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News & Highlights

Hydrogen-Powered Trains Start to Roll

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In March 2022, permanent operations began in Germany for 14 hydrogen-powered trains—"Coradia iLints" (Fig. 1)—built by France's Alstom (Saint-Ouen), one of the world's largest train manufacturers [1]. Running on a regional line between Buxtehude, near Hamburg, and the coastal town of Cuxhaven, the new service caps an 18-month, commercial demonstration trial in which a pair of Coradia iLints transported passengers across more than 200 000 km while spewing nothing but water vapor into the air.

"Alstom's cars are groundbreaking in terms of running in low-density, rural areas of Germany where it is hard to provide electrical power and you do not see big-city ridership volumes," said Gordon Lovegrove, associate professor of civil engineering at the University of British Columbia in Vancouver, BC, Canada. "The iLint beautifully fills a needed gap of onboard, zero-emission electrification."

Success with the iLint has resulted in orders for Alstom to build dozens of similar trains for use in, besides Germany, France, Italy, Austria, the United Kingdom, and Hungary [2–7]. Several other major manufacturers around the world have also begun working on hydrogen-powered rail, or "hydrail," projects of their own.

Hydrogen-fueled cars, trucks, and buses have been in use for decades, albeit with limited commercial success to date [8], but trains have lagged in adopting the fuel source. They have relied instead on diesel, which currently powers about one-fifth of Europe's trains and most of the United States rail fleet, and electricity, generated primarily from fossil fuels in the United States and renewable sources in Europe [9]. The primary reason is that hydrogen technology faces a classic supply and demand conundrum: Suppliers are reluctant to build the big production facilities needed to bring down costs until demand is clearly defined, while customers are waiting for lower prices before switching to a lower-emission fuel [8].

Fig. 1. Following a successful 18-month trial in Germany, 14 Coradia iLint hydrogen-powered trains, built by Alstom, one of the world's largest train manufacturers, will go into service in Germany in March 2022, with additional units scheduled for delivery throughout Europe in the next few years. Credit: Alstom (public domain).

Recently, however, governments around the globe have begun to issue zero-emissions mandates to address climate change. In 2021, for example, the European Union set 2030 as a target for reducing greenhouse gas emissions by 55% compared to 1990, with all such emissions to be eliminated by 2050 [10]. In France, Scotland, and parts of the Netherlands, national train networks have pledged to replace passenger and/or freight diesel engines with clean alternatives by 2035 [11–13]. Germany will eliminate diesel trains by 2038 and the United Kingdom by 2040 [14,15]. By tipping the scale towards increased demand for greener power, including hydrogen, these mandates are driving a flurry of development in the hydrail sector.

Today, most hydrogen fuel is produced through steam methane reformation, in which methane reacts with pressurized steam in the presence of a catalyst to produce "grey hydrogen," and electrolysis of water, in which electricity is run through water to separate hydrogen and oxygen. Steam methane reformation currently accounts for 95% of the world's hydrogen production [16], and while it is economically inexpensive, it is energy intensive. "To produce 'green' hydrogen, you really want to use renewable energy, including hydroelectric off-peak or solar or wind," Lovegrove said.

So-called "green hydrogen" can, however, cost two to five times more to produce than the grey hydrogen generated by steam reformation [17]. To make green hydrogen economically viable, its cost needs to be cut in half, Lovegrove said. At least some experts expect that price reduction to happen by 2030 [18]. Despite its higher overall cost, today's business case for hydrogen-powered trains becomes compelling on rail routes currently occupied by diesel engines where it is technically difficult and cost prohibitive to construct overhead electrification lines, and that are too long or too steep for battery-powered engines.

Alstom built its first iLint trains in 2016 by adapting a diesel engine design. The electric engine is powered by a hydrogen

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fuel-cell, which generates electricity by combining the hydrogen stored on the train's roof with oxygen in the air. Onboard batteries also contribute electricity captured from braking. With a range of 1000 km at a maximum speed of 140 $km\cdot h^{-1}$, the train can carry up to 150 seated passengers and 150 standing passengers. Its electric engines are also quiet. "I have been on it myself," Lovegrove said. "You can absolutely hear yourself think."

To establish a refueling infrastructure for its hydrogen-powered trains, Alstom is working with oil and gas companies, including Linde (Dublin, Ireland) in Germany, and PKN Orlen (Płock) in Poland [7]. During normal service, the iLints can operate for more than 18 h between refuelings. Alstom is also partnering with Hynamics (Paris, France) [19] and Deutsche Bahn (Berlin, Germany) [20] to build mobile stations capable of refueling a train within 15 min, comparable to diesel refueling and much less than the three to four hours needed to recharge an electric battery.

While Alstom has an early lead, other companies have announced plans to deliver competing hydrail. Spain's Construcciones y Auxiliar de Ferrocarriles (CAF, San Sebastián), Germany's Siemens (Munich), and the United Kingdom's HydroFLEX project, a partnership between the Birmingham Centre for Railway Research and Education and the railway company Porterbrook (Derby), are all developing new hydrail technology for use in Europe [21–23]. For the sole hydrail project currently underway in the United States, the Swiss company Stadler (Bussnang) is designing a hydrogen-powered train for a line in San Bernardino, CA, USA [24]. The development of hydrogen-powered trains is also in progress in China, Japan, and Australia [25–27].

One place that may not see passenger hydrail soon is Toronto, ON, Canada. The city recently halted what would been one of the world's largest hydrail projects to date, wherein it would replace its diesel-electric fleet of trams, citing uncertainty regarding hydrogen fuel production, transport, and storage [28].

But other Canadian hydrail ventures are continuing. Ballard Power Systems (Burnaby, BC, Canada) has partnered with China Railway Rolling Stock Corporation (CRRC) Sifang (Qingdao, China) on hydrail trams that are now operating in the Chinese cities of Tangshan and Foshan (Fig. 2) [29,30]. Ballard is also supplying 14 fuel cell modules, each with a power output of 200 kW, in support of Canadian Pacific's Hydrogen Locomotive Program, which is repowering three diesel trains with hydrogen fuel cells. These trains will enter test service in Alberta as early as 2022 [31]. In addition, the company's collaboration with Siemens aims to develop a new generation of hydrogen-powered trains, dubbed the Mireo Plus H (Fig. 3), with trial operations expected to commence in Bavaria in 2023 [32]. Ballard will also supply fuel cells

Fig. 2. Hydrogen-powered trams built jointly by Canada's Ballard Power Systems and China's CRRC Sifang are currently operating in the Chinese cities of Foshan (above) and Tangshan. Credit: Wikimedia Commons (CC BY-SA 4.0).

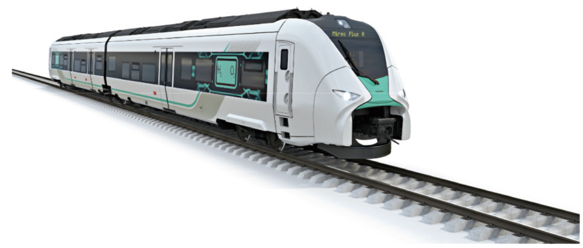

Fig. 3. Siemens' Mireo Plus H hydrogen-powered train is scheduled to begin trials in Bavaria before the end of 2023. Credit: Siemens (public domain).

to Patentes Talgo (Madrid, Spain) for trains the company plans to operate in Spain [33].

Like Ballard's projects in China, Canada, and Europe, most hydrail projects in development involve a mix of equipment designed from the ground up and retrofits of diesel and electric trains to run on hydrogen. "We are looking at both retrofits and original equipment," said Cara Startek, director of technology solutions at Ballard. "The timelines for certification are quite lengthy for custom-built trains, so it is ideal to customize solutions around the trains that are available."

Lovegrove agreed: "Being able to retrofit 30–50-year-old vehicles is pretty exciting. The platform of any real locomotive is very heavy, around 150 tonnes of metal—it is not going anywhere. You can retrofit using the existing engine housing, and you have a vehicle that will easily last for another 50 years—several months, a million bucks, and you are done."

Despite the slew of new projects, the basic technology of hydrail remains largely the same as what was available several decades ago. "There have not been many specific fuel cell technology advancements, but there have been engineering advancements," said Startek. "We have focused on understanding the unique safety systems and shock and vibration requirements of rail and integrating those into our fuel cell system design and operational strategies."

However, some recent innovations could help increase the attractiveness of hydrail. UK engineers, for example, have designed a light-weight fuel-cell converter that uses semiconductors to draw energy in a controlled way from the fuel cells and deliver it to the train's motors; this process normally requires two separate converters, and upgrading to a single, light-weight converter can increase a train's range [34]. Room for innovation that could boost the commercial prospects for all hydrogen-powered vehicles also exists in hydrogen production and distribution. Recent developments of interest include Japanese research purporting to increase the efficiency of solar-energy-to-hydrogen production hundredfold [35] and American efforts to build small, inexpensive hydrogen-from-natural gas fueling stations that could be placed anywhere alongside existing natural gas distribution systems [36].

Manufacturers are also looking at additional ways to further decrease the environmental impact of hydrail. "We are refurbishing fuel cell stacks, recycling 95% of the platinum that comes back, and reusing the plates," Ballard's Startek said. "By focusing on expanding such strategies, we hope to increase the sustainability of our products."

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