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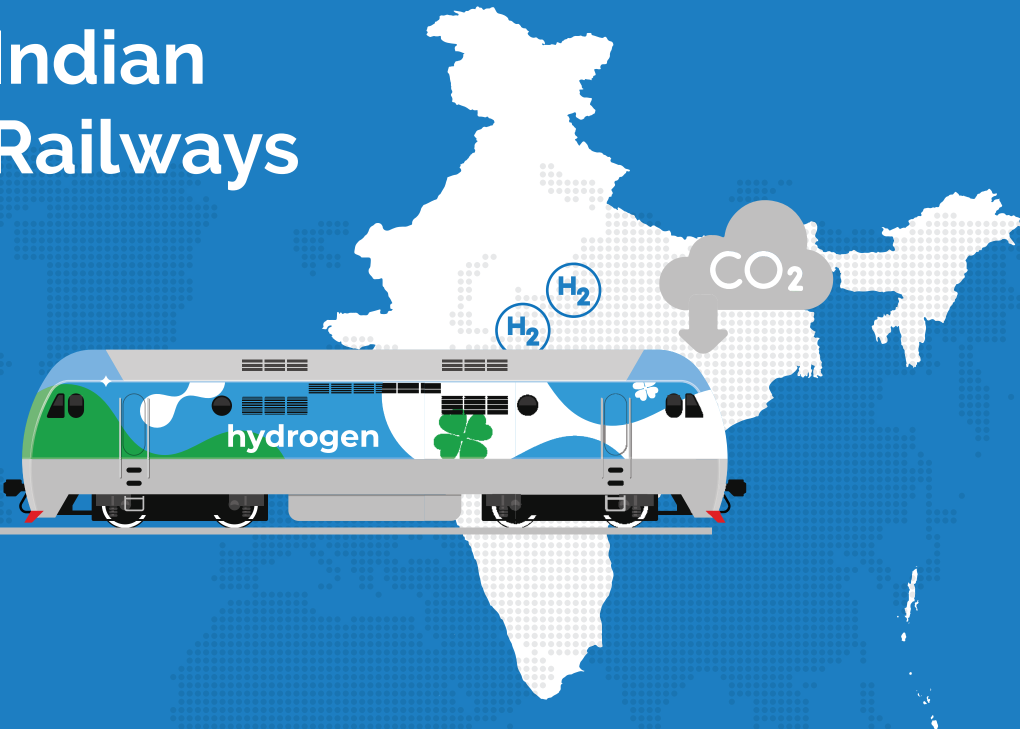
CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

Potential and Challenges of

Using Hydrogen to Decarbonise Indian Railways



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BACKGROUND

The Indian Railways, one of the biggest train networks worldwide, transports over 24 million passengers and 3 MT of freight daily. It is a major energy consumer in the country with a significant emission footprint. To overcome these challenges, the government has set a target to achieve 100% electrification of the railway network by 2024. Currently, 80% of the routes have already been electrified. However, the cost effectiveness and technical feasibility of complete electrification in areas with low grid access or inaccessible terrain or in routes with low frequency remain unclear.

In this regard, the Indian government is looking at the possibility of running hydrogen-powered trains, with an initial use case on eight heritage routes with harsh hilly terrain. The Indian Railways has planned to introduce 35 hydrogen trains under the 'Hydrogen for Heritage' initiative, at an estimated cost of INR 80 crore per train. In addition, the Indian Railways has initiated a pilot project to retrofit a Diesel Electric Multiple Unit (DEMU) rake with hydrogen fuel cells and related ground infrastructure.

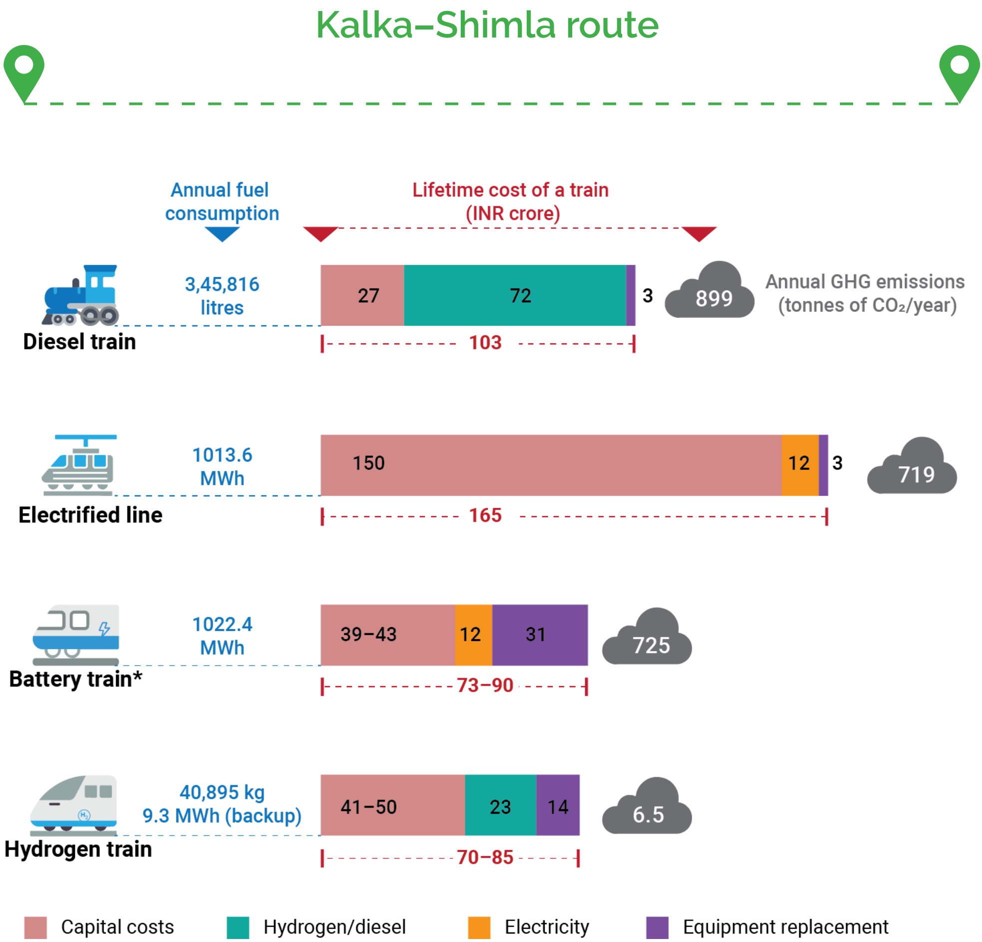
Despite the high density of electrified lines, there remain potential use cases of green hydrogen in railways, such as those in hilly terrains and industrial shunting yards. The uptake of green hydrogen in the railways will also be mutually beneficial for the larger hydrogen economy. At these early stages, increasing the scale of green hydrogen production can help reduce the costs of fuel and associated technologies and drive further penetration of hydrogen into other sectors of the Indian economy.

However, these benefits remain in theory. In this context, an investigation on these hydrogen-powered trains is required. In this regard, the Center for Study of Science, Technology and Policy (CSTEP) conducted a study to examine the feasibility of using green hydrogen on existing railway routes. The technical feasibility and cost effectiveness of hydrogen were assessed based on the following two use cases in Indian Railway routes with challenges in electrification:

- Kalka–Shimla route, a hilly terrain
- Industrial shunting yard route, used by Public Sector Undertakings (PSUs)/ private industries

A hydrogen-powered train was modelled and compared with electric-powered trains (comprising both battery-powered trains and electrified lines) as well as the existing diesel trains. The comparison was made based on the existing technical requirements for locomotives, the lifetime costs of the train, and the associated carbon dioxide emissions. Our findings provide insights into the economic and environmental feasibility of these alternatives for the Indian Railways.

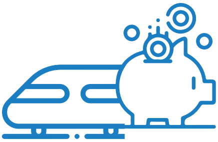
Insights



GHG: Greenhouse gas

**Battery trains exceed the specified weight limit, which is a technical limitation.*

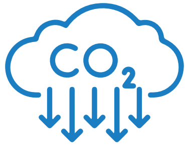
Refer to the Appendix for route parameters.

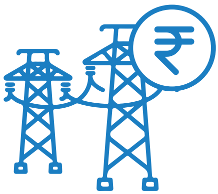


In contrast to existing diesel trains, hydrogen-powered trains offer an **overall lifetime cost savings of INR 18–33 crore.**

The capital expenditure (CAPEX) of the hydrogen trains is higher than that of existing diesel trains (INR 41–50 crore vs INR 27 crore). However, this is compensated by the higher efficiency and calorific value of hydrogen, thereby saving over INR 50 crore in fuel costs over a 30-year period.

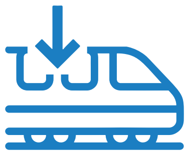
Hydrogen-powered trains also lead to an **annual reduction in emissions of over 892 tonnes of CO_2.**





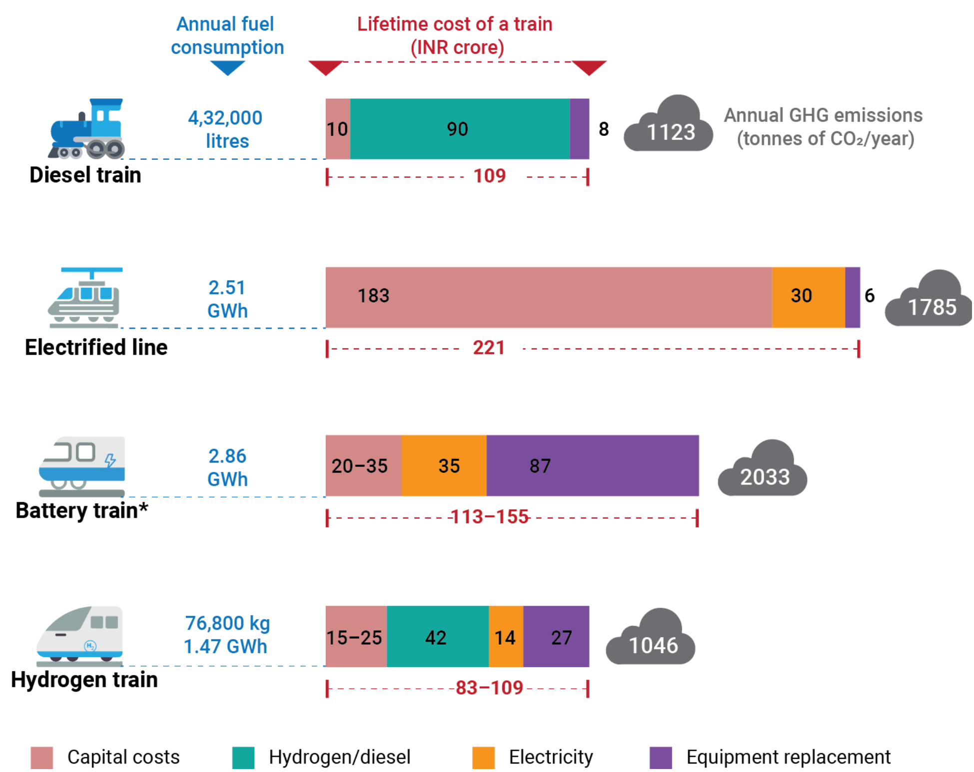
The cost of electrifying the entire Kalka–Shimla route **(INR 165 crore) is more than double the lifetime cost of other alternatives** considered, given the low frequency of locomotives required in the route.

The modelled battery-powered train was excessively large and exceeded the weight allowance. Hence, **battery-powered trains cannot be further considered presently**. However, in view of different circumstances (for example, change in regulations), the financial modelling was still conducted.



Overall, fuel cost savings are expected in case of any electric train (INR 12.5 crore) compared with hydrogen trains (INR 22 crore), given the higher efficiency. However, replacement of batteries over a 30-year period is expensive and may ultimately lead to similar lifetime costs (INR 73–90 crore for battery-powered trains).

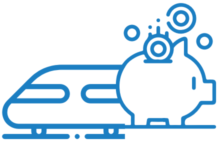
Industrial shunting yard route



GHG: Greenhouse gas

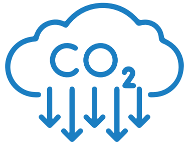
**Battery trains exceed the specified weight limit, which is a technical limitation.*

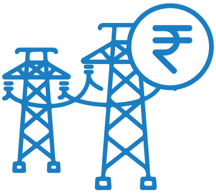
Refer to the Appendix for route parameters.



In contrast to existing diesel trains, hydrogen-powered trains offer an **overall lifetime cost savings of up to INR 26 crore.**

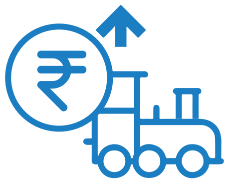
Hydrogen-powered trains also lead to an annual reduction in emissions of **77 tonnes of CO_2.**

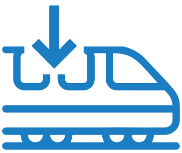




Electrifying the entire industrial shunting yard line is **extremely expensive (lifetime costs of over INR 221 crore)**, given the low frequency of locomotives required in the route.

The **lifetime cost** of diesel trains exceeds **INR 109 crore**, with diesel fuel costs of over INR 80 crore.



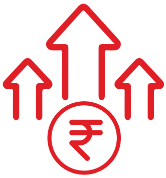


The modelled battery-powered train was **excessively large and exceeded the weight allowance**. Hence, battery-powered trains cannot be further considered presently. However, in view of different circumstances (for example, change in regulations), the financial modelling was still conducted.

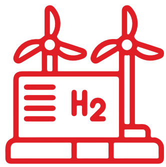
Overall, fuel cost savings are expected in case of any electric train (INR 30–35 crore) compared with hydrogen trains (INR 57 crore), given the higher efficiency. However, the replacement of batteries over a 30-year period is expensive and may ultimately lead to higher lifetime costs (INR 113–155 crore for battery-powered trains).

Challenges

Hydrogen is **gaseous and explosive** in nature. The use of hydrogen in the Indian Railways would require **additional safety precautions** to be factored in during the design and operation of trains.



Owing to the **low adoption rate** of hydrogen technologies the associated **initial costs are high** and domestic suppliers are inadequate. This stems from a lack of technology dissemination, capital, and critical minerals.

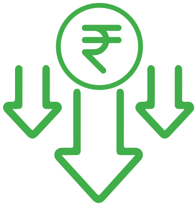


The current study considered a green hydrogen cost of INR 492/kg (or USD 6/kg). However, running a single train on both tracks requires **117 tonnes of green hydrogen** annually. Currently, India has not scaled up the manufacturing of green hydrogen to meet such a demand. To operate hydrogen-powered trains today, the country will have to **heavily rely on green hydrogen imports**.

Uncertainties also remain due to the potential **lack of demand for hydrogen trains** and their extent of implementation across Indian Railway routes in the future.

Building **un-electrified lines** for hydrogen locomotives is also a challenge to connecting existing/ future electrified lines.

Opportunities



Presently, the fuel cost of hydrogen-powered trains is 21% more than the diesel cost of conventional trains. However, a considerable **decrease in the cost of green hydrogen** is expected owing to the **increased penetration of renewables**. Further, there is immense scope for **cost reduction in the nascent hydrogen technologies** (including electrolysers, fuel cells, and storage technologies), which could lower the lifetime costs of hydrogen trains.

Hydrogen-powered trains **can be employed in conjunction with electric-powered trains**, with possible synergies in renewable energy production having the potential to unlock greater emission reduction in the overall railways sector.

Currently, the hydrogen economy in India is only focused on the industrial sector, with minimal green hydrogen production. Through the **wider adoption of hydrogen-powered trains**, the benefits of technology and fuel production may also help overcome the barriers to entry in other sectors of the Indian economy.

Way ahead

The recent budget had relevant takeaways in this matter, from the 'Hydrogen for Heritage' routes and increased promotion of renewable energy to the setup of additional rail corridors in the country. The National Hydrogen Mission also acknowledges the potential role of the Railways Ministry. The Indian Railways can help aid the advancement of hydrogen technologies by taking the following steps:

- **Pilot projects:** To gain a better understanding of the current and potential capabilities of operations, pilot projects must be conducted by the Indian Railways in the future.

- **Route supply chains:** Additional effort will also be required in building backward linkages in selected heritage routes. This includes storage facilities, fuel transportation means (such as pipelines and trailer trucks), and refuelling stations.

- **Identification of suitable routes:** For routes with a low frequency of locomotives, hydrogen trains hold a cost advantage over electrified ones. To identify such suitable routes, a study should be conducted on the brownfield and greenfield projects of hydrogen trains, filtered through the lens of the Indian Railways' track expansion strategy.

In addition, while the Railways will be the implementation authority for hydrogen trains, support is also required from the renewables and environment ministries and PSUs to first build an overall system capable of supporting the hydrogen demands of railways.

- **Mandates:** Given the presence of internal railway tracks in PSUs, the government can mandate hydrogen usage in industrial shunting zones to a greater extent and promote the dissemination of hydrogen-powered locomotive technologies.
- **Clean air action plans:** The use of hydrogen-powered trains should be considered a control measure in building regional clean air action plans. Beyond fuel savings, the implementation of hydrogen trains can help in reducing emission of greenhouse gases and particulate matter in environmentally protected areas/industrial red zones where diesel trains currently ply.
- **Domestic manufacturing strategy:** Hydrogen trains require a large supply of green hydrogen and components such as fuel cells and storage cylinders. A clear manufacturing strategy is required to meet the demands in a cost-effective manner. The strategy must include clear manufacturing targets, financing, and other enabling schemes (such as production-linked incentives, subsidies, and tax rebates).
- **Aggregation programmes:** CAPEX-intensive fuel cell and electrolyser costs can be reduced through large-scale manufacturing (economies of scale). To achieve this, it is vital for manufacturers to receive bulk orders; thus, there is a need to aggregate the demand from different operators (Indian Railways and private operators). Demand aggregation of e-buses across the country by Convergence Energy Services Limited (CESL) is a relevant example in this regard.

Appendix

Railway use cases for decarbonisation

a. Kalka–Shimla route

The Kalka–Shimla route is a narrow-gauge railway, travelling across a mountainous route (approximately 96 km) starting from Kalka (altitude 656 m) to Shimla (altitude 2276 m). This is a 'heritage route', renowned for its scenic views, and multiple iconic toy trains operate on this route. Each toy train consists of a limited number of 5–7 carriages designated for passenger transportation.

Diesel (base)

A 522 kW (or 700 hp) locomotive is used for trains running on this route. Apart from the initial capital expenditure (CAPEX), the fuel cost and equipment replacement cost, with an expected overall lifetime of 30 years, were considered in the study. The technical requirements of any replacement of a diesel locomotive require matching the train's power requirements while maintaining the maximum permissible weight and volume in the locomotive. As per the Railway Development and Standards Organisation (RDSO), for the Kalka–Shimla route, the weight and volume allowance for retrofitting all components is limited to 9.25 tonnes and 32.64 cubic metre, respectively.

Conditions	
Hydrogen-powered train	• Given the cost variance in literature, the cost of a fuel cell is considered over a range, from INR 23,370 per kW to INR 1,02,500 per kW. • Pressure at which hydrogen is stored is 350 bar. • Current cost of green hydrogen production is INR 492/kg. • Fuel cell system (450 kW) is paired with lithium (Li)-ion battery (for meeting peaking and backup energy requirements). • Amount of hydrogen required for a round trip is 136 kg.
Battery-powered train	• Cost of electricity for Indian Railways is INR 7/kWh. • Given the cost variance in literature, the cost of a Li-ion battery is considered over a range, from INR 12,400 per kWh to INR 20,500 per kWh. • Battery is required for a round trip duration of 6.5 h.
Electrified lines	• Backup power by battery will be required for a duration of 60 min. • Cost of laying overhead infrastructure is INR 1.35 crore/km, with an additional cost factor of 20% assumed for hilly terrains.

b. Industrial shunting yards

Several major industries possess their own internal railway tracks for transporting goods and facilitating material transfer within their yards. Typically, these industries maintain 3–4 locomotives to efficiently pull heavy loads. These locomotives cover relatively short distances and operate for approximately 9–13 hours per day. Our model considers one such large industrial site in the country.

Diesel (base)

An 1193 kW (or 1600 hp) locomotive is used for running the trains on this route. Apart from the initial CAPEX, the fuel cost and equipment replacement cost, with an expected overall lifetime of 30 years. The shunting trains run for approximately 8 h per day, with a speed of 15–20 km/h. An estimated 400 km of the railway network is set up within the modelled industrial site. The technical requirements of any replacement of a diesel locomotive require matching the train's power requirements while maintaining the maximum permissible weight and volume in the locomotive. For the industrial shunting yard route, the weight and volume allowance for retrofitting all components is limited to 20.3 tonnes and 164 cubic metre, respectively.

Conditions	
Hydrogen-powered train	• Given the cost variance in literature, the cost of a fuel cell is considered over a range, from INR 23,370 per kW to INR 1, 02,500 per kW. • Pressure at which hydrogen is stored is 350 bar. • Current cost of green hydrogen production is INR 492/kg. • Fuel cell system (800 kW) is paired with a 314 kWh Li-ion battery. • The amount of hydrogen required for a round trip is 256 kg.
Battery-powered train	• Cost of electricity for Indian Railways is INR 7/kWh. • Given the cost variance in literature, the cost of a Li-ion battery is considered over a range, from INR 12,400 per kWh to INR 20,500 per kWh. • Battery will be required for a round trip duration of 10 h.
Electrified lines	• Backup power by battery will be required for a duration of 30 min. • Cost of laying overhead infrastructure is INR 1.35 crore/km.

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