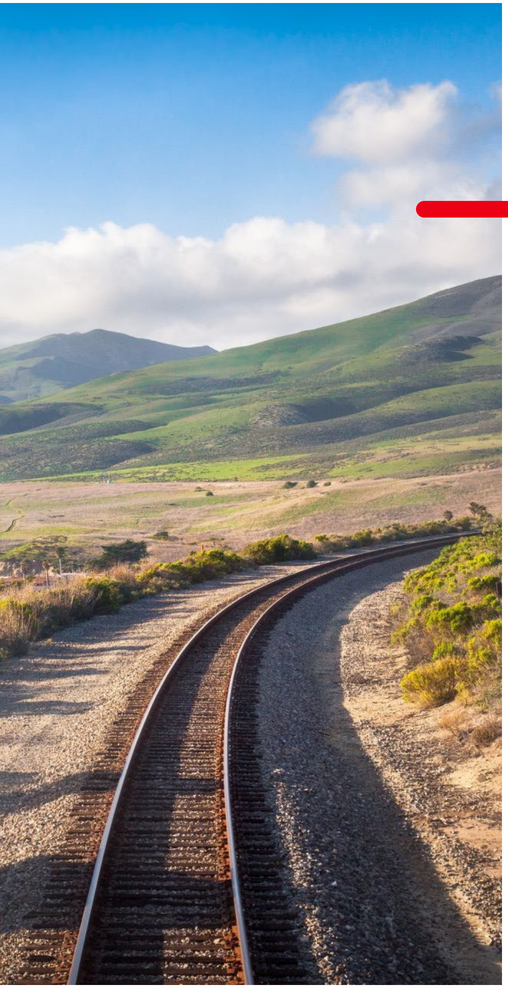


What is Driving Net Zero in Rail?

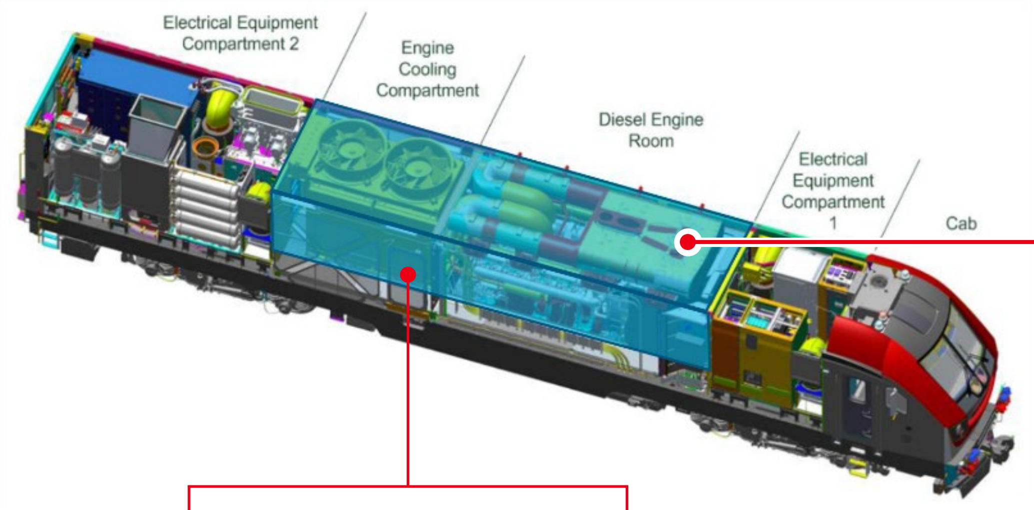
What Options Exist?

Why All the Hype Around Hydrogen?

Does the US Have a Cost Problem?

There are currently three major options to replace the diesel powerplant of existing locomotives with zero-emission alternatives

Rendering of Siemens Charger locomotive
(most modern passenger rail loco on NA market)



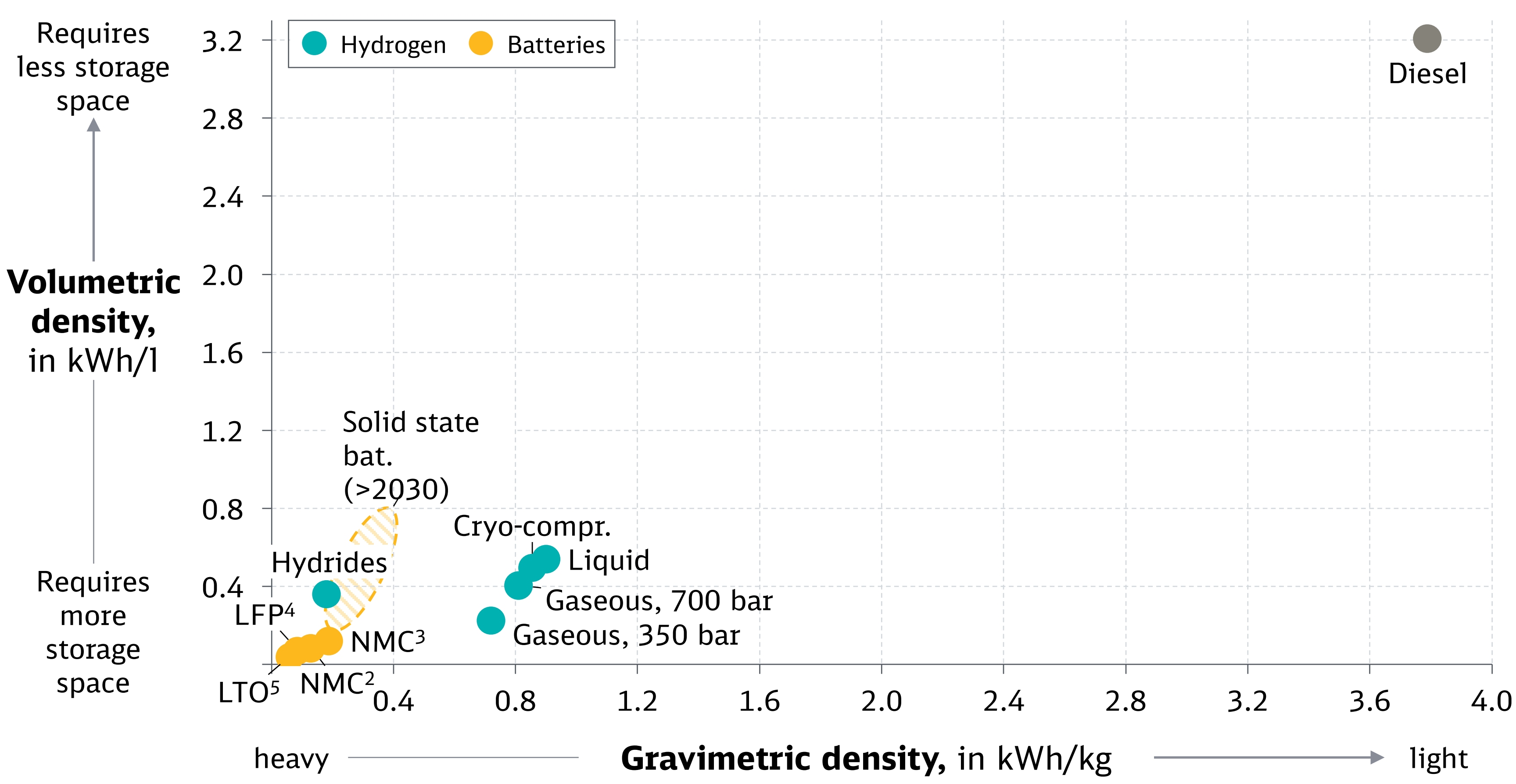
Constraints for alternative powertrain:
- **Mass: 40t**
- **Volume: 59m³**

Option	Required technical equipment			
Hydrogen only	Fuel cell	Hydrogen storage		Power electronics
Battery only	Batteries			Power electronics
Hydrogen/battery hybrid	Fuel cell	Hydrogen storage	Batteries	Power electronics

Source: DB

Diesel is by far the energy densest fuel for rail vehicles – even with projected improvements, batteries still lacking behind hydrogen

Energy densities incl. powertrain efficiencies[1]



Takeaways

- **Liquid fuels**, such as diesel, require the **least space** and are lightest
- A one-for-one replacement of diesel powertrains without changes in expectations is difficult to achieve due to **lower densities of alternatives**
- Zero-emission powertrains will require more space for energy storage and/or changes in locomotive design such as adding additional axles
- The right choice of powertrain will require a trade-off between operation and equipment capabilities

Notes: (1) Diesel-electric: 32%, battery-electric: 85%, hydrogen fuel cell system: 45% (2) Wabtec FLXdrive 2.0 (3) Wabtec FLXdrive 3.0 (projected for 2026) (4) ProgressRail Joule locomotive (5) Siemens Intercity Trainset (Amtrak) | **Source:** GREET, Wabtec, Siemens, DB research and analysis

Low & zero-emission options close to commercial availability in North America; long-range technology needs to be developed

Powertrain	GHG reduc. potential	CAP reduc. potential	Conversion complexity[1]	Use case	Technology readiness	2022 – Timeline to commercial availability in the U.S. – 2035
ICE[2] w/ renewable diesel			[4]	Short-range	✓	1
				Switcher/MoW	✓ (yellow)	3
				Med./Long range	✓	1
Hydrogen fuel cell	ZE	ZE		Short-range	✓	2
				Switcher/MoW	✓	3
				Med./Long range[6]	✗	10
Battery	ZE	ZE		Short-range	✓	3
				Switcher/MoW	✓	3 (MoW)
				Med./Long range	✗	*Battery-only unlikely for intercity rail*
OCS[3]	ZE	ZE	[5]	Short-range	✓	
				Switcher/MoW	✓	2
				Med./Long range	✓	*Network-wide electrification not feasible*

✓ In service/pilots ● In R&D ● R&D not started ■ R&D ■ Pilot & deployment ■ Comm. available

(1) Retrofitting vehicles (2) ICE: Internal Combustion Engine (3) OCS: Overhead Contact System (4) Includes OEM approval of RD for engines, & value chain confirmation
(5) Vehicles only; Infrastructure complexity not included (6) Studies show general feasibility of Hydrail for med./long-range applications | Source: DB estimates

Alternative powertrain technologies are already being piloted or are in operation worldwide

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	Battery			Hydrogen		
	SIEMENS	STADLER	ALSTOM	SIEMENS	STADLER	ALSTOM
Commuter rail	 2022	 2022	 2022	 2024	 2024	 2018
	All also have OCS capability					
	Wabtec CORPORATION	Progress Rail A Caterpillar Company	CRRC	Progress Rail A Caterpillar Company	CRRC	CPKC
Freight/ locomotives	 2021	 2020	 2024	 2022	 2022	 2022
Intercity rail	***Alternative propulsion for intercity rail remains in early R&D phases – renewable diesel as "gap-technology" continues to be utilized and adopted***					

In service · Service planned · Pilot · Research & Development · Example from North America

Source: Company announcements, DB Research

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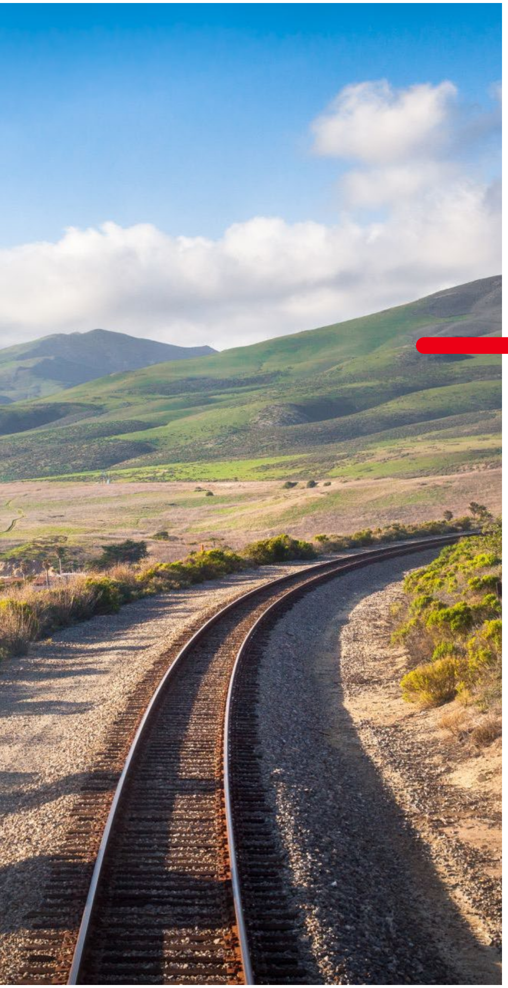

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The DB team uses a 4-factor Technologoy Assessment Framework when making recommendations on technology selection

Criteria to evaluate suitability of main on-board energy technology

Environmental

- Suitable to achieve emission targets (i.e., Zero Emission by 2035)
- Low impact on the ecosystem considering the entire lifecycle

Technological/ operational

- Available and mature at the relevant time
- Fulfils the operational requirements and expectations

Economical (LCC[1])

- The investment and operational costs are reasonable
- Eligible for government-supported funding meeting all regulatory requirements

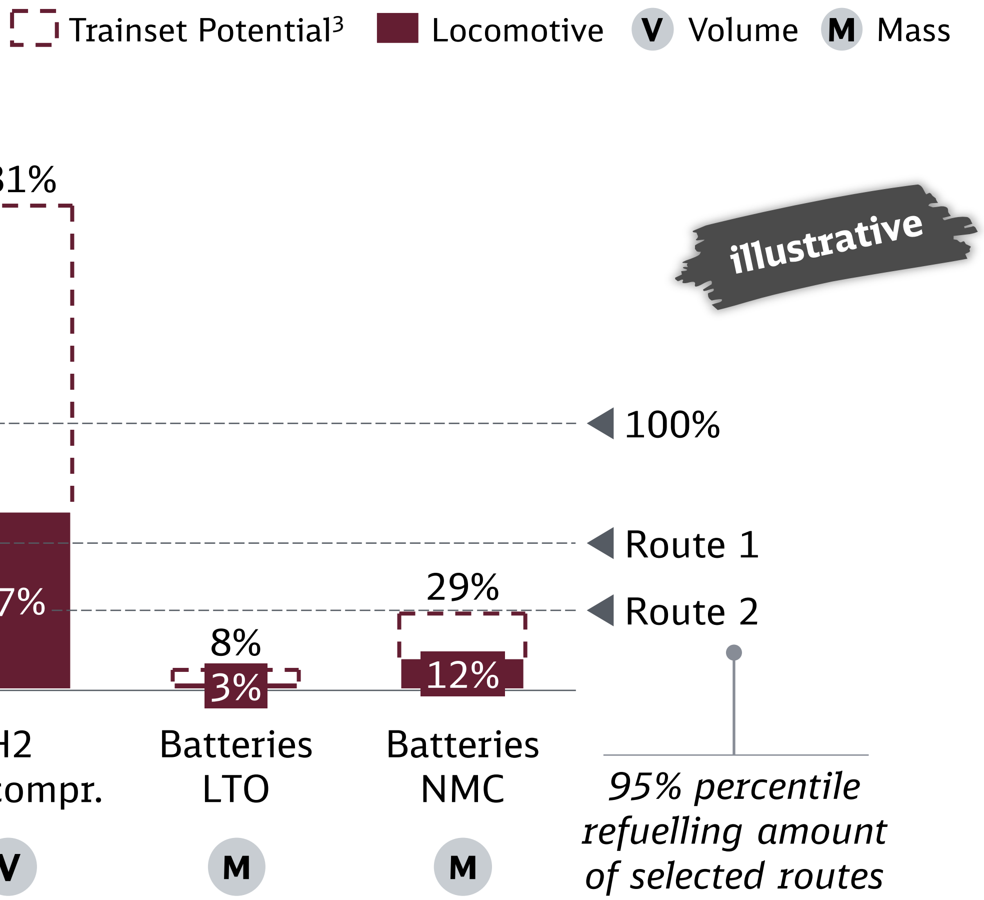
Synergistic

- Creates synergies with other sectors and systems
- Accepted by the wider public

(1) LCC: Lifecycle costs

Some hydrogen storage options meet most operational requirements[1] using only onboard locomotive space, but batteries are not feasible

Energy content at the locomotive DC bus[2,3]
in MWh (% of diesel equivalent tank), today's technology level

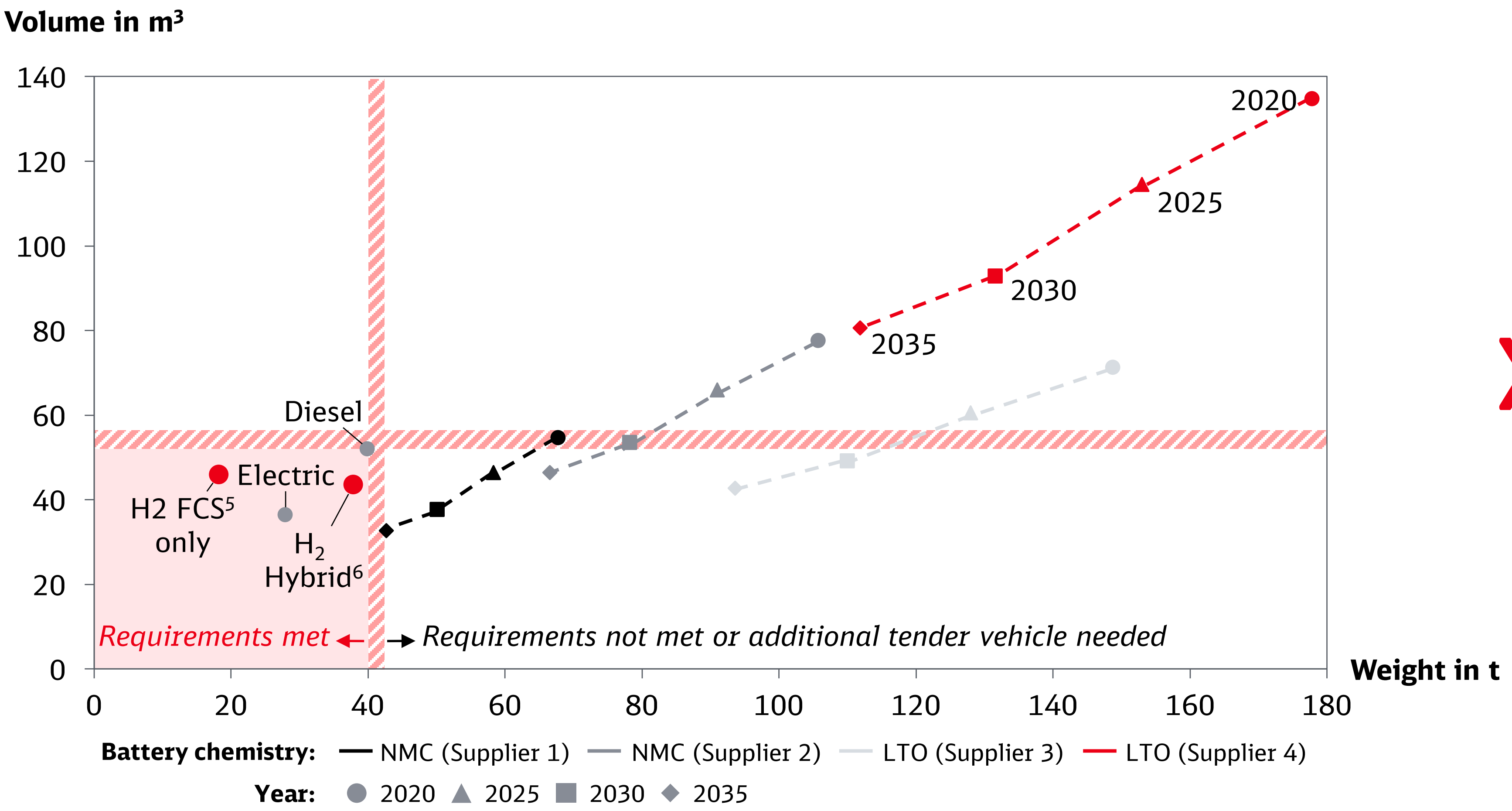


Notes: (1) 95th percentile (2) Factoring in a trip averaged 32% diesel engine efficiency and a trip averaged 45% fuel cell system efficiency implicit in all energy calculations. (3) Volume and mass constraints were considered. Fuel cell size is accounted for. Assumed limits for the locomotive: 40 metric tons, 59 cubic meters in the locomotive, 56 cubic meters added throughout the undercarriages of the intercity trainsets (ICT) - if determined to be feasible (tender cars are an alternative). Limits are based on estimates from technical drawings and will need to be refined from an engineering perspective.

Source: DB analysis

Technological: Even with projected advancements, batteries will not meet the operational requirements of intercity rail

Current and projected[1] dimensions of different powertrains for CA ICPR



Takeaways

illustrative

- Even with projected advances, batteries will not meet operational requirements of intercity rail[4]; to meet requirements[2], the weight of the new propulsion system shall not exceed the weight[3] of **40 tons** and space[3] of **52 cubic meters** (=current diesel solution)
- Even with the projected technological advancements, **batteries alone** will likely **not fulfill[4]** the operational requirements **by 2035**
- Even with the **current hydrogen technology**, based on this initial assessment, CA intercity requirements **can be met**

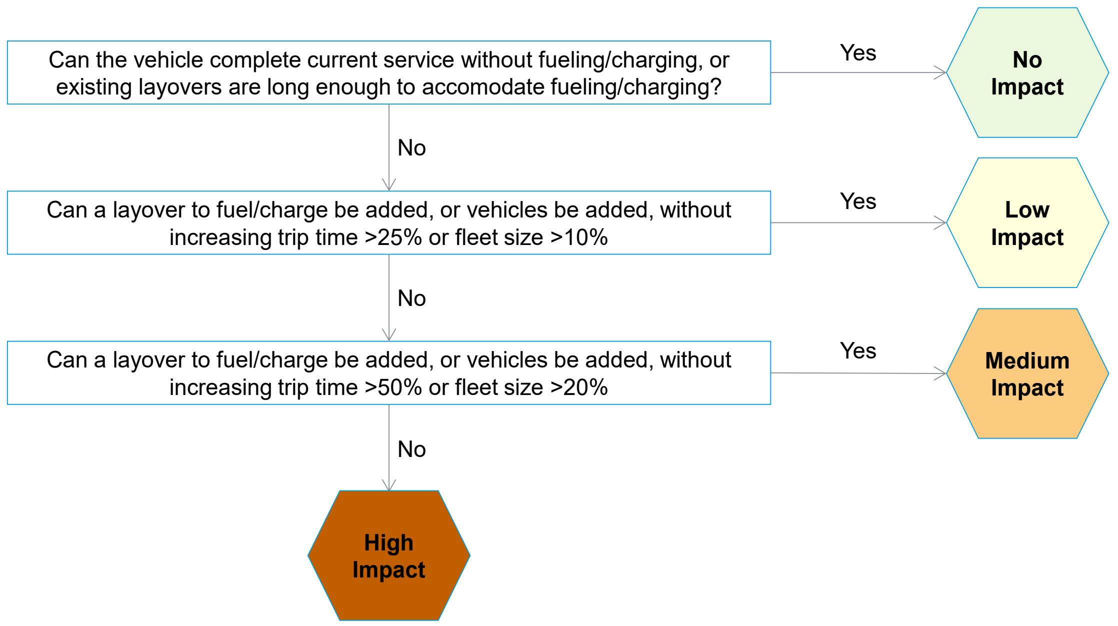
(1) Battery development projected according to Advanced Propulsion Centre UK (APC) applied to 2020 values (2) Assuming energy requirement of 10,343 kWh at DC bus (75% fueling percentile)
(3) Approx. weight and volume of F59PHI diesel locomotive powertrain (4) Assuming no change to the current operating model (no additional vehicles, no additional charging infrastructure, same schedule)
(5) Assuming a 45% FCS duty cycle efficiency (6) Assuming a 1,000 kW FCS and 1,800 kWh battery capacity from Supplier 3, 15% energy saving by regenerative braking, 50% FCS duty cycle efficiency
Source: XALT Energy, Akasol, ABB, Toshiba, APC, DB analysis

This is an example assessment of a representative route, comparing the "impact to service" of battery and hydrogen propulsion options

Illustrative Route
- Route Length: 25 miles
- Consist Type: Multiple Unit
- Round Trips per vehicle, per day: 8

Round trips per refuel / charge for each route

Energy carrier type	Energy capacity setting	Routes A1	Impact to service score
Battery	Low	0.5	High
Battery	High	1.5	Low
Battery	UGV1	1.0	Medium
Hydrogen	Low	11.5	No impact
Hydrogen	High	29.5	No impact
Hydrogen	UGV1	9.0	No impact



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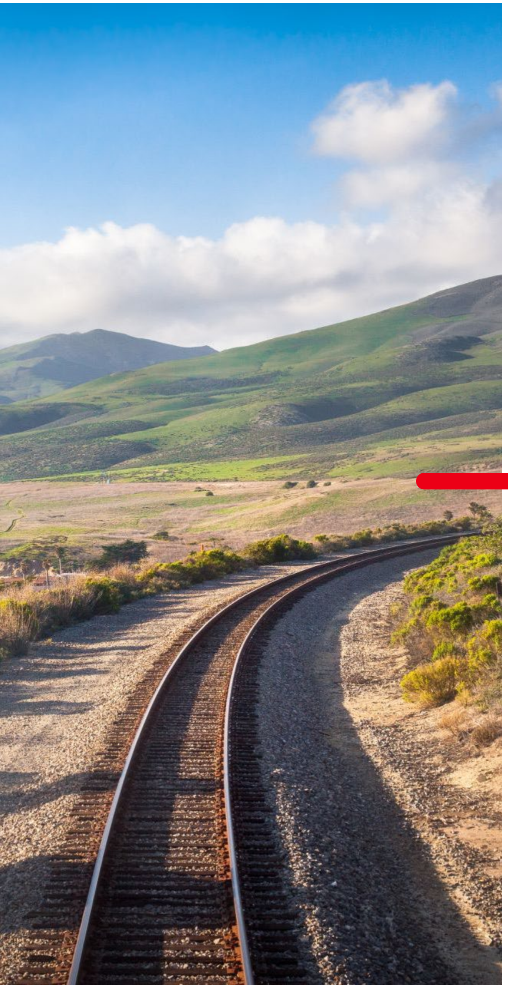

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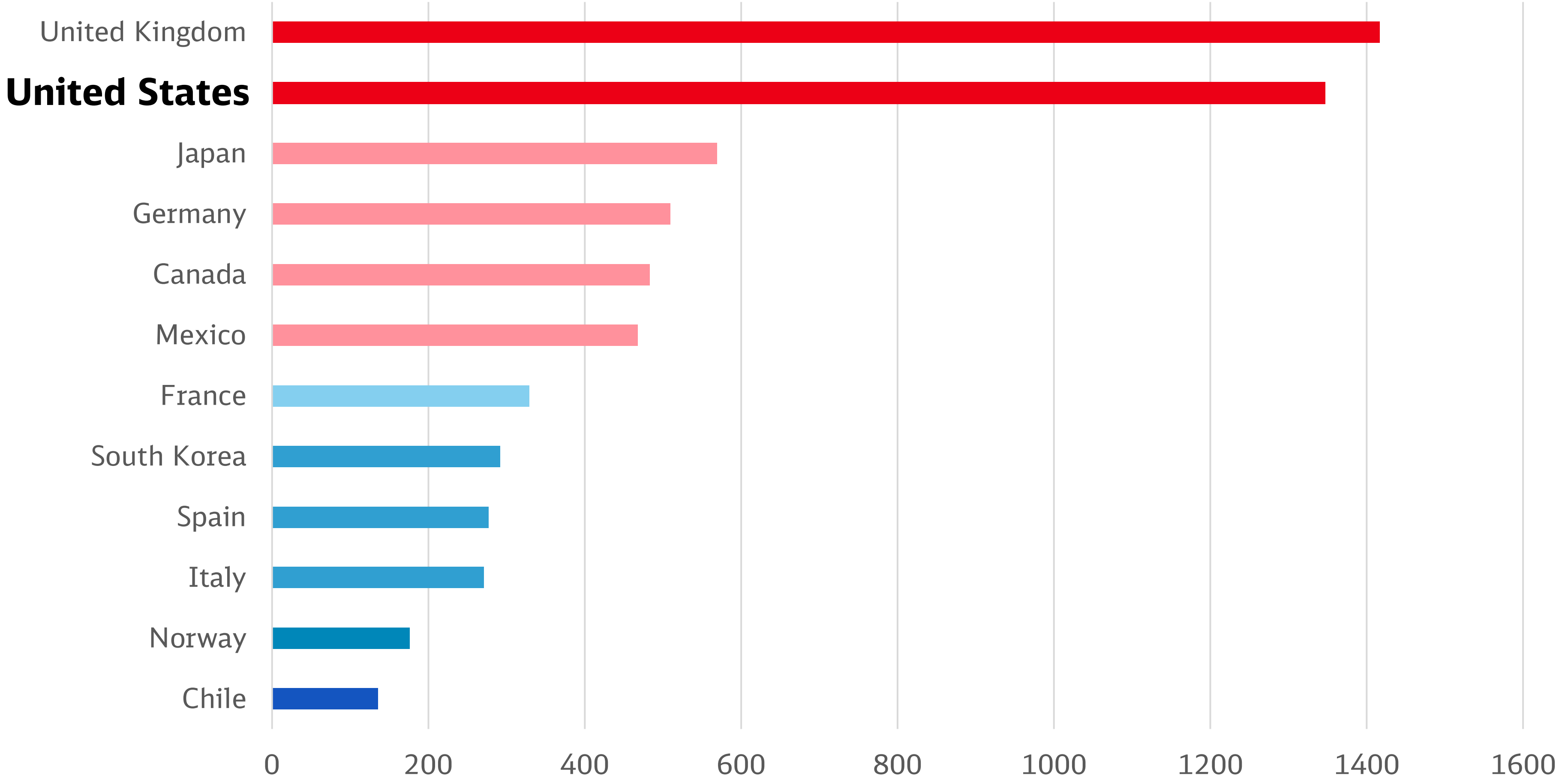
Does the US Have a Cost Problem?

Yes[1]: Systemic cost problem in the US when constructing tunneled urban transit projects

Average cost per mile for primarily tunneled urban transit projects ($USD millions, 2021)

- Adjusted for purchase price parity and construction inflation

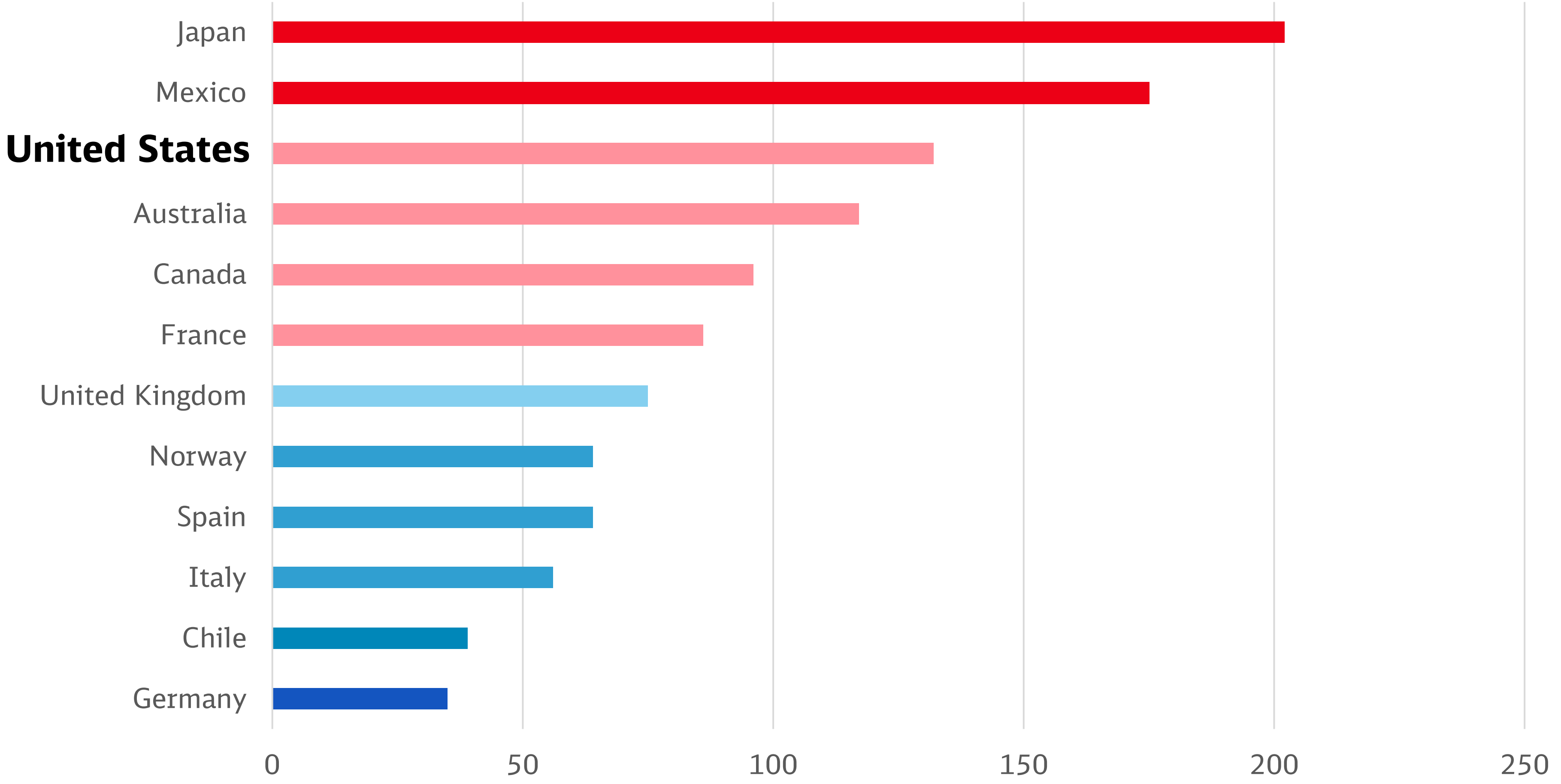


(1) Analysis performed by Eno Center for Transportation

Yes[1]: Systemic cost problem in the US when constructing at-grade urban transit projects

Average cost per mile for primarily at-grade urban transit projects ($USD millions, 2021)

- Adjusted for purchase price parity and construction inflation



(1) Analysis performed by Eno Center for Transportation

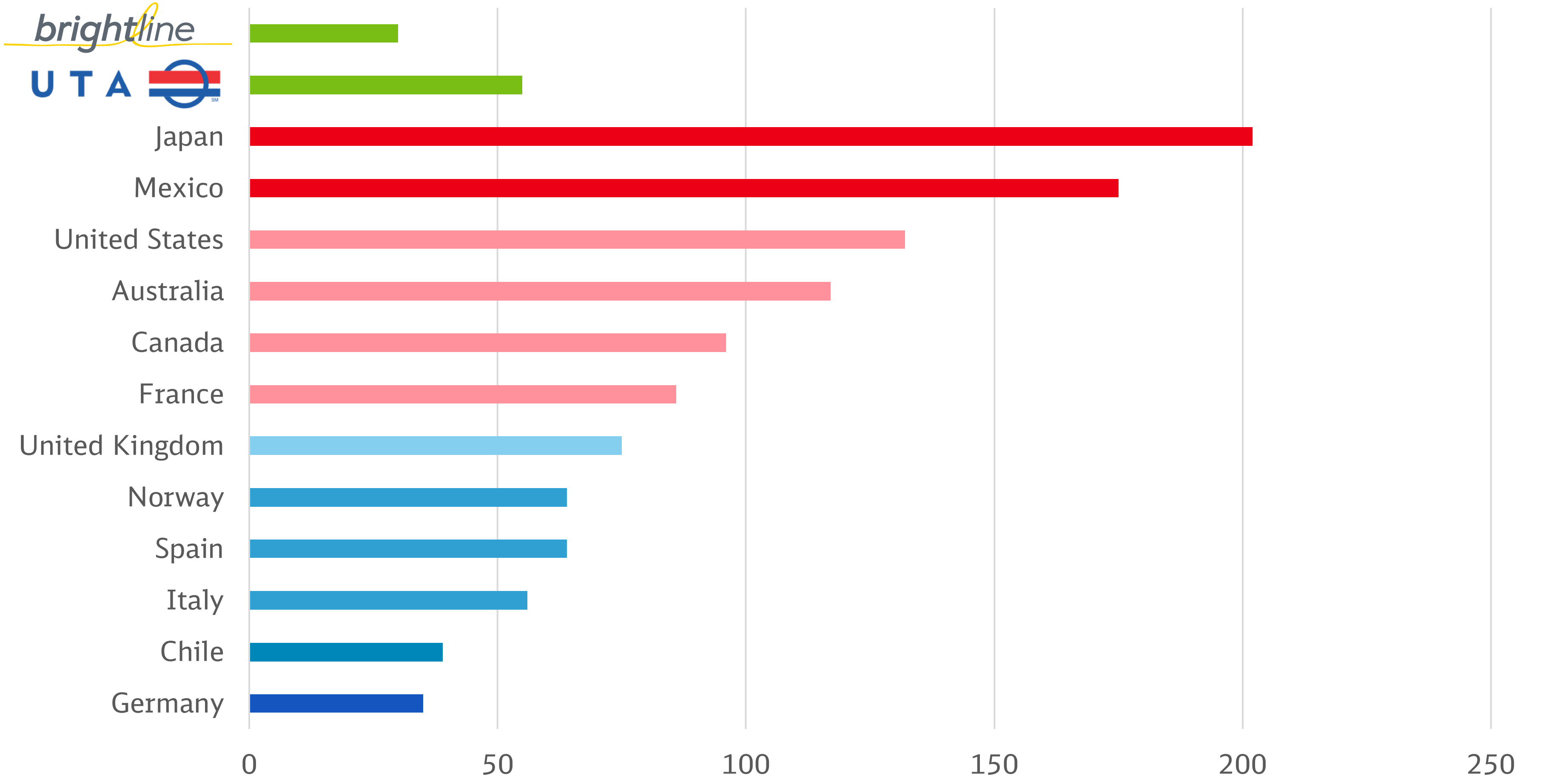
What can we do about it?

10 changes for project sponsors:

1. Build simple and useful projects
2. Adopt contracting best practices
3. Manage more risk on the public side
4. Empower staff to engage community
5. Proceed with the more disruptive timeline
6. Finish planning process before environmental review
7. Boost internal staffing
8. Set agreements with partners early
9. Address institutional governance
10. Learn from peer country examples

There are examples of US projects in Utah and Florida which have been delivered at costs competitive to other countries

- UTA – Light Rail Network, 42.7 miles at Grade
- Brightline Florida Extension, 170 miles at Grate



(1) Analysis performed by Eno Center for Transportation

For more information on project costs in the US you can contact Paul Lewis, Principal Consultant with DB

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Thank you!

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