TRAINS REINVENTED with Solar, Wind and Battery Power

AMERICAN SOLAR ENERGY SOCIETY

By Richard F. Tolmach

Nearly fifty years ago, the California artist and writer Christopher Swan imagined a future in which American passenger trains could be independent of fossil fuel and operate emission-free. In the 1970s, his SunTrain idea was seen as speculative, but today all the building blocks for such a venture are available.

Solar and wind solutions are now cheap, and nearly unlimited in potential capacity. Batteries and alternative power systems capable of powering trains are now available from mainstream manufacturers. In combination with photovoltaic panels, batteries already run remote portions of railway signaling systems and are the fastest growing sector of rail traction power. Fast-charging methods to link wayside power production to trains have been invented, tested, and put into production.

Lightweight battery-electric trains, perfect for efficient, emission-free operation, have also become procurable commodities, with a dozen major producers now offering them around the world. While nobody has yet proposed a new commercial off-grid railway network that runs on solar, wind, and batteries, this is only because most of the innovation has occurred in places like Europe, Japan and China where existing electric railways already are fed by national grids.

Siemens Mireo in April, 2019 during homologation testing at the track in Velim, Czech Republic.

Railways have generic energy efficiency advantages because of their extremely low coefficient of friction, which gives rail transportation using diesel fuel a 50% theoretical cost advantage by rail compared to trucks and buses. In practice, rail advantages have been largely outweighed in the United States by deficiencies in the rail travel product, which suffers from outmoded train motive power, too-heavy trains, and lack of entrepreneurial talent.

For example, the typical Amtrak short or medium distance train has technology that hasn't progressed in any significant way for about 80 years: a 120-ton diesel locomotive for every 4.5 cars, a capacity of about 280 passengers, and an average load of about 130 passengers. With fuel consumption typically averaging 2.1 gallons per mile, net fuel efficiency is 62 passenger-miles per gallon (1254 kJ/passenger mile), not materially different from a Prius, assuming 1.2 occupants.

In contrast to diesel locomotive-hauled trains, European diesel multiple units (DMU) and electric multiple units (EMU) have seen continual improvement, especially since the 1970s. They are significantly quieter, capable of faster travel because of better acceleration, and far more energy efficient. Many of these advantages stem from far lighter weight per seat than American technology, typically 1200 to 1700 pounds (544 to 771 kg) per seat versus 2800 to 3200 pounds (1270 to 1451 kg) on trains powered by diesel locomotives. Even if much of their electricity is produced using petroleum, better design of the trains has doubled the typical effective fuel efficiency on European trains to about 125 passenger-miles per gallon (625 kJ/passenger miles).

In the same way solar and wind electrical generation encouraged autonomous power networks, battery-electric rail technology accelerated the conversion of European branch rail lines to electric traction. Overhead wires no longer have to be present for electric traction to power trains. Wayside charging stations and braking power can be stored by train batteries to stretch the range of electric trains beyond current limits at a fraction of the price of overhead wires and substations.

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CAF trains and Alstom flash charging system on battery light rail in Zaragoza, Spain.

DC Flash Charging Becomes Mainstream in Light Rail Transit

The battery train revolution happened most rapidly in urban transit, where the innovation of flash-charged light rail trains, first implemented in Dubai and Huai'an, China in 2015, spurred a worldwide trend in wireless rail. About one-third of new light rail mileage built since 2018 lacks overhead wires.

The newest networks, such as lines T2 and T3 in Nice, France, run all their surface tracks wirelessly, the majority implanted in lawns and surrounded by trees to optimize environmental impact. The city of Nice flash-charges its Alstom Citadis 405A trams at stations in 20 seconds with American-designed JSR Micro lithium oxide capacitors.

These flash-charging systems are optimal for eventual autonomous solar/wind conversion because they use DC power throughout and need no rectification.

From Prius Hybrids to Hybrid Passenger Trains

Hitachi played a major role in popularizing battery power on modern railroads by adding lithium batteries to its Japanese electric and diesel trains in the 1990s, an offshoot of its work on hybrid automobiles. In Japan, lithium ion batteries provided a feasible way to improve train station environments by ending diesel pollutant and noise emissions at stations. They also allowed extension of EMU service onto branch lines without diesel generators. Test operation of battery EMUs began in Japan in 2009 and revenue operation in 2012, with four routes currently in operation.

Hitachi's entry into the British rail market in 2007 was to remanufacture a mid-1970s HST 125 diesel as a hybrid diesel-electric with battery backup. The original HST, although not formally called a "high speed train," broke speed records with 125 mph service (200 km/h) and helped define the future field. Hitachi's hybrid toured all the main British rail routes and served as a rolling advertisement for capabilities of rail hybrid power, especially its ability to bridge electric and diesel networks, serve all destinations and curtail the need to transfer.

In 2010, Hitachi won the biggest British procurement for electric trains to serve routes into London's Paddington Station. Before the units went into service, however, the Paddington electrification project tripled in cost and went several billion pounds over budget. When Network Rail's electrification contractor failed to deliver the full 25 kV electrification by 2016, the government wielded the axe on the branch line electrifications. Hitachi cooperated with Network Rail and Great Western Trains (today called GWT First) to revise the fleet order and provide a 100% hybrid fleet, including generators and batteries so trains could cover all destinations originally planned. Hitachi then also added these features to its previously all-electric designs for service throughout Britain, selling the advantages of safety and reliability in power outages.

21st Century Revival of the Battery Train

These events in Britain were, in retrospect, a first step toward reintroduction of battery electric trains throughout Europe. The benefit of service through to regional destinations is widely appreciated, but few systems want to pay the high costs of branch-line electrification. Hitachi's brilliant synthesis, already convincing, became even more persuasive when better batteries made generators superfluous.

Siemens, Bombardier, Alstom and Stadler have all produced their own variants of the popular "no-transfer" solution. Each of the manufacturers now offers battery trains capable of at least 50 miles range without overhead wires. Recent advances in technology will make a 100-mile range feasible.

One of the reasons battery-powered trains have been developed so rapidly is that they are not a new technology. The first battery-powered trains were developed in Germany in the late 1880s, were mass-produced starting in 1907, and after several generations of improvement, were only retired in the 1990s. The advantages of battery trains were largely rediscovered in the past two decades as climate change and the need for carbon-neutral solutions entered public consciousness. Batteries were an obvious add-on to EMUs to cover segments without overhead wires. That makes them battery electric multiple units (BEMUs).

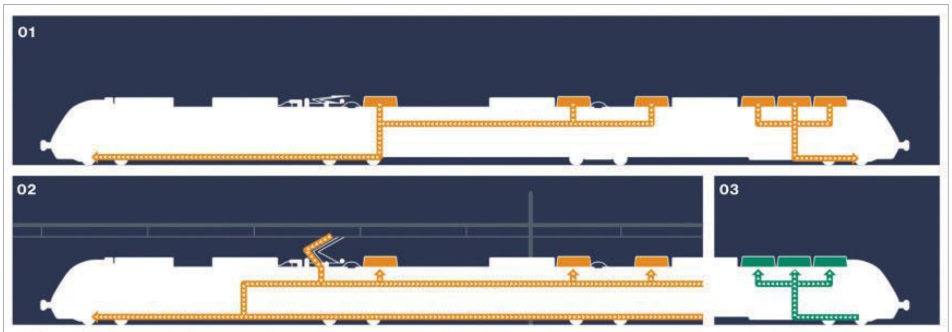
Unlike historic battery trains, 100% dependent on battery power, BEMUs draw their power from the overhead catenary, wherever available. Batteries are used for the non-electrified sections and are recharged at the end points or when entering electrified territory again. Another source for the recharge is regenerative braking energy, which is not fed back into the power grid (as it is for other electric trains).

BEMUs have not been designed from scratch. All battery vehicles on the market today are based on proven EMU platforms that have evolved and been refined for decades. The modification involves only the installation of batteries, typically on the roof, and their connection to the existing power supply and power management system. As of the current date, there are approximately 10 different BEMUs being offered on the world market, including models by CAF, CRRC, Hitachi, Stadler, Siemens, Bombardier, Alstom and Vivarail. The most prominent among these are:

- Stadler Flirt Akku (55 units sold to the German state of Schleswig-Holstein)
- Siemens Mireo Plus B (20 units sold to the German state of Baden-Württemberg)
- Siemens CityJet Eco (revenue testing in Austria, 25 units expected)
- Bombardier Talent 3

Stadler Flirt Akku

Stadler previously offered battery packages as part of its Flirt alternatives, but almost no buyers took them up. In 2018, reacting to the growing German market for emission-free vehicles, Stadler Deutschland GmbH, based in Berlin, developed a customized version of its three-car electric Flirt using power control components and batteries sourced from Intilion GmbH, the Zwickau, Germany specialist in rail traction. Stadler had already experimented with prototype Akku



01 Operation in traction battery mode on catenary-free track sections
02 Battery charging under overhead lines and overhead line islands
03 Battery charging via recuperation while braking

© Stadler

The Akku battery-powered vehicles belong to the Flirt train family, popular in Europe.

sets on lines in the eastern Netherlands and presented its prototype on a short run in Berlin suburbs following exhibition at the September 2018 Innotrans show.

In July 2019, the Flirt Akku won the Schleswig-Holstein procurement of 55 emission-free vehicles, including a 30-year maintenance contract and an option for 50 additional trains. The initial contract value is 600 million EUR.

Each German state is looking at emission-free rail solutions, and dealing with the politics and economics of the choices. Originally, Schleswig-Holstein had favored an Alstom fuel cell solution, but local activists protested the plans for massive gas conversion plants required to produce the hydrogen and sequester the carbon from natural gas. The policy issue of dependency on natural gas for production of “emission free” hydrogen convinced state authorities to have an open procurement without dictating technology. Schleswig-Holstein included energy production costs in the tender, as a way of ensuring an affordable life-cycle solution. Alstom and its energy company allies launched a legal protest, but the regional court found in favor of the authorities, and the award to Stadler proceeded.

Only 29% of Schleswig-Holstein’s tracks are electrified. The land is flat and population is relatively low-density. The settlement pattern is sparse north of Hamburg, but cities are just populous enough that the stops can add up to sufficient traffic. The only electrification project there in the past decade was Hamburg-Lübeck-Trevemünde. The result is that no major destination in the region is more than 37 mi (60 km) from an electrified track. Battery electrics are a brilliant solution for the terrain because they can charge while under catenary, or at a terminus using a purpose-designed charging station, then again once they return to wired territory, providing emission-free service without high capital cost. Local activists hope trains will eventually use power from Schleswig-Holstein’s ubiquitous wind installations.

The Flirt Akku, as delivered to Schleswig-Holstein, has a top speed of 87 mph (140 km/h) under catenary, 50 mph (80 km/h) in battery mode, 154 seats, and a total capacity of 310, and it can be run as double or triple three-car units.

Siemens Mireo Plus B

In 2016, Siemens began a custom redesign of its Desiro EMU range to obtain lighter weight, faster acceleration, lower operating cost and other features desired by customers, and to better compete with Stadler and Bombardier products which have made major inroads into its domestic German market. In 2018, the first production EMUs were completed and began testing in April, 2019 at the Velim, Czech Republic test track.

Siemens made its first sale of 24 Mireo EMUs in 2017 to DB Regio, which has been chosen by Baden-Württemberg to operate primary local services under contract to the state on mainlines. The Mireo is intended to reduce energy use by up to 25% compared to the Desiro ML. In March 2019, Siemens made its first sale of 20 of the battery version to the Baden-Württemberg State-owned SFBW train fleet company. The fleet will be used on five mostly-nonelectrified routes radiating from Offenburg on relatively flat ground in the Rhein Valley.

Siemens not only won the construction contract, but will maintain the fleet for 29.5 years. SFBW set a contractual requirement that the manufacturer be responsible for fleet availability and energy consumption for the lifetime of the trains. As on the Schleswig-Holstein contract, a BEMU beat out the Alstom hydrogen fuel cell variant as being the most cost-effective choice. The Mireo Plus B has three cars, a top speed of

99 mph (160 km/h) under catenary, a range of at least 50 mi (80 km) wire-free, and 220 seats. Siemens also offers a hydrogen fuel cell version, the Mireo Plus H, which has not yet received any orders.

Vivarail – Flash Charging Recycled Trains at Terminals

British rolling stock firm Vivarail, like Alstom's Citadis urban solution, depends upon flash charging instead of catenary. However, it does so only at terminals, not at intermediate stops. Vivarail claims it can fully charge its class 230 BMU (battery multiple unit) in 7 minutes for a 60-mile (97 km) trip. The top speed is more like that of its predecessors: 62 mph (100 km/h), but its acceleration is very impressive for a BMU: 3.3 ft/s2 (1 m/s2).

Vivarail uses stationary battery packs at the endpoint stations, which are trickle charged from the public grid throughout the day. The charge is then dumped into the train in a very short time using supercapacitors. Its third and fourth rail shoe gear is made of carbon ceramic to withstand the heat and handle the extreme high currents required.

Vivarail believes in recycling and has refurbished and converted London Underground D78 stock originally manufactured in the 1980s. It built three prototypes, and one of them, the 230002, was equipped with batteries. The experimental battery pack was originally sourced from the United States; however the production supplier will be Intilion GmbH, the same battery manufacturer used by Stadler. Isle of Wight and Midlands British rail segments are under development.

It is interesting to note that the main financier behind Vivarail is Henry Posner III of the Railroad Development Company based in Pittsburgh, who would like to see this technology applied in the United States.

Powering New American Trains with Solar and Wind

Passenger rail is a natural ally for the movement for energy independence from the petrochemical and auto industries. A demonstration rail system to pioneer solar/wind/battery rail operation might make sense in the American West, where railway electrification is currently almost entirely urban, and public demand for low emissions transportation is especially strong. Because there is so little wired mileage of railroads, a network entirely free of overhead catenary has significant operational and cost advantages.

Recent US and British electrification of mainline tracks with 25 kV alternating current (AC) overhead has been so plagued with cost overruns that it has become a target for reformers.

Direct current (DC) has been disparaged by the electric power industry, which favors 25 kV AC rail electrification because it uses national AC power grids and is easier to manage over long distances. However, AC installations have fire and safety downsides that recently have become better appreciated during California's past three fire seasons. DC power is still the dominant mode for urban rail electrification and has been adopted on about 25% of European intercity rail lines. It was seen as outmoded by many in the field, but this was before solar, wind, and battery resources became serious components of the power economy.

The national grids have resisted incorporating DC-generated power and say there is "too much" solar and wind power, although it costs a fraction of legacy carbon-based solutions. Tony Seba, a Stanford University lecturer and energy expert, demurs. "When a system generates hyperabundant electricity at a marginal cost close to zero, the potential for new value creation is limitless. This isn't a problem of overcapacity."

Wayside Charging: Efficiency and Price Advantages

The development and mass-production of Tesla Powerpack, Supercharger, and Megacharger technologies and their competitors portend similar low-cost solutions for passenger rail service.

Already, Alstom, CRRC and Vivarail have demonstrated that flash-charging light rail facilities significantly undercut the cost of conventional electrification. Operating cost is also lower per train-mile because instead of having to constantly energize the overhead wires, power remains in batteries when it is not actually being used. The additional increment of power needed for intercity and commuter trains is not very significant, and it appears feasible to recharge at terminals and each 100 miles at regional station/charging hubs.

Even at $15 to 20 million a copy, flash-charging rail facilities are very cost-effective compared to conventional overhead catenary and substations, which have cost over $12

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million per track mile in recent US and British implementations, and typically represent 20% of cost of typical rail system capital costs. Flash charging facilities are probably closer to 5% of system capital costs, and have the advantage of being scalable to actual need.

A practical design of flash-charging stations would include integrated photovoltaic and wind power installations, battery and/or capacitor storage, and inductive-coupled chargers. These features could all be incorporated within footprints of station facilities purpose-designed for expanded passenger service.

Rail for the Solar Era

If the goal is to create an emission-free transportation network, electric rail powered by off-grid solar, wind and batteries seems to offer the best prospect of a sustainable, cost-effective development. Christopher Swan's dream of solar/wind electric trains has been feasible for well over a decade and could become reality in the next five years if enough supporters and entrepreneurs who see the potential can be mobilized.

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About the Author

Richard F. Tolmach has 46 years of experience in analysis, design and development of rail passenger and bus services. Since 1974, he has been continuously involved in rail projects and has worked on a variety of system startups in rail, bus, boat and multimodal. He retired from the California Department of Transportation, Division of Rail and has a private consulting practice, and has served on boards of two private European transport startups.