Overview of Low - and Zero - Emission Technology Options for Railway Motive Power

DB E.C.O. North America | Dr. Andreas Hoffrichter | FRA Decarbonization Workshop | Denver, CO | May 16, 2023

Agenda

1. Motive power options overview & energy density
2. Low Emission Technologies
3. Zero Emission Technologies
4. High level comparison
5. Decarbonization steps

Example: Mainline, long-distance railway in North America: Motive power options for low- and zero-emissions

Levers		Options						
Motive Power Often Scope 1	Main on-board Fuel [a]	*Diesel*	*Renewable diesel*	*Natural Gas*	*Renewable gas*	*Battery*	*Hydrogen*	*Hybrid*
	After-treatment system	*Below Tier 4*		*Tier 4*		*Tier 5[b]*		
	Degree of electrification	*No full wayside electrification*	*Charging points at stations / facility*	*Partial electrification [c]*	*Full wayside electrification*			
Energy Supply Chain Often Scope 2	Power source	*Procure energy from renewable sources ("buy")*	*Power generation at facilities ("make")*					

Total emission reduction potential (incl. energy supply chain) for a typical railway

Intermediate solution

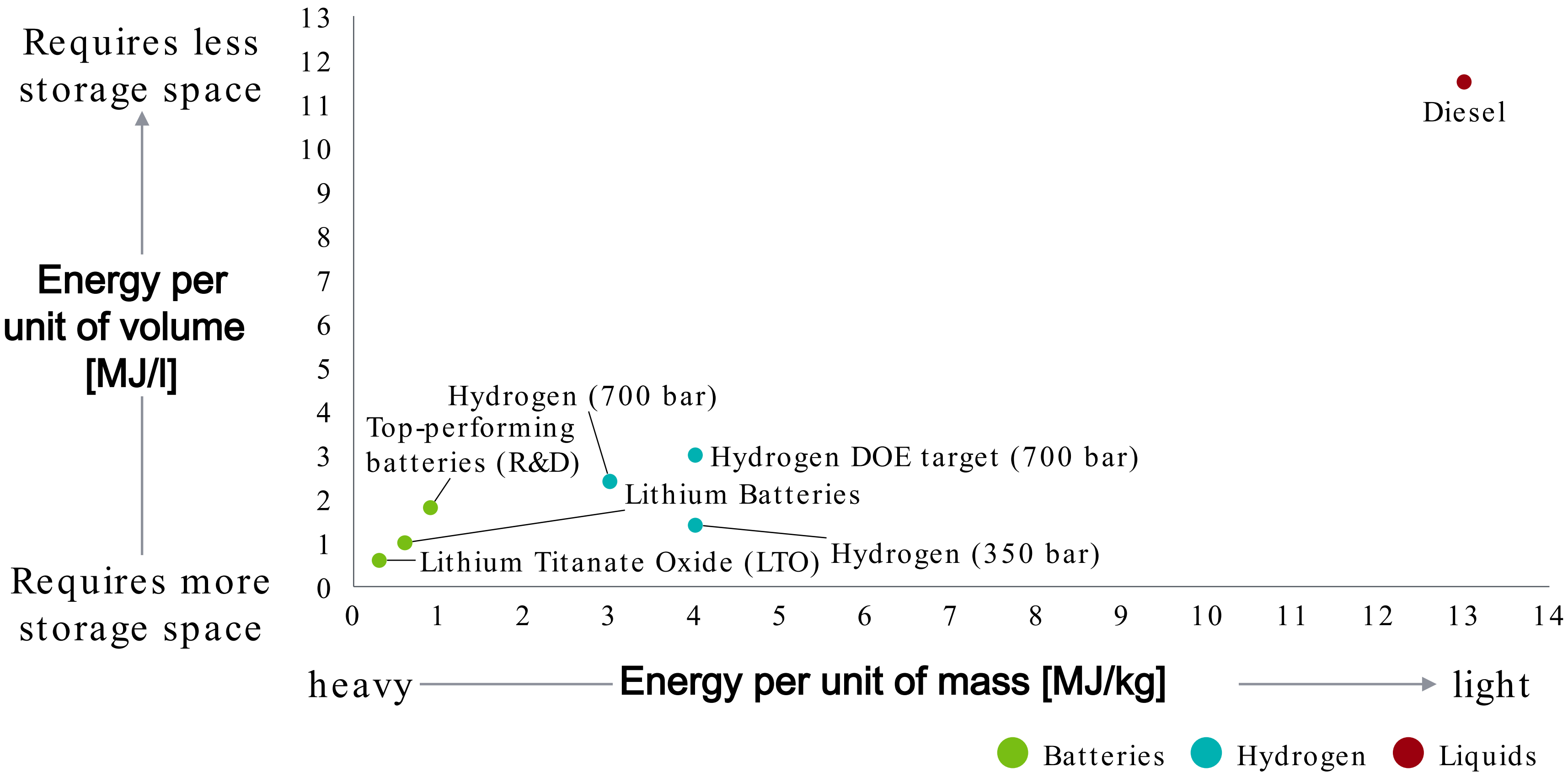
Long-term solution for many railways

(a) In addition: power generation on railcars (e.g., solar) to reduce HEP load (b) By legislation or voluntarily
(c) Use existing or planned OCS infrastructure, electrification of challenging or busy sections

Why are we still using liquid hydrocarbon fuels?

Although not zero emission, they are best from an energy density perspective

Energy density comparison including tank system and powertrain efficiencies



- Liquid fuels, such as diesel, require the least space and are lightest
- Challenging to implement alternatives due to densities
- A one-for-one replacement with changes in expectations is difficult to achieve (e.g., range, refueling time, refueling frequency)

Source: IEA (2009), Johnson Matthey (2017), Hexagon (2019), DB analysis

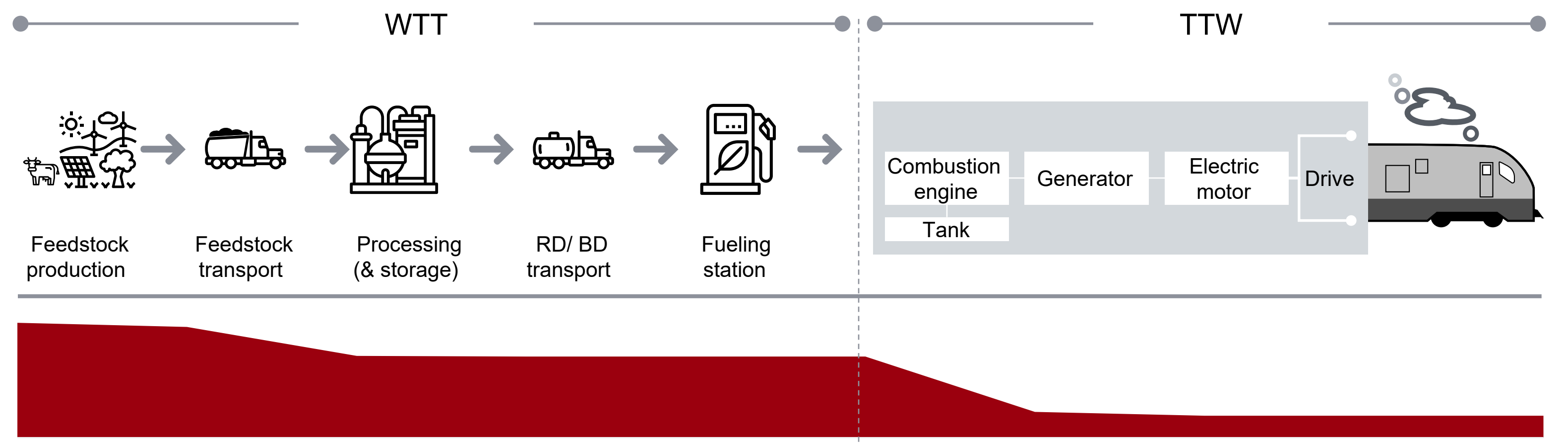
Low Emissions: Alternative Fuels
General Overview

Description

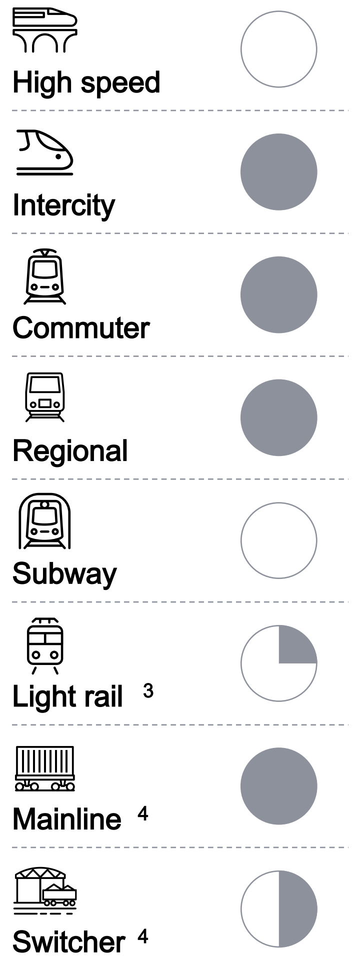
- Biofuels and synthetic fuels
- Renewable diesel (RD), e.g., Hydro treated vegetable oil (HVO), and biodiesel (BD) fuels are alternatives to traditional ULSD[1] that produce less air pollution and reduce GHG emissions, primarily in the production process
- RD uses plant/animal (by)products that are upgraded with hydrogen; BD uses plant/animal products with esterification during production. Both are equivalent / nearly equivalent energy density to ULSD
- Higher blends of BD have significant thermal restrictions – poor performance in cold weather. Lower blends (e.g. B20) generally ok.
- Several transportation agencies, mostly on-road, are using RD, or BD blends. Only moderate adoption in the rail industry to date
- RD and BD blends are already used in the US for rail, with total contribution of ~5%, this share can be increased
- Zero emission at the point-of-use cannot be achieved with either fuel type as combustion with air and the fuel is a hydrocarbon
- Significant well-to-wheel GHG and point of use CAP reduction potential, particularly if domestic 2nd or 3rd generation feedstock utilized or waste products from other industries

Energy supply chain

Efficiency



Current application [2]

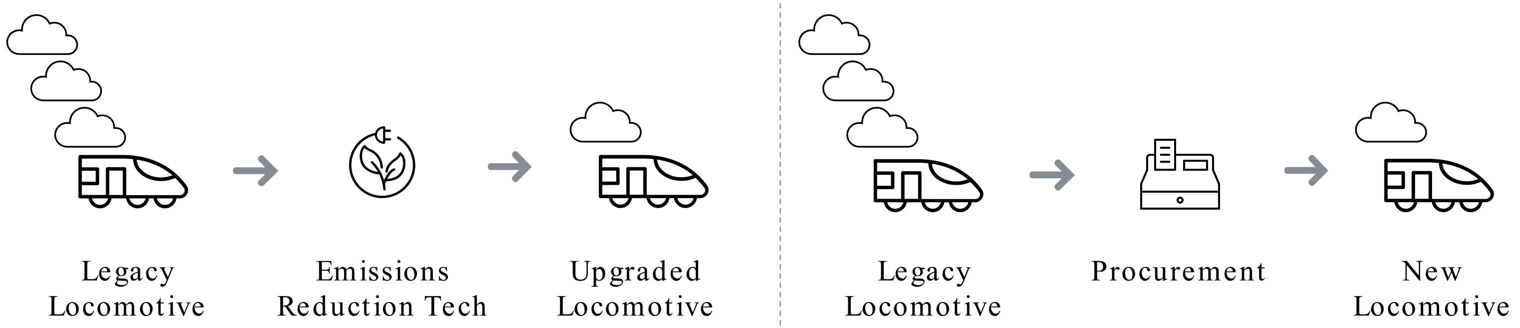


Suitable Not suitable

(1) Ultra Low Sulfur Diesel (2) Pending testing and approval by owner agencies
(3) Most light rail are electrified (4) In general suitable; Trials started

Low-Emissions: Reduction Technologies
General Overview

DB

Description	– Primarily targeted at reduction of criteria air pollutants – Newly purchased locomotives often have emission reduction technology already installed, e.g., to meet Tier 4 – Emissions reductions can be achieved by engine modifications, engine replacement (prime mover and HEP[1]), retrofit emissions reduction systems, and new locomotives – Legacy locomotive prime movers and HEPs can be removed and replaced with cleaner burning (i.e. EPA Tier 4) engines – Engines can be modified with technologies such as ECO-tip injectors and/or exhaust gas recirculation to reduce emissions – Emissions reduction technologies (e.g. Selective Catalytic Reduction systems) can be installed to reduce emissions – Replacement locomotives and engines (prime movers and HEPs) are commercially available – Modification of existing engines and retrofit emissions reduction systems are mostly in developmental stages, more research and testing needed – Agencies should consider fleet EOL, cost-benefit impacts, and future ZE / net-zero strategies prior to implementation
Implemen - tation	

Current application

High speed	Not suitable
Intercity	Suitable
Commuter	Suitable
Regional	Suitable
Subway	Not suitable
Light rail [2]	Partially suitable (quarter-filled circle)
Mainline	Suitable
Switcher	Suitable

● Suitable ○ Not suitable

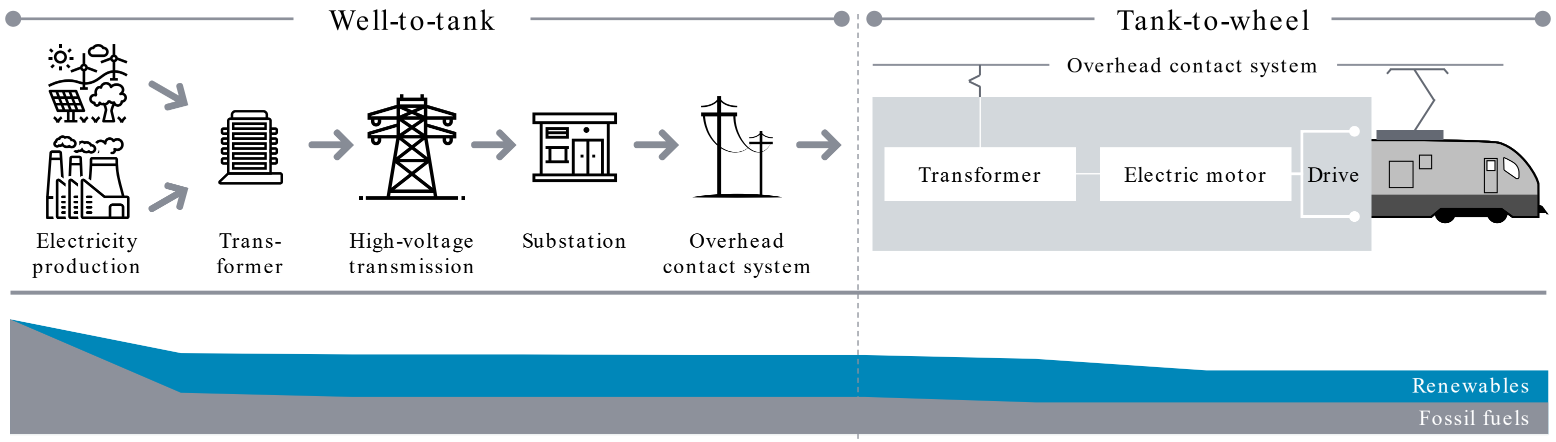
(1) Head End Power (2) Most light rail are electrified

Wayside electrification
General Overview

Description	– Power provision through wayside electrification and use of electric motive power vehicles is one of the most common technologies for railways. The technology is often employed on lines with frequent service, such as subways, and in very high-power demand situations, such as high speed rail – Electric motive power vehicles offer the best operational performance with fast acceleration, high speed capability, high tractive effort, and low vehicle maintenance – The biggest challenge is the expensive wayside infrastructure, which is particularly challenge for long routes and large networks – The visual impact of electrification infrastructure has led to alternative options in some situations, e.g., in historic city centers – There are many situations where electrification is not feasible due to infrastructure characteristics of the railway or due to economical considerations.

Energy supply chain

Efficiency



Current application

High speed	Suitable
Intercity	Suitable
Commuter	Suitable
Regional	Suitable
Subway	Suitable
Light rail	Suitable
Mainline	Suitable
Switcher	Suitable

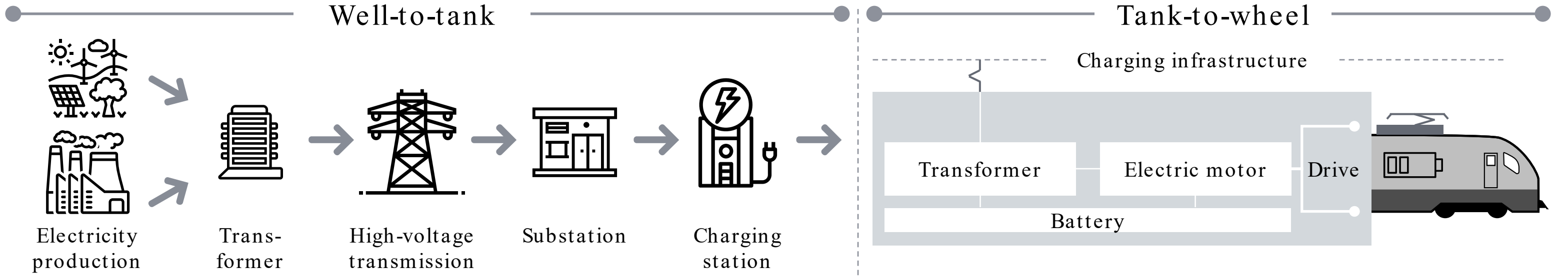
● Suitable ○ Not suitable

Batteries
General Overview

Description

- To charge, wayside power supply is required, such as sections of electrification or charge bars. Existing wayside electrification can be used to charge batteries and supply traction current on routes where part of the journey is on electrified sections
- Typical, practical operating range on batteries is 20-60 miles followed by charging, requiring >45min. Much shorter operation (~2-3miles) combined with frequent 'flash' charging from infrastructure is possible, becoming increasingly popular in light rail applications.
- Batteries can be used in hybrid powertrains, where two or more power sources are available on the vehicle. The batteries can enable regenerative braking and allow operation of the primary power plant in the most efficient region reducing energy consumption and subsequent emissions.
- Improvements in energy density, both gravimetric and volumetric, faster charging, and price reductions are anticipated, widening the suitability of the technology to more railway services.

Energy supply chain



Efficiency

Current application

High speed	Not suitable
Intercity	Not suitable
Commuter	Not suitable
Regional	Suitable
Subway	Not suitable
Light rail	Suitable
Mainline	Not suitable
Switcher	Suitable

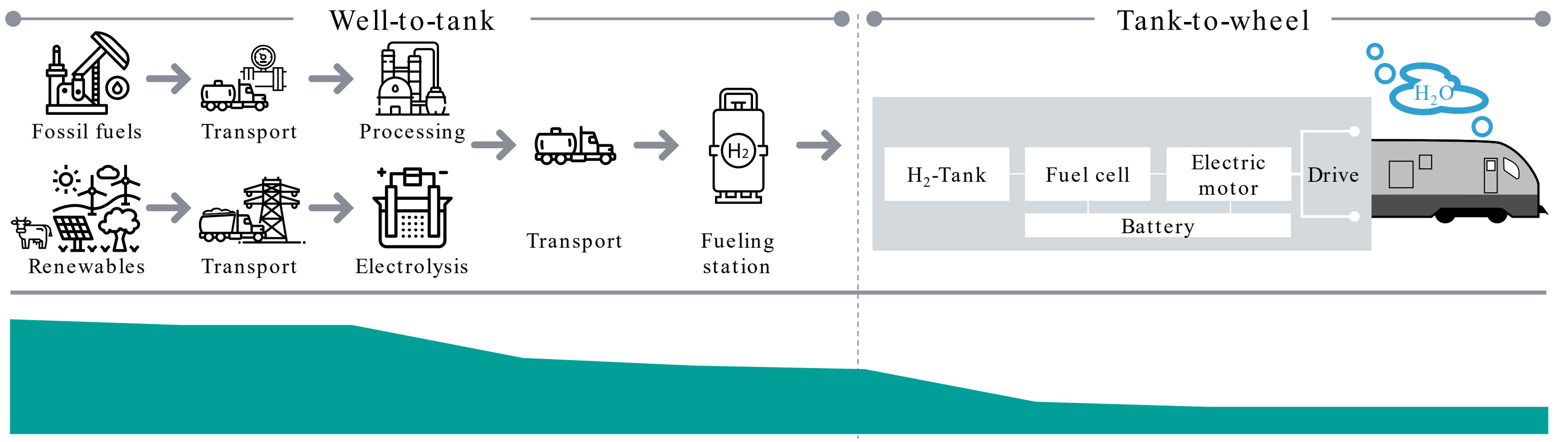
● Suitable ○ Not suitable

Hydrogen (Hydrail) General Overview

Description	– Offers good technical performance with similar flexibility and versatility as diesel. – Most hydrail vehicles have a hybrid powertrain with batteries. – Can be competitive with diesel when low price hydrogen is available. Often economically attractive on routes longer than 20 miles, especially compared to electrification, and where batteries are not practical. – Low-priced hydrogen is already available at high consumption; renewable hydrogen prices are becoming increasingly competitive and are already very attractive in some locations, leading to lower operating cost than conventional diesel vehicles. – The technology has great potential for most railway applications; for long ranges combined with relatively infrequent refueling a tender might be required. – Refueling time is similar to diesel, for example, ~15min for a regional train. – Significant cost reduction for powertrain components and refueling infrastructure expected. – System effects with other sectors, especially renewable power generation (wind, solar) can be realized.

Energy supply chain

Efficiency



Current application

Application	Suitability
High speed	Not suitable
Intercity	Not suitable
Commuter	Not suitable
Regional	Suitable
Subway	Not suitable
Light rail	Suitable
Mainline	Not suitable
Switcher	Not suitable

● Suitable ○ Not suitable

High -level assessment

Suitability of motive power technology depends on the application

	Passenger						Freight	
	High speed	Intercity	Commuter	Regional	Light rail	Subway	Mainline	Switcher
	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
	Not suitable	Suitable as hybrid	Suitable as hybrid	Suitable	Suitable	Not suitable	Suitable as hybrid	Suitable
H_2	Not suitable	Suitable	Suitable	Suitable	Suitable	Not suitable	Suitable	Suitable

Suitable | Suitable as hybrid | Not suitable

Source: DB E&C USA assessment

Steps in the decarbonization of freight and passenger rail transportation

Strategy, implementation planning, asset development, and implementation

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- **ZE Strategy development**
- Well to wheel energy analysis
- Emissions modeling
- Inventory assessment
- Technology Road Map/ Transition Strategies
- **Route performance modeling & simulation**
- Infrastructure assessment
- Technology specification
- Technology integration planning
- System design & development
- Infrastructure Specification design
- Vehicle technical specification design
- Fleet conversion planning
- **Pilot / prototype project planning**
- Procurement support
- **Design review and approval**
- Component & vehicle FAI support
- Testing & commissioning support
- Pilot integration & certification
- Training development
- Early operations

THANK YOU!

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Photo courtesy of Doug Boulton