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Hydrogen as an alternative energy source in railway vehicles

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The potential of hydrogen related to the popularization of alternative energy sources is confirmed by the "Green Deal" implemented by the European Commission, which aims to reduce CO_2 emissions in transport by 30% by 2030 and ultimately achieve climate neutrality by 2050. Additionally, the geopolitical situation in the world , characterized by increasingly difficult access to conventional energy sources, resulting in increasing costs of their purchase, confirms the validity of taking up the topic in the area of hydrogen drives in railway vehicles.

The article classifies fuels that power railway vehicles. Hydrogen fuel is presented as an alternative to powering railway vehicles. A review of railway vehicles and countries that currently have and are introducing hydrogen-powered vehicles. The advantages and threats of introducing hydrogen as a power source in railway vehicles are presented. Plans in Poland regarding the construction of hydrogen-powered railway vehicles and the planned construction of infrastructure accompanying the fuel in question were presented. The legal requirements accompanying the introduction of a railway vehicle powered by hydrogen fuel into operation in Poland are presented.

1. Introduction

For many decades, rail vehicles have been powered by different types of fuel. Initially, fossil fuels – coal (steam locomotive) – were used to power rail vehicles, and with the development of technology, the sources of vehicle power were changed, switching to oil, gasoline (in some countries) or electricity. Many techniques and sources are used to produce electricity. In Poland, electricity primarily comes from burning coal. In 2021, the amount of electricity coming from coal-fired power plants was 72% [6].

Admittedly, electricity is a good and ecological source that powers locomotives, electric multiple units, streetcars, trolleybuses or the increasingly popular electric buses and passenger cars. However, the guarantee of ecological use of these vehicles is the power supply provided by renewable energy sources.

Currently, environmental conditions force developing and developed countries to adopt more and more stringent regulations and directives aimed at lower greenhouse gas emissions into the atmosphere, and thus lower society's exposure to climate change, by using alternative and renewable energy sources [4]. One of the sectors of the economy that has a direct impact on climate change is undoubtedly transport [3]. The article focuses on rail transport, which is one of the most popular passenger transport.

Due to the above, the "Green Deal" has been implemented by the European Commission, the aim of which is to reduce carbon dioxide emissions in transport by 30% by 2030 and ultimately achieve climate neutrality by 2050 [8, 18], it is necessary to look for alternative energy sources that can efficient way to replace currently used technologies.

Taking into account the increasingly restrictive environmental regulations as well as the ongoing climate change in the world, the topic of finding alternative energy sources for passenger transport is an important issue for the industry in the coming years and decades. Among them, hydrogen is one of the most promising energy source for the near future [10].

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2. Review of rail vehicles and countries that currently have and are introducing hydrogen-powered vehicles was conducted

Comparing many branches of transport, railway is quite an economic and ecological means of transport [19], but continuous development requires the search for alternative energy sources.

Industry and society, as a result of increased awareness of environmental protection and the impact of the fossil fuels used, are looking for an economical, environmentally friendly and stable source of energy. One solution is to use hydrogen as a fuel and energy storage.

According to the Encyclopedia, hydrogen is a non-metal, a chemical element with an atomic weight of 1 discovered in 1766, which under standard conditions exists as a colorless, odorless gas. As the element with the smallest atomic weight, hydrogen forms many chemical compounds. Typically, hydrogen combines with nonmetals. In addition . hydrogen compounds, in the form of water or organic compounds, are among the most widespread substances on Earth [7]. Due to its natural physical and chemical properties, it is very suitable as a fuel. It has the highest of all fuels, in terms of mass, in calorific value (120 MJ/kg [18]) as well as in heat of combustion (141.9 MJ/kg [18]). With these properties, hydrogen can contribute to reducing CO_2 emissions into the atmosphere once it is deployed on a large scale in transportation, industry and power generation.

Carriers and operators in developed countries are putting into service vehicles that run on hydrogen to replace more emission-intensive combustion units [5].

In June, a Polish presentation of the Coradia iLint traction unit took place at the experimental track of the Railway Institute in Zmigrod. It is a vehicle manufactured by the Alstom concern. The unit is 54 meters long, develops a speed of 140 km/h and is used to transport passengers in regional traffic [9]. The vehicle has Canadian-made fuel cells combined with lithium-ion batteries. The tanks contain up to 94 kg of hydrogen. The vehicle can travel about 700 km on full tanks. Figure 1 shows the Cordia iLint vehicle.

Another hydrogen-powered vehicle for regional and suburban connections with a maximum speed of 160 km/h is Siemens Mireo Plus H. This vehicle is a two-unit multiple unit with a maximum range of up to 800 km. The drive power of 1.7 MW allows acceleration up to 1.1 m/s^2. The vehicle is shown in Fig. 2.

Fig. 1. The Coradia iLint train [1]

Fig. 2. The Mireo Plus H Siemens train [17]

Polish rolling stock manufacturer PESA Bydgoszcz S.A. also wants to develop its range of vehicles, and despite the undeveloped hydrogen infrastructure, according to the market-railway portal and AutoWorld, the developed SM42-6Dn hydrogen shunting locomotive is already ready and has passed the final stage of approval tests. The tests were held at the experimental track of the Railway Institute Center in Zmigrod [11, 12]. The locomotive is to be used for shunting at the Plock Refinery by PKN Orlen. The vehicle has hydrogen tanks with a total capacity of 175 kg. This allows the locomotive to operate around the clock. The vehicle's traction system includes two fuel cells with a power of 85 kW each, a battery and four traction motors. The SM42 6Dn locomotive is a 4-axle shunting locomotive with 4 × 180 kW traction engines. The vehicle is shown in Fig. 3.

PESA Bydgoszcz S.A.'s further development plans include the use of hydrogen cells in passenger vehicles. The projects named Regio160 and Inter-Regio200 and 250 assume the production of regional and agglomeration trainsets with a maximum speed of 160 km/h. The next step is to be the Inter-Regio200 project, which has already been started, and involves the production of vehicles with a maximum speed of 200 km/h. These vehicles are to be used for interregional traffic [2].

Fig. 3. Shunting hydrogen locomotive SM42-6Dn [13]

At this point, hydrogen vehicles do not reach dizzying speeds. For railbuses, there is talk of a maximum of 160 km/h, but in the case of the SM42 6Dn shunting locomotive, a high speed is not required, since, as the name suggests, the locomotive will be used for shunting and shunting cars, as a rule, on railroad sidings.

Hydrogen may also be the answer to the sought-after clean, low-cost energy for powering vehicles. With the rising cost of electricity consumption in the country, but also in Europe. An additional fact in favor of using hydrogen as a power source for transportation is the unstable geopolitical situation in Europe, problems with the continuity of fossil fuel supply chains and the numerous embargoes imposed on major suppliers in Europe.

According to PKP Intercity in its announcement in early January, "Compared to January 2022, the price of electricity on the Towarowa Giełda Energii increased by as much as 62.18 percent. This will directly translate into a significant increase in the projected 2023 charges for active energy, which is part of the traction electricity charges, and, as a consequence, an increase in the cost of services provided by PKP Intercity" [16].

According to PKP Energetyka, one of the innovations they want to introduce is to launch a hydrogen-based solutions project as a complement to the development of the Green Railway assuming the construction of 50 hydrogen railroad stations by 2028. Hydrogen fuel could replace diesel in places where electrification is difficult, i.e. 36% of the Polish railroad network. Hydrogen sold at PKP Energetyka stations will be produced by electrolysis from local RES sources or purchased from third-party suppliers. The planned number of hydrogen refueling stations is expected to meet the demand of the country's rail sector. Prior to the construction of the station, an assessment of the potential for use of hydrogen by the railroad end user is to be carried out each time, as well as letters of intent/promises to receive hydrogen from the constructed station are to be signed. The Hydrogen Railway is expected to enable the emergence of a Polish hydrogen market, starting with local hydrogen producers, refueling station manufacturers, and ending with those producing and upgrading hydrogen rolling stock [15].

Benefits of implementing the Hydrogen Railway from information from PKP Energy [15]:

- Distribution of ~4,000 tons of hydrogen per year reducing nearly 40 million liters of Diesel fuel, or 100,000 tons of CO_2 per year
- Building a complete value chain for the use of hydrogen in the Polish railroad sector
- Enabling the emergence of a market of manufacturers of Polish hydrogen refueling stations.

Another argument in favor of using hydrogen as a fuel is the continuing rise in the price of electricity in Poland. As mentioned earlier, most of it comes from coal in our country, and thus also increases the emission of carbon dioxide into the atmosphere, which raises further costs of its emission and more air pollution [6].

In practice, however, no energy source has only advantages. There are also risks that engineers must face.

Of the threats for the next few years, despite the plans, first and foremost there is the problem of access to stationary refueling stations located along railroad tracks. Opposite are the mobile stations for hydrogen refueling, which unfortunately still do not exist much, an additional problem may be access to the infrastructure of the mobile station in question, which is simply a tractor-trailer with a tanker filled with hydrogen.

Another risk, which is indirectly linked to the previous one, is the distance that hydrogen-powered vehicles could cover. At the moment it is assumed that the maximum distances are 800 kilometers, so the vehicles would mainly be used for agglomeration traffic, and at night they would have to be refueled to be able to meet the next day's passenger service. Here comes the need to build hydrogen stations.

Additional risks that arise in hydrogen vehicles are the safety requirements for its storage in tanks, as well as the tightness of the entire system, which should be inspected at short intervals to minimize the likelihood of unsealing the system to an acceptable minimum.

Production as well as distribution of hydrogen is another risk that can be defined.

The projected European hydrogen-powered rail vehicle fleet from 2028–2030 in the baseline scenario, in total, is shown below in Table 1. The projected number of the listed categories of hydrogen-powered railroad vehicles is presented by three groups of markets. Markets with advanced development of hydrogen technology, these are northern and central European countries, markets in the early stages of hydrogen technology deployment, and the last group are

markets that are planning to develop hydrogen technology.

Table 1. Projected European hydrogen-powered rail vehicle fleet from 2028 to 2030 in the baseline scenario, total [14]

Specification	Countries advanced in the development of hydrogen technologies	Countries starting to implement hydrogen technologies	Countries planning to implement hydrogen technologies
Hydrogen-powered traction units	273	21	15
Hydrogen-powered line locomotives	20	28	8
Hydrogen-powered shunting locomotives	25	29	19
Hybrid (diesel-electric) units	805	467	398
Total	1123	525	439

Table 1 present that technologically advanced countries will lead the development of hydrogen-powered rail vehicles. These will mainly be traction units and hybrid units, which will be used to transport people in large agglomerations. There is also a trend towards hybrid units (diesel-electric). Linear and shunting locomotives in each group in the table have a small share in the overall development of hydrogen technology in rail. This may be related primarily to market demand and the development and needs of agglomeration railways.

3. Summary

Railway, as a branch of transport and an ecological one, strives for broadly understood sustainable development and climate neutrality. Many countries are wondering whether to invest in hydrogen infrastructure or electrify railway lines that do not have electric traction. Nevertheless, economic and ecological issues support the search and use of alternative energy sources, such as hydrogen.

However, the most important advantage is the fact that in order to protect the planet and save it for future generations, we need to look for alternative energy sources, reduce carbon dioxide emissions into the atmosphere, and transport is one of the industries in which this is highly necessary. There are many opportunities for broadly understood ecology in transport, and hydrogen is one of them.

Nomenclature

CO_2 carbon dioxide

RES renewable energy systems

Bibliography

[1] Alstom: Światowa premiera: 14 pociągów wodorowych Coradia iLint będzie obsługiwać pierwszą w 100% wodorową linię kolejową (in Polish) https://www.alstom.com/pl/press-releases-news/2022/8/swiatowa-premiera-14-pociagow-wodorowych-coradia-ilint-bedzie-obslugiwac (accessed on 01.09.2023).

[2] Czubiński R. Wodór na kolei: Przyszłość bliska czy daleka? (in Polish). Rynek Kolejowy. Tabor i Technika. 21.06.2021 https://www.rynek-kolejowy.pl/wiadomosci/wodor-na-kolei-przyszlosc-bliska-czy-daleka-103074.html (accessed on 01.09.2023).

[3] Deng K, Fang T, Feng H, Peng H, Löwenstein L, Hameyer K. Hierarchical eco-driving and energy management control for hydrogen powered hybrid trains. 2022;264:115735. https://doi.org/10.1016/j.enconman.2022.115735

[4] Desantes JM, Molina S, Novella R, Lopez-Juarez M. Comparative global Warming impact and NO_x emissions of conventional and hydrogen automotive propulsion systems. Energ Convers Manage. 2020;221: 113137. https://doi.org/10.1016/j.enconman.2020.113137

[5] Durzyński Z. Hydrogen-powered drives of the rail vehicles (part 1). Rail Vehicles/Pojazdy Szynowe. 2021;2:29-40. https://doi.org/10.53502/RAIL-139980

[6] Dusiło M. Transformacja energetyczna w Polsce (in Polish). Edycja 2023. Forum Energii 04.2022. www.forum-energii.eu (accessed on 01.06.2023).

[7] Encyklopedia PWN. Wodór (in Polish). https://encyklopedia.pwn.pl/haslo/wodor;3997333.html (accessed on 01.06.2023).

[8] European Commission. Regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law). European Commission, 2020.

[9] Fisher K. Polska premiera pociągu wodorowego. Rynek Kolejowy. Tabor i Technika. 06.2022 https://www.rynek-kolejowy.pl/ (accessed on 01.09.2023).

[10] Fragiacomo P, Genovese M. Technical-economic analysis of a hydrogen production facility for power-to-gas and hydrogen mobility under different renewable sources in Southern Italy. Energ Convers Manage. 2020;223:113332. https://doi.org/10.1016/j.enconman.2020.113332

[11] Grabek K. Pierwsza polska lokomotywa wodorowa już gotowa. Pesa pokazała wideo z testów (in Polish). 17.12.2022. https://www.auto-swiat.pl/ev/wiadomosci/pesa-pierwsza-polska-lokomotywa-wodorowa-juz-gotowa-wideo-z-tesow/71xpyqv (accessed on 01.06.2023).

[12] Lokomotywa na wodór od PESA – znamy szczegóły modelu SM42Dn. http://gashd.eu/2021/05/13/lokomotywa-na-wodor-od-pesa-znamy-szczegoly-modelu-sm42dn/ (accessed on 01.06.2023);
[13] Madrjas J. Lokomotywa wodorowa Pesy: Wkrótce pierwsze jazdy z wodorem. Rynek Kolejowy. 26.09.2022. https://www.rynek-kolejowy.pl/mobile/lokomotywa-wodorowa-pesy-wkrotce-pierwsze-jazdy-z-wodorem-film-110023.html (accessed on 01.09.2023);
[14] Menes M. Stan i kierunki rozwoju wodoryzacji gospodarki ze szczególnym uwzględnieniem transportu (in Polish). Wydawnictwo Komunikacji i Łączności. Warszawa 2021.
[15] PGE Energetyka Kolejowa. Rozwiązania oparte na wodorze jako uzupełnienie rozwoju Zielonej Kolei® (in Polish). pkpenergetyka.pl/projekt/paliwo-przyszlosci (accessed on 04.01.2023).
[16] PKP Intercity. PKP Intercity aktualizuje ceny biletów (in Polish). https://www.intercity.pl/pl/site/o-nas/dzial-prasowy/aktualnosci/pkp-intercity-aktualizuje-ceny-biletow.html (accessed on 04.01.2023)
[17] Przybylski R. Wodorowy pociąg Siemens Mireo ruszy na trasy w 2024 roku. https://logistyka.rp.pl/szynowy/art37032251-wodorowy-pociag-siemens-mireo-ruszy-na-trasy-w-2024-roku (accessed on 01.09.2023).
[18] Rand DAJ, Dell RM. Hydrogen energy: challenges and prospects. Cambridge, RSC Publishing 2007. https://doi.org/10.1039/9781847558022
[19] Ritchie H, Roser M. Transport. https://ourworldindata.org/transport 03.01.2024.