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Review article

A review of novel energy options for clean rail applications

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A R T I C L E I N F O

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A B S T R A C T

In this review paper, some novel energy options for clean rail applications are discussed and evaluated. Rail transportation is of strategic importance and therefore a reliable, clean, sufficiently abundant and cost expensive fuel is required. It has been found that integration of selective catalytic reducer and increase of bio-diesel used (including blending with petrochemical diesel) may be an immediate solution which bring some benefits such as up to 50% reduction on environmental impact. However, accounting for the technical feasibility of the solution, the worldwide existence of a well-established infrastructure, high efficiency and lower emissions, the natural gas appears as a key potential option for the railway. Other reviewed technologies include the CNG, LNG-LPG, methanol, ammonia and hydrogen as fuels. Electrical railways represent a solution where large investment is available. Hydrogen, is most likely a solution for the far future, when an infrastructure could be set-up. The life cycle assessment shows high ecological advantages of NG with respect to the baseline diesel with average 15% decrease of environmental impact categories. A novel criterion has been used here to assess the environmental impact which is suitable for pollutant emitting applications such as railway transportation. This criterion is denoted as environmental impingement work of the polluting effluent which is calculated based on the chemical exergy of the polluting species. Chemical exergy is a true measure of the impingement (change, modification) produced by the pollutant on the environment. It is shown that the well-to-wheel environmental impingement of natural gas fuelled locomotive is inferior with at least 15% to diesel-electric locomotive equipped with a selective catalytic reducer. The environmental impact in terms of work impingement on the environment and environmental pollution cost are slightly similar for natural gas, ammonia, methanol and biodiesel fuels. The life cycle environmental impact categories of natural gas locomotive are overall 15% lower than for the conventional diesel-electric locomotive. According to our conclusion, liquefied natural gas is indicated as a prime potential option for clean rail transportation.

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1. Introduction

Human activities are essentially considered interrelated with transportation technology which influenced the world development in the past, it influences it at present and it definitely contributes to the shaping of the world future. Construction of roads and communication ways is expensive and laborious, requiring high investment. However, due to the high interest in infrastructure development for commercial and strategic uses, the construction, expansion and maintenance of communication ways have been on the agenda of many jurisdictions since old times.

The road and marine transportation were very well developed at the verge of nineteenth century when the railway era begun. It has been only in 1830 when the first ever public railway transportation system has been put in place demonstrating a travel speed of 30 km/h. Since then, 185 years passed and the technology evolved further with diesel electric and electric only locomotives until the today's high speed trains running at over 300 km/h. In Japan, the Shinkansen train can overpass 500 km/h. However, it is worth noting that the gauge of 1435 mm proposed by Stephenson for the pioneering railways is used until today, since this gauge has been adopted as a standard for railway construction worldwide. This shows how a past decision can influence the future development in long term.

Rail transportation is considered the best land transportation option due to many economic, social, energetic and environmental advantages. For example, rail transport represents a congestion-free traffic and high safety, reduced emissions and fuel consumption per passenger (or freight unit) transported, reduced use of land (three times less land requirement as compared with motorways) and high transportation speed. The main part of rail transport operations is due to freight transport, generally carried as cargos by light rail, heavy rail; in addition, goods are transported through tram, funicular and monorail means. Three modes of rail transport are used today: the unit train, the carload and the intermodal mode which integrates with the marine and road transport using trailers, containers and tanks. The rail cars run on single fixed-type and dual-type rails.

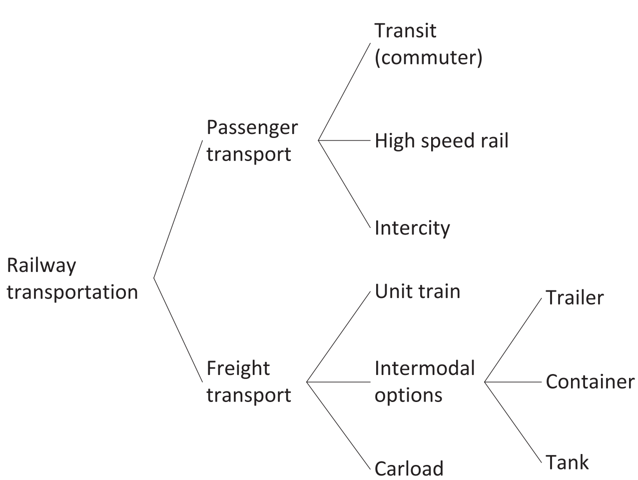

Fig. 1. Railway transportation modes and averaged carload for freight commodities.

Rail transportation established a development paradigm of humankind civilisation. As Georgescu-Roegen (1986) suggests, the burning of coal and/or wood in steam engine developed sufficient motive power in a ready-to-use manner such that minerals were much easily extracted and processed, railroads construction facilitated by better technology using machines, more and better steam engines, railroad locomotives and railcars were created. During the period of 150 years of marked domination of steam locomotives, the coal consumption increased "exponentially" worldwide and with this the GHG emissions into the atmosphere. The railroad success in creating more businesses stimulated the technological development such that the steam locomotive became obsolete as they are nowadays completely replaced by diesel-electric locomotives. In some limited jurisdictions, electric railways are constructed which allow for the use of electric-only locomotive.

Bejan and Lorente (2011) draw the attention about the universality of the paradigm change phenomenon that happens in any process when an initially abundant resource stimulates an exponential consumption and therefore the development. The paradigm change consists of the fact that due to the finiteness of resources, the development cannot be sustained and a decrease in growth rate must occur after a while; see also, Hubert peak theory in Hubbert (1949). The railway transport paradigm shifted today since the humankind reached a moment when the fossil fuel resources deplete fast due to the continuous growth of consumption, and, together with those, more of the negative impact of atmospheric pollutant is observed through the danger of global warming.

At present, the greenhouse gases (GHG) emissions due to diesel-electric rail locomotive operation is around 120 kt CO_2 equivalent per year with a projected increase rate of 2.8 kt/year for the next 15 years. These facts result from a past analysis of Dincer et al. (2015). In jurisdictions, such as Japan and European Union the electric train is extensively used, with electricity supplied by a power generation mix of that region. In general, grid power generation is based in majority on fossil fuel combustion (or even indirect fossil fuel combustion such as in nuclear power), therefore, the electric train solution is not entirely emission-free.

The specific energy consumption of rail transport is around 0.4 MJ per freight ton and km. Based on this indicator one deduces that 150 g or CO_2 are emitted in the atmosphere by coal-fired power stations to supply electricity for rail transportation of one ton for one km. In the same context one mentions that there is a positive annual growth rate of transportation sector as observed in past years and predicted for the near future. Mantzos (2003) predicts the growth rate of rail transport in European Union to 125% by 2020 implying about 1% of the European energy consumption and the corresponding amounts of GHG emissions due to energy resource utilization.

Multiple forms of pollution are involved and correlated with an increase of rail transport activity. Such pollutant emissions are mainly given, in averages, as follows: the CO emissions with 1.6 g/kWh, non-combusted hydrocarbons with 0.81 g/kWh, NOx with