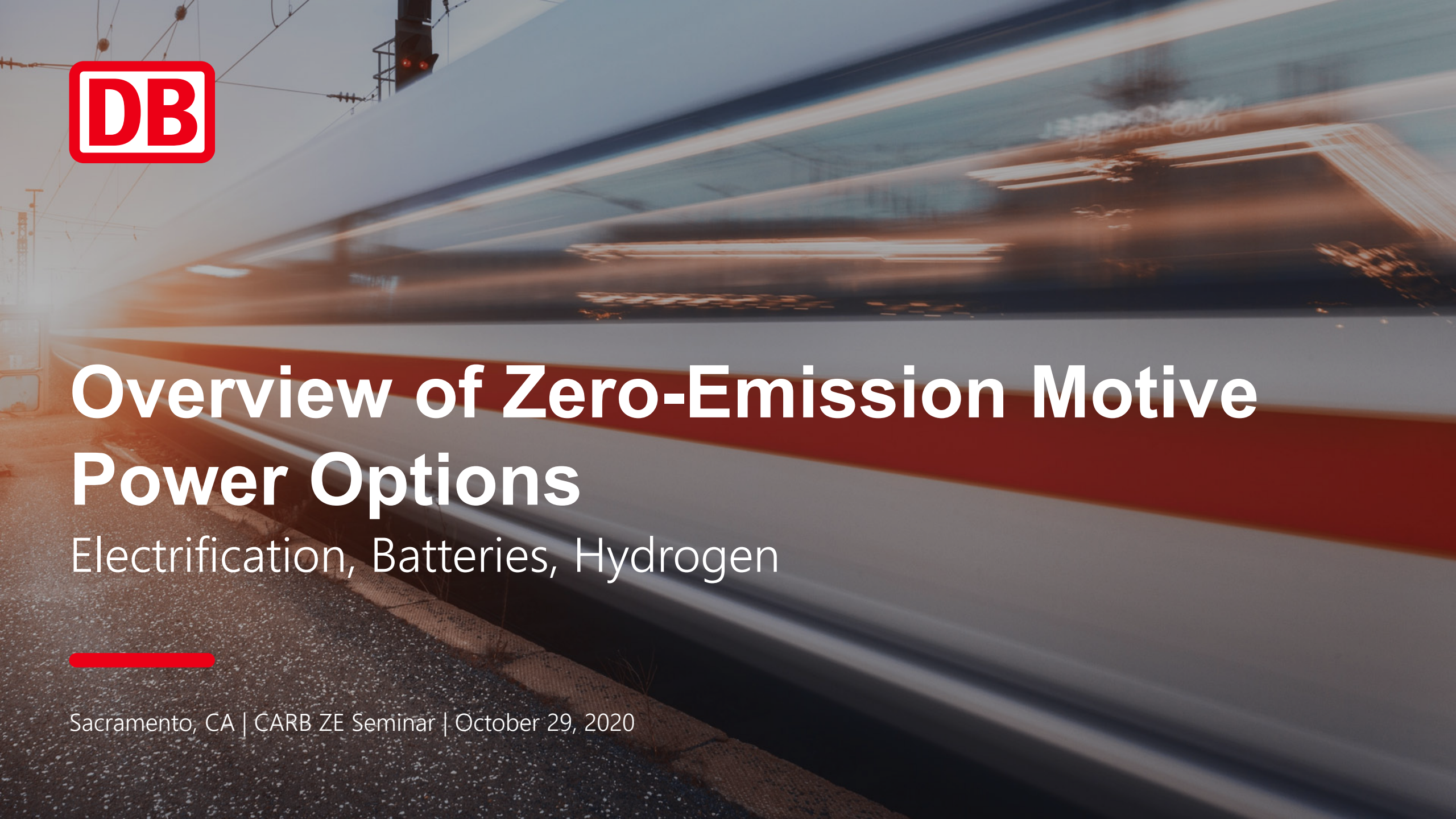


# Overview of Zero-Emission Motive Power Options

## Electrification, Batteries, Hydrogen

Sacramento, CA | CARB ZE Seminar | October 29, 2020

# DB is one of the largest rail companies with leading market positions in Europe and the world

Our Group

**Deutsche Bahn** DB

On **33,200 kilometers** more than **25,000 bridges** and **700 tunnels** in the railway network of the DB

Around **7.4 million** passengers a day on trains and buses in Germany

**5,700 stations** in Germany

Every day, around **4,350 freight trains** and over **1 million metric tons of goods** by rail

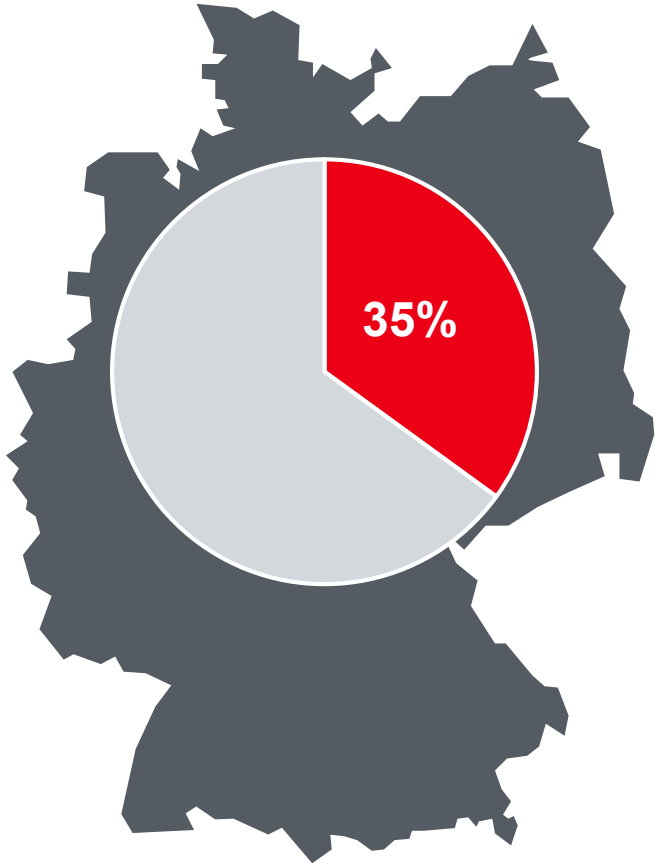
Data as of March 2018

Photography: Deutsche Bahn AG/Barteld Redaktion

# DB faces the challenge to reduce emissions significantly

## Three options to enable zero-emission motive power and traction

**Proportion of diesel motive power in Germany's regional rail passenger transport**




**Ways to achieve zero emissions**

***Wayside electrification***
*Electrification of rail lines*
*Power supplied via overhead contact system*

***Battery-powered trains***
*Electrification of vehicles*
*On-board batteries charging via (partial) overhead contact system*

***Hydrogen trains***
*Electrification of vehicles*
*Refueling with hydrogen and on-board power conversion*

# Power provision

## Our goal is to use 100% renewable power for our traction current[1] by 2038


**Proportion of renewable power supply**
**in the DB traction current mix[1]** *[in %]*


- **Motive power** options that are zero-emission during operation are already available for all railway service segments.
- **Low carbon and renewable power sources**, are essential for sustainable operation, as the impact of power supply must be considered when changing motive power options.
- **Electricity** is employed to provide power for traction current on wayside electrified lines, to charge batteries, and can be utilized to produce hydrogen. The use of low- and zero-emission sources is essential.
- Hydrogen can be produced from many feedstock, like electricity. Employing low- and zero-emission sources is essential.
- **DB is already** the eco-pioneer of the transportation sector in Germany, with ~60% of the traction current used by DB rail companies coming from renewable power. Our aim is to increase this proportion to 100% by 2038.

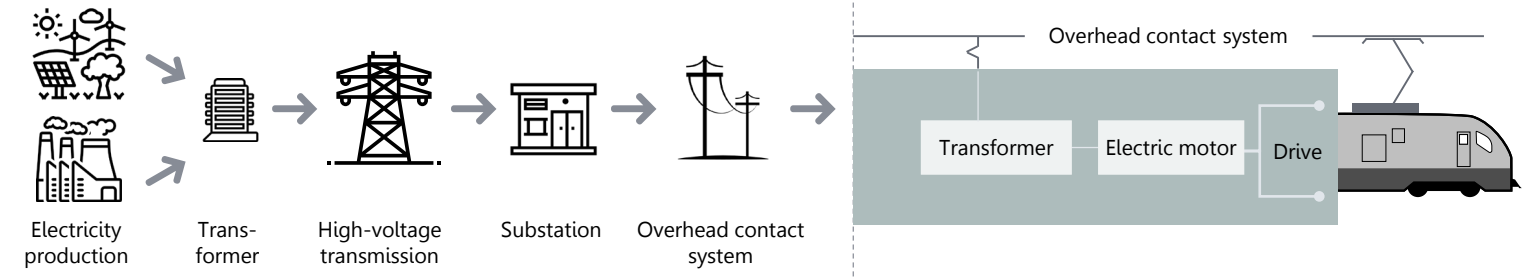
(1) For wayside electrified lines

# Wayside electrification
## General Overview

**De-scription**

- 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 presents particular difficulties 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 network or due to economical considerations.

**Energy supply chain**




**Efficiency**


**Current application**

- **High speed**[1]
- **Intercity**
- **Commuter**
- **Regional**
- **Subway**
- **Light rail**
- **Mainline**
- **Switcher**

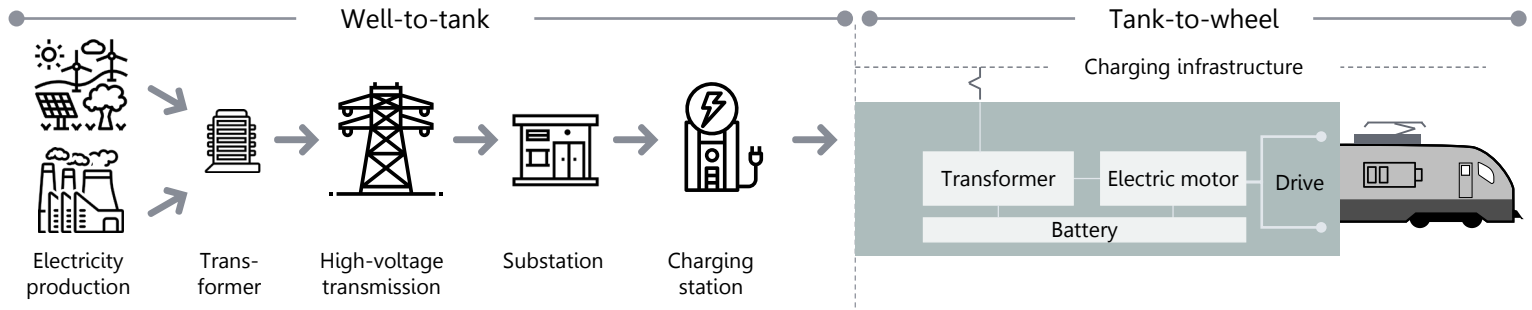
(1) >125 mph

# Batteries
## General Overview

**De-scription**

- 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 (if the batteries are close to empty). 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[1] | ○ |
| Intercity | ○ |
| Commuter | ○ |
| Regional | ● |
| Subway | ○ |
| Light rail | ● |
| Mainline | ○ |
| Switcher | ● |

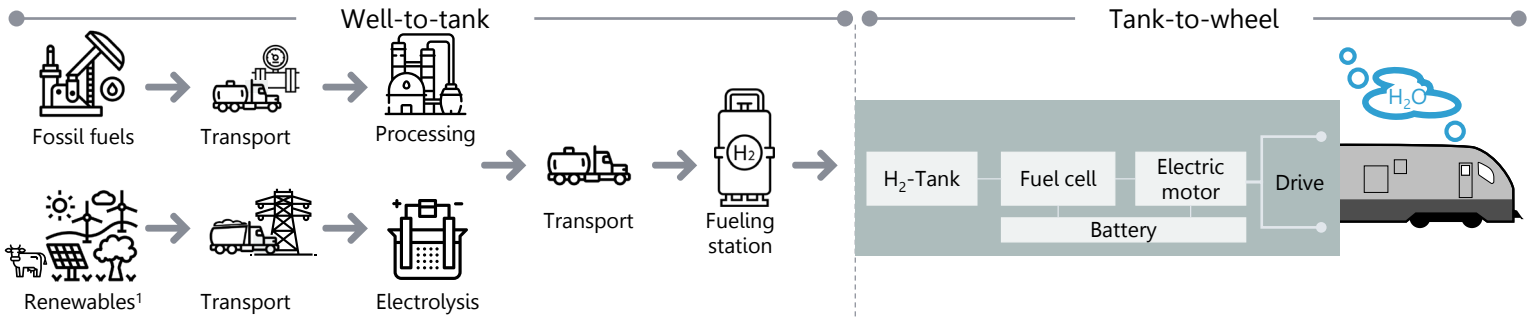
(1) >125 mph

# Hydrogen (Hydrail)
## General Overview

**De-scription**

- Offers good technical performance with similar flexibility and versatility as diesel.
- Most hydrail vehicles have a hybrid powertrain with batteries.
- Often economically attractive on routes longer than 20 miles, especially compared to electrification, and where batteries are not practical.
- Can be competitive with diesel when low price hydrogen is available. 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. Hydrogen could be stored on-board as a gas (the option in most vehicles, including current rail motive power), liquid, or through other means, e.g., metal hydrides.
- 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**

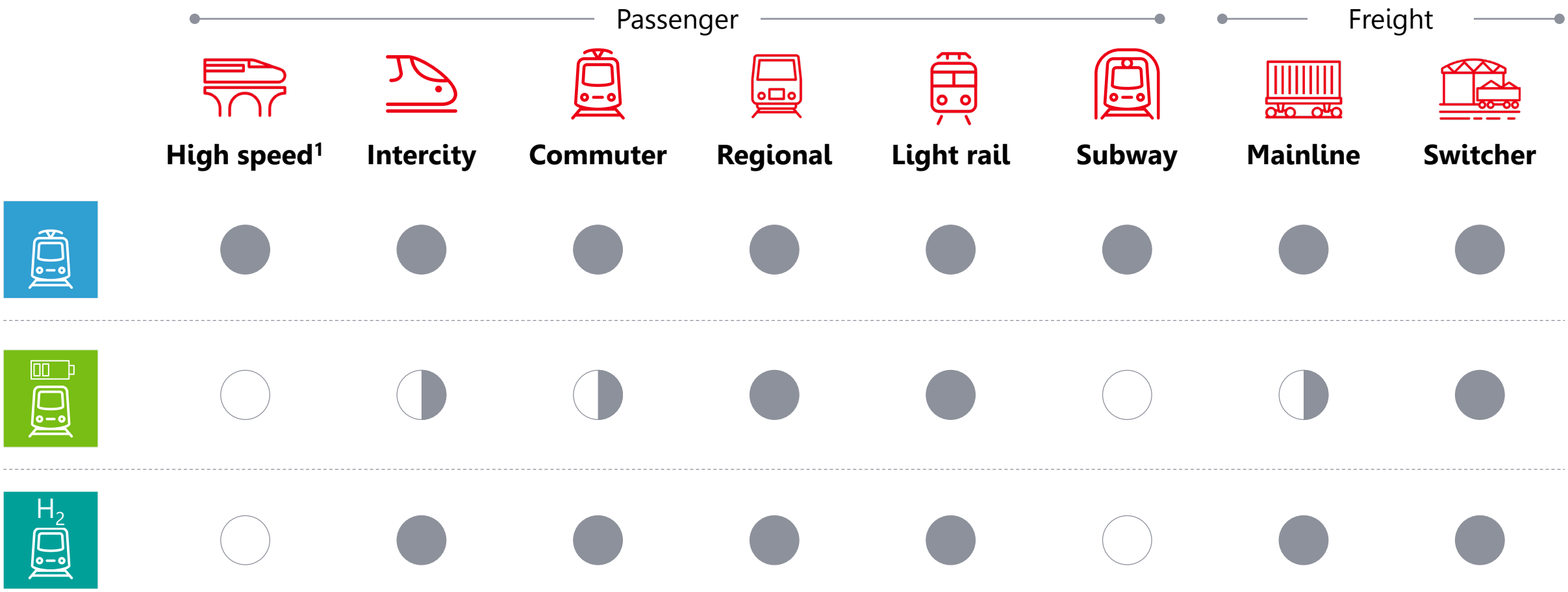
**Current application**

| | |
|---|---|
| High speed[1] | ○ |
| Intercity | ○ |
| Commuter | ○ |
| Regional | ● |
| Subway | ○ |
| Light rail | ● |
| Mainline | ○ |
| Switcher | ○ |

(1) >125 mph

# High-level assessment

## Suitability of motive power technology depends on the application




(1) >125 mph
Source: DB E&C USA assessment

Suitable | Suitable as hybrid | Not suitable

# Thank you

If you have any questions, feel free to reach out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