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Vectron as an Example of a Modern and Versatile Electric and Diesel Locomotive for Passenger and Freight Transport

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Summary
The Vectron locomotives are a Siemens proposal covering locomotives dedicated to both passenger and freight traffic, capable of operating under a wide range of supply voltages (multi-system, single-system, etc. versions are offered), on both normal and broad-gauge track. A diesel version was also designed for operation on non-electrified lines. The Vectron locomotives are a variant of the Eurosprinter ones, developed in the early 1990s and enriched by the operation experience acquired, both on the German or Austrian railway network and in other EU countries (acceptance to operate as part of the liberalization of the common market). To date, circa 1,500 Eurosprinter locomotives have been sold, primarily in Europe and also in the USA, where they are operated in moderate climate, and both the Mediterranean one and the cold Scandinavian winters.

Keywords: electric locomotives, multisystem voltage locomotives, Vectron, Siemens

1. Introduction

One of the sources of the success of the Vectron locomotives is the use of three-phase motors and their pulse control, and the modularity of the vehicle design has facilitated their production and operation. The introduction of three-phase drive systems for locomotives and multiple units in western Europe in the early 1990s significantly changed the philosophy of the construction of similar vehicles. Above all, because of the significantly higher specific power of the asynchronous or synchronous motor compared to the DC motor (usually 1.4–1.6 MW compared to 0.7–1.0 MW), it made it possible (while maintaining vehicle power) to fit not six, but four traction motors in the example locomotive. Thus, in addition to the simplification of the mechanical part, the construction of 6-axle locomotives, which had previously been supplied to operators in Europe for use in freight traffic, was virtually abandoned. The most widespread vehicles became 4-axle locomotives, which also began to be used to run freight trains due to their higher power output than their predecessors (in terms of the traction motors used – three-phase versus direct current). Example locomotive power were 5–6 MW versus 3–4 MW. It should be added that 6-axle locomotives continued to be built, but only in justified circumstances. An example is the EG 3100 class produced by Siemens for DSB to run freight trains over the Øresund Bridge and Tunnel between Denmark and Sweden, where correspondingly high tractive effort is required due to the significant gradients. Another example is the Dragon locomotives produced by Newag and sold to some Polish operators (e.g. PKP Cargo), where it was used the Co'Co' axle arrangement to achieve adequate tractive effort and not to exceed the 20 t axle load, which is still present on many secondary lines within the PKP PLK network.

Achieving similar versatility for electric locomotives made it possible to unify them and create an universal vehicle – for both passenger and freight traffic. An example is the Taurus locomotives (Eurosprinter ES64U2 variety, series 1016 and 1116) produced by Siemens between 2000 and 2005 for ÖBB, with a total of 332 vehicles. It will be obvious that reducing the number of locomotive series within ÖBB makes rolling stock management much easier and reduces the cost of vehicle maintenance or repair.

The three-phase drive has also changed high-speed train design. The first TGV PSE trains produced by Alsthom-Francorail in the early 1980s received DC motors with a power of 537 kW, which, in addition to the bogies in the motor cars, had to be installed also in the bogies of the passenger cars adjacent to

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the motor ones to achieve the train's power (a total of 6,444 kW for 25 kV 50 Hz). The next version of TGV, Atlantique, was fitted with synchronous motors with a unit power of 1,100 kW, which made it possible not only to increase the train's power to 8,800 kW but also to abandon the installation of traction motors in the bogies of the passenger cars neighboring the motor ones. This change also served as a branding element when setting TGV speed records (the PSE version achieved a top speed of 380 km/h while Atlantique of 515.3 km/h[2]). TMST trains of the 373 class, manufactured by GEC Alsthom and placed in service by Eurostar since 1994, were adapted to meet the specific requirements for passenger safety when crossing the Eurotunnel. Traction motors (asynchronous) were also installed in the bogies of the passenger cars with a unit power of 1,020 kW to achieve adequate vehicle power (12,240 kW for 25 kV 50 Hz). It is possible to speculate that with DC motors and the need to install more of them (similar to TGV PSE), the construction of a TMST train would be much more technically complex. Modifications similar to those applied in TGV can be seen in the construction of Shinkansen trains in Japan (the 100 class versus the 0 class), where asynchronous motors were fitted instead of DC, making it possible to reduce the number of driving axles (from 64 to 48), while maintaining a similar power (11,840 kW versus 11,040 kW).

The downside of a three-phase motor versus a DC motor is a significantly higher vehicle purchase cost. However, it is cost-effective as the three-phase motor is maintenance-free and does not require the installation of brushes or commutators and their frequent adjustment, which increases maintenance costs. To put it in perspective – the Warsaw metro's 81-class cars produced by manufacturers MMZ or Vagonmash (Russia), equipped with DC motors, have to undergo a technical inspection every 1–2 days, while the Metropolis (produced by Alstom) and Inspiro (produced by Siemens) trains have to be inspected every 1–2 months, respectively. In addition, in the case of older rolling stock (with DC motors), the operator is responsible for the inspection and maintenance of the vehicles, while modern rolling stock (AC motors) is the responsibility of the manufacturer. Therefore, the purchase of a three-phase rolling stock makes the existing complex maintenance facilities largely redundant.

In the early 1990s, the higher cost of constructing vehicles meant that manufacturers had to acquire larger orders to make the cost of building vehicles viable. This resulted in the take-over of smaller plants by the larger giants, leaving a few strong players in the manufacturing market – Siemens, Alstom and Bombardier – and smaller companies such as AnsaldoBreda and CAF. In other words, the market of rolling stock manufacturers in Europe has become more international from their point of view. The higher cost of building the vehicles forced their unification, i.e. modularity, which is why Europe's railway networks have been – more or less – dominated by locomotives such as Prima, Traxx and Vectron, produced by Alstom, Bombardier and Siemens, respectively. Additionally, the mastering of current processing by the proliferation of silicon semiconductors in the 1970s made the construction of the electrical part of the vehicles much simpler. It became possible to use 1 or 2 types of motors (depending on the power requirement), regardless of whether the overhead line was supplied with DC or AC voltage (in the case of AC, the current was converted from AC to DC nonetheless) after an initial voltage reduction by a transformer (for example, from 15 or 25 kV to 1–2 kV) and then converted by inverters into three-phase voltage, which was directed to the traction motors. It has also become possible to install a regenerative brake (in which case, a bi-directional inverter is required); however, in the case of DC voltages (1.5 kV DC, 3 kV DC) there are limits to the permissible voltage in the overhead line (e.g. 2.8–3.3 kV for PKP PLK), so not all of the recuperated energy can always be returned to the overhead line. In such cases, it is necessary to use brake resistors. The advantages of a three-phase motor were already recognized in early 20th century when on 23 October 1903 and 27 October 1903, the electric cars manufactured by Siemens-Halske and AEG achieved speeds of 206.7 km/h and 210.2 km/h, respectively. However, they were not suitable for commercial use – test runs took place on a specially prepared section between Marienfelde and Zossen near Berlin, and the cars themselves were powered by three independent wires (10–14 kV 38–48 Hz).

The described facilities of current conversion has also simplified the construction of multi-system locomotives. Prior to the aforementioned "silicon revolution", similar vehicles were, in fact, manufactured, but they were mostly short series not used on a wider scale. The CC 40100 / 18 class manufactured by Alsthom for SNCF / SNCB, 4-system (1.5 kV DC, 3 kV DC, 15 kV

[2] It was a shortened version of the TGV Atlantique – 2 motor carriages and 3 passenger carriages; in addition, the overhead line voltage was raised and larger diameter wheels were installed. In the case of TGV PSE, a train without technical modifications was used when setting the aforementioned speed record.

16.7 Hz, 25 kV 50 Hz) are an example. One of the features of locomotives currently being procured by EU operators is that they are multi-system (single-system vehicles are procured on a rather exceptional basis[3]), and electric locomotive lessors order virtually only this type of vehicle. As a consequence, it is possible to conduct transport in several countries – examples include PKP Cargo or DB Cargo, the latter performing transport services in most EU countries. This modularity also enables the use of diesel locomotives, although in this case, electric traction motors with a lower power – usually 500 kW – are installed as a result of lower power requirements of the vehicle (diesel traction in EU countries is mainly used on secondary lines).

In Poland, the implementation of the three-phase drive took place in a specific way. Due to the economic crisis of the 1980s and the imposed economic system, the purchase of modern technology abroad was impossible at the time. Therefore, the use of impulse start-up (and mostly DC) in traction motors in Poland, which began to be applied in western Europe in the late 1970s and early 1980s, was virtually absent[4]. Similar solutions were adopted by the then East German manufacturer LEW Henningsdorf and Škoda from Czechoslovakia, so on the DR or ČSD networks, the vehicles described became standard – class 243 (DB 143) and E 499.3 (ČD / ŽSR 163). However, the transition to a market economy after 1989 was associated with an increasing of the already existing economic crisis in Poland, although access to Western technologies became easier. Hence, the crisis of the 1980s persisted through the 1990s. Attempts were made to purchase modern locomotives for the PKP – EU11 / EU43 class produced by Adtranz / Bombardier (now Alstom) – or modern cars for the Warsaw Metro but without success. It was not until Poland's accession to the EU in May 2004 and the availability of aid funds (POIiŚ, CEF, etc.) that operators began to procure locomotives such as Traxx or Vectron, while foreign operators present in Poland also had similar rolling stock (e.g. DB Cargo).

Polish manufacturers, despite having virtually no experience in the design or production of three-phase vehicles, could not count on state aid, however, they quickly made up for this by developing modern vehicles such as the Dragon or Griffin (Newag) and Gama (Pesa) locomotives and multiple units: Impuls (Newag) or Elf (Pesa). The presence of Traxx and Vectron locomotives, as well as Pendolino and FLIRT emus on the PKP PLK network, further mobilized Polish companies to continuously improve their vehicles and win their first export contracts.

A comparison of the technical parameters of Prima (Fig. 1), Traxx (Fig. 2), and Vectron locomotives is

Fig. 1. Prima locomotive #437017 (1.5 kV; 15 kV 16.7 Hz; 25 kV 50 Hz) owned by SNCF Fret (Cargo); SNCF Lens-Méricourt locomotive depot, France (10 June 2005) [photo by L. Charlier]


Fig. 2. Traxx DC locomotive #E483 251 owned by Railpool and leased by the rail operator Lotos Kolej at Muszyna station (13 August 2016) [photo by M. Graff]

[3] An example is the ordering of Traxx locomotives operating at 3 kV DC only for the Italian operator Ferrovia Adriatico Sangritana or Ferrotramviaria (these operators perform only national services) and Vectron for VR (25 kV 50 Hz only), whereas due to the track gauge of the Finnish railway network (1,524 mm), the potential entry on the SJ or NSB network (1,435 mm) is impossible, while RZD – impractical, in the last case also due to a different voltage (3 kV DC), which is the electrified border section – Vainikkala – Buslovskaya (VR / RZD).

[4] Only prototype designs, such as the emu class EW60 and the class EM10 shunting locomotives, were built. Although the plans included the installation of a pulse start-up system for traction motors, the EP09 series designed at the time received a starting resistor, which was already outdated.

Table 1

Comparison of technical parameters of Prima, Traxx and Vectron locomotives

Manufacturer	Alstom	Bombardier	Siemens
Trade name of locomotives	Prima	Traxx	Vectron
Power supply system	1.5 kV DC, 3 kV DC, 15 kV 16.7 Hz, 25 kV 50 Hz		
Production period*	2003–	1999–	2010–
Number of locomotives produced (2021)	~1750	~1800	~1500
Track gauge [mm]	1435, 1520, 1676	1435, 1520 / 1524, 1668	1435, 1524, 1668
Axle arrangement	Bo'Bo' / Co'Co'	Bo'Bo'	Bo'Bo'
Maximum length [mm]	19 520	18 900	19 049
King pin spacing [mm]	10 060	10 440	13 800
Maximum width [mm]	2857	2989	3013
Bogie base [mm]	2600	2800	3000
Maximum height [mm]	4310	4283	4248–4400
Service mass [t]	89–90	81–86	80–90
Maximum axle load on the track [kN]	221	211	221
(Single-unit) locomotive power [kW]	4200–6000	4200–6400	5200–6400
Wheel diameter [mm]	1150	1250	1250
Control system	no data	MITRAC	Sibas 32
Safety system	(national)		
Maximum tractive force [kN]	300		
Railway brake types	ED (regenerative and resistance), disc and spring brakes		
Maximum speed [km/h]	120–200	140–160	160-200
Diesel version	+	+	+
Notes	locomotives are in service mainly by French and non-European rail operators	there were also versions developed for U.S. rail operators at voltages of 12.5 kV 25 Hz, 12.5 kV 60 Hz, 25 kV 60 Hz	

*Production in progress [own study].

shown in Table 1. Even a cursory comparison of the data shows that these are comparable vehicles (similar length, weight, and wheel diameter) that are suitable for running on different track gauges and are powered by several available voltages. The difference is that Traxx and Vectron designs evolved from vehicles designed for German-speaking countries to „European" locomotives, while Prima – after its initial debut on the rail network in France – became a popular locomotive in selected non-European countries – Morocco, Syria, Israel, and others. In addition to the Vectron platform, two-unit versions of the Traxx and Prima locomotives were developed for rail operators from China, Russia, Kazakhstan, or India where there is a higher power requirement (~10,000 kW) compared to vehicles for rail operators from the EU countries.

2. Vectron locomotive prototypes

The article outlines the evolution of the Vectron locomotives designed and manufactured by Siemens, from the prototype Eurosprinter design through to the vehicle named Taurus (Fig. 3) to its current form. In other words, the modifications consisted of adapting a vehicle originally intended only for German or Austrian rail operators to a European locomotive, i.e. a multisystem locomotive that is capable of running on tracks other than 1435 mm rail gauge – also 1524 mm and 1668 mm ones.

Fig. 3. The EU44-004 (Taurus) locomotive of PKP IC operator with an IC train at Warszawa Wschodnia station (21 January 2012) [photo by M. Graff]

2.1. ES 2007 locomotive

The prototype for the Vectron locomotives was a vehicle conventionally referred to as the ES 2007 (Eurosprinter), which was developed by Siemens and which was also the design platform for electric and diesel locomotives adapted to run on normal or wide rail gauge track. The ES 2007 locomotive was based on solutions developed in successive generations of Eurosprinter locomotives developed by Siemens since 1992. Furthermore, the ES 2007 series was used for designing locomotives for several rail operators:

- Portugal railway – CP – version for 1668 mm rail gauge and 25 kV 50 Hz voltage, with Bo'Bo' axle arrangement;
- Belgian railway – SNCB – version for 1435 mm rail gauge and voltages of 3 kV DC, 1.5 kV DC and 25 kV 50 Hz, with Bo'Bo' axle arrangement;
- Lithuanian railway – LG – a version for 1520 mm rail gauge, equipped with a diesel engine, with a Co'Co' axle arrangement.

As the regulations that rail vehicles had to comply with around 2000 changed several times, Siemens decided to modify the design of the Eurosprinter locomotive. Due to the wide range of changes, the new design platform for diesel locomotives was named EuroRunner, while retaining some of original features – a modular design common to the electric and diesel versions of the locomotive, or the passenger and freight versions. As the use of three-phase traction motors in new vehicles was already prevalent after 2000, so modularity also extended to the bogie design. Other top manufacturers, Alstom and Bombardier, also opted for modular design of electric and diesel versions of the locomotive. A similar solution has both advantages and disadvantages – high-power diesel locomotives (in the order of 4,000–5,000 kW) are not used in EU countries due to the electrification of principal routes, and the use of diesel traction is limited to secondary lines with lower axle loads, which reduces the permissible weight of the diesel engine in the locomotive. The lower power of diesel locomotives, compared to electric ones, and the maximum speed also affect the design of bogies. Hence the decision whether to design a diesel locomotive and an electric locomotive separately or together is an open one.

2.2. LE 4700 locomotives of the Portuguese railways

In January 2006, Siemens received an order from the Portuguese railways (CP) to manufacture 15 locomotives plus 10 as an option suitable for running on a 1668 mm rail gauge track and electrified at 25 kV 50 Hz [1]. The power of the locomotives is 4600 kW and the maximum speed at 140 km/h. The rail operator originally planned the designation as the class 4600 but decided on LE 4700 to distinguish it from the 5600 series locomotive already in service, which was also a Siemens-manufactured locomotive from the Eurospinter family for CP (Fig. 4). The locomotive contract also included the maintaining and repairs to the new vehicles for 10 years [2]. Two companies (Siemens and Bombardier) entered the tender, and CP selected the first bidder and signed the contract in January 2006. Initially, CP planned to acquire 15 locomotives for €70 million, however, it was decided to add an option for 10 more vehicles and the order value increased to €94 million. The funds for the purchase came from 30% of the company's funds and 70% from loans, including a 25% EBOR loan. Locomotives were delivered from August 2008 to the end of 2009. The production of the locomotives was carried out at Siemens's Allach plant in Munich and the final assembly was carried out by EMEF (*Empresa de Manutenção de Equipamento Ferroviário*), a subsidiary of CP. The new locomotives aimed to replace CP's #2500 and #2550 locomotives in service, dating back to the 1950s and 1960s, which were becoming increasingly expensive to operate. The LE 4700 series locomotives were tested in the second half of 2008. The first three locomotives were manufactured at the Siemens plant in Munich, while another 22 were assembled at a plant in Portugal. The LE 4700 series locomotive ran its first test train on the CP network in October 2008. It was a 900 t, 550 m long container train between Poceirão and Terminal XXI. The Single Vehicle Approval Certificate was issued in February 2009. The relatively high power of this locomotives allows to pull trains of 1,000 tonnes smoothly over the entire CP network located mostly in mountainous terrain. The 4600 class locomotive is the second variant of the Eurospinter family to be placed in service on the aforementioned rail network. The technical data of LE 4700 locomotives are shown in Table 2.

Fig. 4. LE 4709 locomotive (1668 mm, 25 kV 50 Hz) at Valongo (Estação) station, Portugal (21 June 2010) [photo by T. Miranda / Wikimedia Commons]

Table 2

Technical data for LE 4700 locomotives of the Portuguese railways

Rail operator	CP
Version	ES46F1
Numbering	4701–4715
Number of locomotives ordered	25
Years of production	2007-2009
Start of operation	2009
Axle arrangement	Bo'Bo'
Track gauge [mm]	1668
Voltage	25 kV 50 Hz
Total length [mm]	19 850
Maximum width [mm]	2989
Maximum height (with a pantograph folded) [mm]	no data
Bogie type	no data
Bogie base [mm]	no data
Diameter of new / worn wheels [mm]	no data
Minimum railway curve radius [m]	no data
Locomotive weight [t]	87
Axle load [kN]	213.2
Traction motors	AC 3~
Maximum power [kW]	4600
Maximum tractive force [kN]	300
Maximum speed [km/h]	140
Safety systems	CONVEL
Multiple traction	no data

[Own study based on the Siemens Mobility catalogue].

2.3. HLE 18 and HLE 19 series locomotives of the Belgian railways

In 2006, the Belgian railways placed an order for 60 tri-mode (1.5 kV DC, 3 kV DC, 25 kV 50 Hz) high-power locomotives – 6,000 kW and a maximum speed of 200 km/h, with an option for another 60 vehicles (entry made in 2008) [3, 4, 5]. The multimodal nature of the locomotives is due to the fact that they can access the rail networks of neighboring countries (1.5 kV DC in the Netherlands, and 25 kV 50 Hz in France and Luxembourg, as well as high-speed railway lines in Belgium). Several safety systems were installed on the vehicles for traffic safety:

- SNCB: TBL1, TBL1+, TBL2 and Crocodile;
- NS: ATB–EG (option);
- SNCF: KVB, Crocodile;
- CFL: Crocodile, ETCS 1.

The contract value is EUR 440 million. The series was designated by SNCB as:

- HLE 18 (1801-1896), 96 locomotives fitted with UIC screw coupling (Fig. 5);
- HLE 19 (1901-1924), 24 locomotives fitted with Scharfenberg automatic coupling (Fig. 6).

Fig. 5. HL 1879 locomotive with an IC train at Brussels Nord station, Brussels, Belgium (20 September 2015) [photo by M. Graff]

Fig. 6. HL 1921 locomotive with an IC train at Bruges station (Station Brugge), Belgium (22 September 2015) [photo by M. Graff]

Technical problems with the locomotives class 13, which were previously supplied by Alstom in the number of 60 ones, were one of the reasons for ordering new locomotives, so the option of procuring another 60 locomotives of this series was abandoned in favor of ordering completely new vehicles. Although it had been planned to launch the tender in 2004, the decision to launch the tender came in 2006, as SNCB's doubts concerned the technical parameters of the vehicles – whether to choose tri-mode or four-system locomotives. Eventually, following concerns raised by SNCB Cargo (B-Cargo), which decided to abandon its earlier intention to purchase 30 diesel locomotives and cancelled the acquisition of more new electric locomotives, a tender was launched in 2006 for tri-mode locomotives for passenger traffic. In January 2007, the tender was awarded to Siemens. The first locomotive, #1801, was presented in 2008 at the InnoTrans fair in Berlin. In December of that year, technical and operational tests began on the test track in Velim, the Czech Republic. Another #1802 locomotive was delivered to SNCB in early March 2009. Trials on the SNCB network were prolonged due to, among other things, problems with the 3 kV DC supply to the vehicles. As the resolution of this problem did not occur until mid-2011, the manufacturer paid SNCB a contractual penalty of €20 million. The described locomotives are suitable for running push-pull trains assembled from I11 and M6 carriages (single- and double-decker). The introduction of the HLE 18 and HLE 19 series locomotives into SNCB stock resulted in the redeployment of the previously in-service locomotives the class HLE 13 and HLE 27 from passenger service and the retirement of the locomotives class HLE 23 and HLE 26. Since February 2015, two locomotives of this class have been in service on the SNCF rail network between Cean and Cherbourg. The technical data of the class HLE 18 and HLE 19 of the Belgian Railway / SNCB are shown in Table 3.

Table 3

Technical data of the HLE 18 and HLE 19 series locomotives of SNCB [6]

Rail operator	SNCB
Numbering	1801–1896 1901–1924
Number of vehicles ordered	120
Years of production	2010–2014
Start of operation	2011
Axle arrangement	Bo'Bo'
Track gauge [mm]	1435
Total length [mm]	19 580
Maximum width [mm]	no data
Maximum height (with pantograph folded) [mm]	4279
Bogie type	no data
Bogie base [mm]	no data
Diameter of new / worn wheels [mm]	1250 / n/a
Minimum railway curve radius [m]	no data
Axle load [t]	22
Locomotive weight [t]	88
Voltage	1.5 kV DC, 3 kV DC, 25 kV 50 Hz
Traction motors	AC 3~
Hourly / continuous power [kW]: – 25 kV 50 Hz – 3 kV DC – 1.5 kV DC	 6000 / 5000 no data / 5000 no data / 2400
Regenerative / resistance (ED) brake power [kW]: – 25 kV 50 Hz – 3 kV DC – 1.5 kV DC	 5000 / – 5000 / 2600 2400 / 2600
Maximum tractive force [kN]	300
Maximum speed [km/h]	200
Safety systems	TBL 1, TBL 1+, TBL 2, KVB, ETCS 1, Crocodile
Multiple traction	no data

2.4. ER20CF series locomotives of the Lithuanian railways

Locomotives from the ER20 (EuroRunner) family were primarily ordered by Austrian railways ÖBB in 2002 (2016 class, Hercules, 100 units) and, to a lesser extent, private operators working in Germany and Austria, such as Nord-Ostsee-Bahn (NOB) or Steiermärkische Landesbahnen (STLB) [7, 8] (Fig. 7). Some of these locomotives are leased by the manufacturer, while a few have been purchased by a Hong Kong operator. The freight version of locomotive ER20F is not equipped with a train heating system. The ER20CF series vehicles produced by Siemens can be manufactured in the following variants:

- type of locomotive: diesel (the manufacturer also offers an electric version, although, to date, no operator has placed such an order);
- track width: 1,435 mm / 1,520 mm / 1,668 mm;
- gauge: UIC 505–1 / EBO G2 / GOST 9238, determined by modifying the width and height of the vehicle and the roof structure;
- (diesel) engine power: 2,000 kW to 3,500 kW;
- electric traction motors used: asynchronous three-phase motors and IGBT inverters;
- vehicle weight/axle load: from 120 t / 20 t to 138 t / 23 t (weight adjustment is carried out by ballasting the locomotive);
- top speed: from 100 km/h to 160 km/h (this is achieved by varying the ratio of the main transmission from 8.1 to 5.1);
- tractive force: up to 540 kN;

- fuel tank capacity (diesel locomotive): up to 7,000 l;
- additional equipment: WC in driver's cab, exhaust catalyst, train heating system (up to 500 kVA), fire extinguishing system.

Fig. 7. ÖBB locomotive ER 2016 055 class with a passenger train heading to Vienna at Bratislava hl. st. station (22 August 2006) [photo by M. Graff]

EuroRunner locomotives were developed in several versions, depending on the power of the diesel engine: 2,000, 3,000, and 3,500 kW, with only the first version (for Lithuanian railways) having been ordered [9, 10] (Fig. 8). As part of the modernization of its rolling stock, virtually all of which came from Soviet manufacturers, Lithuanian railways decided to place an order for 34 new-generation locomotives adapted to run on 1,520 mm rail gauge track. Due to the different track gauge, the vehicles were transported on special trolleys on the DB Netz network to Sassnitz-Mukran station, where there a 1,520 mm rail network is present (the only station in Germany equipped with wider rail gauge tracks)[5], from where they were transported by ferry to Klaipėda in Lithuania. Locomotive deliveries were slightly delayed – originally planned to start in 2007, they were eventually completed by 2010. Nowadays, locomotives of this series lead freight trains in single or double traction on the LG network, mostly from/to the port of Klaipėda to the Lithuanian-Belarusian border or selected LG stations, or transit trains between the Königsberg region and Belarus/Russia on Lithuanian territory. The locomotives were designated in Lithuania as ER20CF (C – 6-axle locomotive, F – freight). The cost of purchasing the new vehicles was estimated at around EUR 123 million. They replaced, i.e, older locomotives of the M62 or 2M62 series, whose operation had become increasingly uneconomical (inefficient diesel engines, the need to purchase spare parts abroad). A technical description of the ER20CF series is provided in Table 4.

Fig. 8. A locomotive of the ER20-002 class (1,520 mm) with a freight train at Radviliškis station, Lithuania (14 July 2010) [photo by H. Pokk]

Table 4

Technical data concerning ER20CF-series diesel locomotives [9, 10]

Vehicle type	diesel-powered locomotive
Series	ER20CF
Years of delivery	2007–2009, 2010
Gauge	GOST 9238-83 / DSB 3A 16383
Axle arrangement	Co'Co'
Track gauge [mm]	1,520
Vehicle weight [t]	138
Axle load [t]	23
Total length [mm]	22,850
Maximum / continuous tractive force [kN]	450 / 360
Width [mm]	3,202
Height from the rail head including a KW antenna [mm]	4,942
Diesel engine	MTU 16V 4000 R41
Diesel engine power [kW]	2,000
Transmission	electric, AC-AC
Diesel engine rotation range [1/min]	600-1,800
Bogie base [mm]	2,045 / 1,795
Electrodynamic brake power [kW]	1,600
Maximum speed [km/h]	120
Transmission ratio	6.8
Intended use	freight traffic
Fuel reserves [l]	7,000
Diameter of new / worn wheels [mm]	1,100 / 1,020
Traffic safety/communication system	KLUB-U / RVS1
Number of locomotives ordered	34+10
Locomotive operating temperature range	–34°C – +40°C

[5] This is a remnant of the Soviet army's presence in Germany – the station was built in the 1980s to ensure communication between Soviet military units and the USSR bypassing Poland.

3. Vectron locomotive

3.1. Vectron – description of the design

Vectron is a new family of locomotives, the concept of which was developed in 2007 by Siemens [6, 11]. For the first time, the prototype was presented in June 2010, following successful technical and operational testing at the Wegberg-Wildenrath test track in Germany [12, 13, 14, 15] (Fig. 9, 10, 11). In addition, Siemens unveiled a diesel-electric version of the Vectron locomotive at the Innotrans fair in Berlin in September 2010 (Fig. 12). Locomotives from the Vectron family, which are a development of the Eurosprinter locomotive concept, offered to customers can be both electric and diesel, representing Siemens' answer to the Traxx vehicles offered by Bombardier (Fig. 13). Vectron locomotives can be equipped and adapted to various European safety systems, including ETCS. The manufacturer offers the following Vectron locomotive variants [16]:

- multi-system (AC and DC) with 6,400 kW power and a maximum speed of 160/200 km/h;
- AC-powered – 6,400 kW (high power), 160/200 km/h;
- AC-powered – 5,600 kW (medium power), 160 km/h;
- DC-powered 3 kV – 5,200 kW, 160/200 km/h;
- diesel with an electric transmission of 2,400 kW and a speed of 160 km/h.

Fig. 10. Machine compartment of the Vectron locomotive [photo by Siemens]

Fig. 11. Control panel of the Vectron locomotive [photo by Siemens]

Fig. 9. Vectron locomotive for ČD during assembly at the Siemens Allach plant, Munich (27 June 2016) [photo by M. Graff]

Fig. 12. Vectron DE 247 905 (28 January 2017) [photo by Siemens]

Fig. 13. Vectron MS 193 206 leased by RailJet with an IC train at the Český Těšín station, Czech Republic (28 July 2017) [photo by M. Graff]

Potential customers may include operators, mainly from Germany and Austria, as well as those operating from Italy across the Alpine range into northern Europe, from stations in western Europe towards the east, or operators from the new EU countries. The adaptation to work with different power systems and the equipping with national safety systems enables locomotives to be widely used in international passenger and freight traffic [17]. The manufacturer's latest offer, shown in March 2018 and destined for the German market, is an low-cost version of the vehicle called Smartron [18, 19, 20, 21]. The main difference compared to Vectron is that Smartron is a ready-made locomotive without the possibility of fitting additional equipment or changing, for example, the maximum speed. The versatility of the Vectron platform lies in the fact that individual (redundant) components are subtracted from a hypothetical vehicle equipped with all possible traffic safety systems or electrical apparatus suitable for operation under four known power systems until the desired configuration is achieved.

Vectron is based on solutions implemented in earlier Siemens locomotives, including ES 2007, on which, among other things, the external design of the body was inspired. The positioning of the crash zones was changed, the exterior mirrors were replaced by cameras, and the machine compartment was redesigned, with a passageway in the middle in the electric version and two passageways at the side walls in the diesel version. Pneumatic lines were routed under the floor. Depending on the version, the weight of the four-axle locomotive oscillates between 80–90 t, with the 3 kV DC version weighing around 80 t, and the AC version 84–85 t (the increase in weight is due to, among other things, the transformer), and the multi-system version 88–89 t. The power transmission takes place via a hollow shaft and a flexible coupling made of steel components. The body is coupled with the bogies by using springs as the Flexicoil system. At the front of the vehicle, there is an energy-absorbing zone in the event of a collision (crash zone). The operation of the wheelsets is based on linkages. The transmission of longitudinal forces (tractive and braking) is carried out using the pivot. The electric traction motors are not fully sprung, but are suspended from the bogie frame and transmit torque to the wheelsets via a transmission connected to the shaft of each motor via two flexible steel connectors [22, 23]. Although steel components are not as flexible as rubber ones, the overall design is simpler to build and less expensive. The forces generated by the motor's torque are only slightly higher than in the case of a full-spring solution. The version adapted to a maximum speed of 200 km/h can be fitted with additional horizontal dampers that form part of the inter-bogie coupling. The lower speed of Vectron (160/200 km/h) compared to Taurus (230 km/h), which is Vectron's predecessor, enabled the mechanical part to be simplified and allowed the manufacturer to reduce the purchase price of the vehicle. The primary brake is the electrodynamic brake while the disc brake is used at low speed. All electrical equipment is located in the machine compartment except the transformer and batteries, which are below the level of the frame. The locomotive roof consists of three removable parts. Multi-system (AC/DC) vehicles have four pantographs, while other electric locomotives have two (internal DC or external AC). Vectron can operate in multiple tractions, with push-pull trains, and is compatible with the Eurosprinter family of vehicles supplied earlier. The bogies of different versions of Eurosprinter locomotives, including Vectron, are shown in Fig. 14–18, and the pantographs in Fig. 19–21.


Fig. 14. The bogie of an LG-owned ER20 series (1,520 mm) locomotive [photo by M. Graff]

Fig. 15. The bogie of an SNCB-owned HL 1800 series locomotive [photo by M. Graff]

Fig. 16. The bogie of an ÖBB-owned ER20 series locomotive [photo by M. Graff]


Fig. 17. The bogie of a PKP IC-owned EU44 series locomotive [photo by M. Graff]


Fig. 18. The bogie of a Vectron locomotive [photo by M. Graff]


Fig. 19. The pantograph of an SNCB-owned HL 1800 class locomotive [photo by M. Graff]


Fig. 20. The pantograph of a PKP IC-owned EU44 class locomotive [photo by M. Graff]


Fig. 21. The pantograph of a Vectron DC locomotive [photo by M. Graff]

In 2010, six locomotives were produced; two multi-system (193 901, 193 902), AC (193 921, 193 922), and DC (193 951 and 193 952). Slightly later, another three AC vehicles (193 923 to 193 925) and one prototype diesel vehicle (247 901) left the factory. Thanks to the issuance of a temporary certificate of release for operation by the Polish UTK (Office of Rail Transport) in November 2011, at the turn of 2011/2012, both DC version locomotives began a period of temporary operation on the PKP network. Since December 2011, vehicle 193 951 (now bearing number EVN 91 51 5 170 020-9) is used by DB Schenker Rail Polska. The second unit, presented at the Trako trade fair and bearing the designation EVN 91 51 5 170 021-7, was initially handed over to ITL Polska on 6 January 2012. From March 2012 onwards, it was loaned to PKP IC.

From 1 April 2011, Vectron was operated with two pairs of trains on the Warszawa Wschodnia [Warsaw East] – Kraków Płaszów section: TLK Brzechwa and Ex Małopolska (13101/3510 and 5311/31100) with a daily mileage of approximately 1,200 km. The planned period of monthly operation has been extended to the end of May 2012. The advantage of Vectron in the DC version, emphasized by the manufacturer, is the low weight of the vehicle, which allows its operation on lines with a permissible load of 20 tonnes (196 kN), and therefore, in the case of Poland, on the entire electrified railway network.

Siemens received the first orders for locomotives from this family in December 2010 from Railpool, which decided to obtain six 6,400 kW Vectron locomotives operating at 15 kV 16.7 Hz. The vehicles (193 801 to 806) are also used in passenger and freight traffic in Germany and Austria. In 2012, two DC locomotives were made for Italian operator Furio Muro.

The locomotive can be fitted with a low-power diesel engine (~180 kW, Euro IIIB emission standard), allowing it to run on non-electrified lines or spurs. Compared to the electric version, the diesel one is about 1 m longer and the wheel diameter is slightly smaller. The drive unit ,is a 16-cylinder MTU 16V 4000 R84 engine with a forked cylinder arrangement, in line with the Euro IIIB emission standard. The driver's seat is placed on the right-hand side by default (right-hand traffic is used on the DB Netz rail network). The version produced for the Finnish railways (1,524 mm) has a greater height in the middle section due to additional protection of electrical equipment against snow and ice on the roof. It should be added that VR Vectron's feature a body with the same dimensions as the locomotives intended for a 1,435 mm track gauge. A version has also been developed for the US operator Amtrak – the multi-system electric Amtrak Cities Sprinter (AC) and the diesel Siemens Charger, both capable of running at 200 km/h on the Northeast Coast (NEC) and in California, respectively. A comparison of the parameters of Vectron locomotives operated by PKP IC (lease) and VR (purchase) is shown in Table 5.

Table 5

Technical data for Vectron locomotives – DC and Finnish / VR rail versions [24]

Rail operator	PKP IC	VR
Numbering	–	3301-3380
Power supply system	3 kV DC	25 kV 50 Hz
Years of delivery*	–	2016–
Number of locomotives ordered	–	80
Track gauge [mm]	1435	1524
Axle arrangement	Bo'Bo'	
Total length [mm]	18 980	19 049
King pin spacing [mm]	no data	13 800
Total width [mm]	3012	3013
Bogie base [mm]	3000	
Maximum height [mm]	4248	4400
Service mass [t]	80	90
Maximum axle load on the track [kN]	196	221
Locomotive power [kW]	5200	6400
Additional diesel engine power [kW]	–	360
Wheel diameter [mm]	1250	
Control system	Sibas 32	
Safety system	SHP, CA	JKV, ETCS
Maximum tractive force [kN]	300	no data
Brake force (ED brake) [kN]	150 (optional 240)	no data
Maximum speed [km/h]	160 (200)	200
Notes	leased locomotives	–

*Production in progress.

3.2. Vectron – early days of operation

In late June 2012, the first Vectron locomotive was certified for operation on the Romanian rail network for an indefinite period (25 kV 50 Hz), as well as for temporary operation on the Swedish (15 kV 16.7 Hz) and Polish (3 kV DC) rail networks, and in September 2012 it was certified for operation for an indefinite period by the UTK / Office of Rail Transport (a rail regulator) (in Sweden from May 2013). The certificate issued by the Federal Railway Authority (EBA) for the approval of Vectron ACs' operation on the DB Netz rail network was issued in December 2012 (for multi-system versions, in July 2014). In March 2013, Vectron locomotives were allowed to run on the ÖBB rail network and in December on the MÁV rail network. In early July 2014, the Norwegian rail transport authority Statens Jernbanetilsyn approved similar locomotives adapted for both 15 kV 16.7 Hz and 25 kV 50 Hz operation (able to enter the Danish rail network) and set the maximum speed for the Vectron's at 200 km/h. Vectron locomotives can work with other Siemens vehicles of the 120, 152 (ES64F), 182 (ES64U2), and 189 (ES64F4) series, using ZDS (German: *zeitmultiplexe Doppeltraktionssteuerung*) or ZMS (German: *zeitmultiplexe Mehrfachtraktionssteuerung*) systems for double and multiple tractions, respectively. Approval for operation on the Turkish rail network for an indefinite period for Vectrons was issued in November 2014, and a temporary one for the Slovak or Czech rail network (for the 3 kV DC version), and in May 2015, a similar document was also issued for the multi-system version in both countries. ČD Cargo acquired 8 similar MS version locomotives, which are employed in Czech-German traffic, including for running EC trains between the two countries on the Hamburg-Berlin-Dresden-Prague main line (the locomotive swap takes place at Dresden Hbf. station), although locomotives leased from ELL Austria are also employed in traction work. Approval for operation on the Italian rail network was issued in July 2015 for the 3 kV DC version and for the multi-system version in February 2017. The approval for operation on the rail network of Slovenia (3 kV DC) and Croatia (25 kV 50 Hz) was issued in September 2015. The Finnish rail transport authority approved the Vectron for operation in May 2017, and in September 2017 the Vectron MS version received approval for operation on the Dutch rail network. A kind of record was recorded in June 2017, when similar locomotives were approved by regulators in Switzerland, Serbia, and Bulgaria. The multi-system version of Vectron was approved for operation on the PKP network for an indefinite period in August 2015 by the Office of Rail Transport. The diesel version of the Vectron, on the other hand, was approved for operation on the German rail network in September 2014, and in Austria and Turkey in August 2015. A summary of Vectron approvals, by version, for the national rail networks is given in Table 6.

Table 6

Approvals for Vectron locomotives on the rail networks of individual countries in Europe (2022)

Country	Version				
	MS	AC	DC	DE	Hybrid
Austria	+	+	–	+	+
Belgium	+	(+)	(+)		–
Bulgaria	(+)	(+)	–		–
Croatia	+	+	–		–
Czech Republic	+	+	+		–
Denmark	–	+	–		–
Finland	–	+	–	–	–
Germany	+	+	–	+	+
Hungary	+	+	–	–	–
Italy	+	–	+	–	–
Netherlands	+	–	–	–	–
Norway	–	+	–	–	–
Poland	+	–	+	–	–
Romania	+	+	–	–	–
Serbia	(+)	(+)	–	–	–
Slovakia	+	+	–	–	–
Slovenia	+	–	–	–	–
Sweden	–	+	–	–	–
Switzerland	(+)	(+)	–	–	–
Turkey	+	+	+	+	–

Symbols: + → vehicles in operation, (+) → ordered vehicles [own elaboration based on manufacturer's data]

3.3. VR's Vectron (1524 mm)

Locomotives from the Vectron family have also been supplied to the Finnish railways, VR-Yhtymä, and are currently the most modern vehicles owned by this operator [25, 26, 11, 27, 28]. A total of 80 locomotives were ordered, with an option to add another 97 units (Figures 22, 23). Serial deliveries began in 2016, with planned operation in June 2017. Due to Finland's harsh climatic conditions, technical and operational trials of Finnish Vectron took longer than analogous ones for countries with a milder climate (Germany, Austria, Poland, etc.). It was assumed that VR's Vectron would have a maximum speed of 200 km/h, an axle load of 22,5 t, and an operating temperature limit of –40°C.

Fig. 22. Vectron VR 3306 (1524 mm, 25 kV 50 Hz) near Äänenkoski station, Finland (27 September 2017) [photo by P. Trippi]

Fig. 23. Vectron VR 3306 locomotive (1524 mm, 25 kV 50 Hz) at Vanha Asema station, Finland (27 September 2017) [photo by P. Trippi]

The locomotives are designed for operation on a railway network with a track gauge of 1524 mm and electrified at 25 kV 50 Hz. The described vehicles are intended to replace the current used Sr1 class, built, among others, by the Novocherkassk factory (today Russia) in the late 1970s and 1980s. It should be added that the Vectron is a proven design and that the locomotives produced in 2010–2011 by Siemens have traveled a total of > 5 million km. A tender for similar locomotives for VR was awarded in December 2013 – out of the bids submitted by Alstom, Bombardier, and Siemens, the last bidder's vehicles were selected (with a purchase cost of €300 million), with the ordering party assigning the responsibility of repairing and maintaining the vehicles to the manufacturer. The agreement was signed in February 2014. Domestic manufacturer Transtech chose not to place an order, as building such a complex vehicle with a relatively short series did not guarantee a profit or even a cost recovery. For example, exporting vehicles and competing with other manufacturers, especially for the 1520/1524 mm rail gauge, was unlikely to succeed, as VR's requirements for vehicles are very specific. The accepted practice among established manufacturers in EU countries is to produce a prototype unit, which is usually disposed of after testing. The test results help the manufacturer to optimally adapt the offer to the operator's expectations and, if necessary, modify the technical documentation of the vehicle. The first VR's Vectron started technical and operational testing in April 2015, which lasted until September 2016, after which the locomotive was sent back to the manufacturer. Three prototype vehicles – Sr3 3302, 3303, and 3304 – were delivered to VR between January and May 2016 [25, 29], while the Sr3 3301 locomotive underwent technical and operational tests on the test track at Velim in the Czech Republic and Wegberg-Wildenrath in Germany (on 1435 mm track gauge). In the first half of 2017, five Vectron locomotives were delivered to VR and entered scheduled service in June. The manufacturer began series production of Sr3 locomotives in 2018 with a plan to complete delivery of the vehicles in 2026. The operator plans to exploit these locomotives until 2070.

The power of VR's Vectron is 6400 kW, and tractive force is 350 kN, which allows trains of 2100 t gross to be run on gradients of up to 10‰ in single traction [30, 31, 15]. Heavy freight trains loaded with coal or iron ore (wagons of Russian operators) with an average weight of 5500 t run in double traction (VR's locomotives are equipped with LAF – SA-3 + UIC mixed coupler) also run on VR's network (Fig. 24). It should be added that the maximum speed of VR's Vectron that has been achieved on the Finnish rail network is 220 km/h, and the maximum gross weight of a train operated with the 3300 series reaches 5700 t. The locomotive is equipped with an additional 360 kW diesel engine enabling it to operate on non-electrified sections and travel almost 100 km at 20 km/h.

In Sr3 compressed air is supplied by 2 oil-free reciprocating compressors with a capacity of 3,500 l/min, with the main compressed air tank volume of 1 m^3. The compressor was installed in the locomotive along with an air dryer and a system for monitoring compressed air parameters. VR's Vectron is equipped with Trainguard 100, a variant of ETCS, and the JKV traffic safety system used on the VR rail network. In addition, the vehicle is equipped with WLAN and DGPS devices. The Sibas vehicle control system, which also acts as a diagnostic system, sends information about potential faults to the service technician, allowing repair facilities to be prepared in advance, even before the locomotive arrives at the home locomotive depot. The LAF locomotive coupler, a combination of an SA-3 coupler and a UIC screw coupler, is fitted with a decoupling device controlled from the driver's cab, and the whole thing is described as Unilink. The installed EKE Trainnet system is responsible for closing/opening the doors in the passenger cars and controlling the brake system in the cars. The vehicle control system is compatible with the equivalent from Sr2 series locomotives (manufactured by Bombardier) and works with control trailers manufactured by Transtech. The locomotive is equipped with an electrodynamic regenerative brake as principal brake, 410 Ah batteries, and LED headlights with 220 kcd light output.

Fig. 24. LAF (UIC + SA-3) mixed coupler on VR's Vectron locomotive [photo by M. Graff]

Other changes compared to other Vectron locomotives include side windows, additional steps and handrails, a thermally insulated driver's cab, and bogies made in such a way as to make it more difficult for snow and ice to accumulate in the locomotive chassis (Fig. 25). The front wall of the locomotive has been reinforced to protect the driver in the event of a collision, such as with a moose. Compared to its counterpart on other Vectron locomotives, the snow plow has been suitably reinforced. The locomotive bogies are designed in such a way that, in addition to wheelsets for the 1524 mm gauge, it is also possible to fit wheelsets for the 1668 mm gauge. The driver's cab is heated and air-conditioned. The first major overhaul of the locomotive is carried out after 1.2 million kilometers.

Fig. 25. Vectron locomotive for VR (1524 mm) during an assembly at the Siemens Allach plant, Munich (27 June 2016) [photo by M. Graff]

3.4. ACS-64 series, or Vectron for the USA

Siemens has also developed a version of the locomotive for the North American market [32, 33, 34, 35]. Thus, the Vectron variant for the Amtrak operator designated ACS-64 (Amtrak Cities Sprinter), is a locomotive based on solutions used in previously produced vehicles [36, 32, 33], but due to differences, solutions required only in the USA have been implemented. These are additional crash zones and reinforcement of the driver's cab structure (Fig. 26, 27). The purpose of the purchase of the new 70 locomotives for Amtrak was to replace the older AEM-7 and HHP-8 series vehicles, two-cab and one-cab respectively, in service on the Northeast Corridor (NEC), connecting Washington, New York, and Boston. The first locomotives were taken delivery in February 2014 and delivery was completed in August 2016. In addition to Amtrak, similar locomotives have been ordered by another operator, SEPTA Regional Rail, which operates in the south-eastern part of the state of Pennsylvania, and 15 vehicles were taken delivery in 2018. Locomotive production was carried out at plants in the USA, including the corporation's main factory in Florin near Sacramento, California. The electrical part for the ACS-64 series was manufactured at the Norcross and Alpharetta plants in Georgia, the converters at the Alpharetta plant, and the traction motors, and transmissions at the Norwood plant in Ohio. The contract, which was concluded in February 2013, is worth USD 466 million, with the funds coming from, among other things, a USD 562.9 million in loan from the federal government granted as part of the railway revitalization and rolling stock renewal program.

Fig. 26. ACS-64 (US Vectron) #903 and #904 of the rail operator SEPTA at the CSX Locust Point yard Baltimore, Maryland, USA (20 February 2018) [photo by B. Phillips]

Fig. 27. Amtrak's ACS-64 601 (US Vectron) prior to delivery to the Avondale Transportation Test Center in Pueblo, Colorado, USA (8 June 2013) [photo by N. D. Holmes / Wikimedia Commons]

The locomotive body is a uniform structure including the locomotive frame and side walls. The effect of a similar modification is an increase in locomotive weight and axle load and tractive force. The ACS-64 axle load of 24.5 tonnes is high, however, this is not a problem in the USA – a similar value is standard for passenger locomotives (freight locomotives: 30–35 tonnes). The ACS-64 is suitable for operation on the 25 kV 60 Hz, 12.5 kV 60 Hz, and 12 kV 25 Hz electrified lines used for the electrification of NEC. The power supply to electric motors is provided by inverters made up of water-cooled IGBT transistor converters, with one converter supplying one pair of motors. Additional (auxiliary) converters supply a HEP module through the onboard equipment on the locomotive. The locomotive body is made of steel and bogies are connected to the body by a pivot and low-lying traction links (bogie-to-body connections), with both sides, with rubber inserts at the ends to reduce the transmission of vibrations from the bogies to the locomotive body[6]. The transmission of torque from the engine through the drive to the wheelsets is analogous to that of standards Vectron locomotives. The locomotive's high power of 6400 kW and axle load allows running trains consisting of 18 Amfleet cars at a maximum speed of 201 km/h (125 mph) without any problems. For safety reasons, modified AAR couplers were installed to better protect the train from disengagement during a derailment or tipping over on its side in the event of a collision with an obstacle. The main advantage of this class is the efficient electrodynamic regenerative brake (efficiency of approximately 100%), and the recuperated energy can be returned to the network or used for supplying a HEP (head-end power) module, which provides electricity for air conditioning or heating.

The first three ACS-64 locomotives were delivered in mid-May 2013, with #600 and #601 tested at the Transportation Technology Center test track in Pueblo, Colorado, and #602 on the NEC line. At the official presentation of the locomotives in mid-February 2014 at 30th Street Station in Philadelphia, top government officials – including Vice President J. Biden – was present. The last locomotive #670 was taken delivery in early June 2016. The introduction of ACS-64 locomotives resulted in the withdrawal of previously used locomotives on the NEC line. There are six locomotives in the rolling stock reserve and their use is planned in case of, for example, an increase in consequences of trains in the future [37].

Another rail operator – SEPTA – signed a contract in November 2015 for the delivery of 13 ACS-64 locomotives (with an option for five more) for USD 118 million (with option – USD 154 million) to replace 7 Series AEM-7 and ALP-44 locomotives, with delivery in 2018 [38, 39]. Finally, the train operator decided to order a total of 15 locomotives. In February 2016, Amtrak leased one locomotive – #664 – to SEPTA for trials on this rail network. In mid-March 2016, the locomotive was returned to the owner. The first units of the manufactured locomotives were taken delivery of in mid-December 2017, and scheduled operation began in January 2018. The technical data for the U.S. rail operators of Vectron locomotives are provided in Table 7.

Table 7

Technical data of Vectron locomotives of U.S. rail operators [36]

Vehicle type	**electric locomotive**
Manufacturer	Siemens Mobility
Rail operators	Amtrak: 600-665, 667-670; SEPTA: 901-915
Number of vehicles ordered	Amtrak: 70 SEPTA: 15 (option for 3 more)
Years of production	Amtrak: 2012–2015 SEPTA: 2015–2018
Years of delivery	2013–2016 (Amtrak)
Start of operation	February 2014 (Amtrak)
Axle arrangement	Bo'Bo'
Track gauge [mm]	1435
Total length [mm]	20 320
Maximum width [mm]	2984
Maximum height (with a pantograph folded) [mm]	3810
Bogie type	SF4
Bogie base [mm]	9900
Diameter of new / worn wheels [mm]	1117 / 1041
Minimum railway curve radius [m]	76
Axle load [kg]	24 610
Locomotive weight [kg]	97 766
Voltage	12 kV 25 Hz, 12,5 kV 60 Hz, 25 kV 60 Hz,
Traction motors	3~ AC
Railway brake types	electrodynamic, electro-pneumatic and disc
Hourly / continuous power [kW]	6400 / 5000
HEP (head end power) (heating of carriages)	970 kW, 480 V 3~, 60 Hz, 1000 kVA
Maximum tractive force [kN]	320
Factor of adhesion	2.99 (33.4%)
Brake force [kN]	150
Maximum speed / vehicle design speed [km/h]	201 / 217
Safety systems	FRA, ACSES II
Multiple traction	yes

[6] A traction link is used for the transmission of tractive longitudinal forces from the bogie to the locomotive body and usually consists of a steel rod attached at one end to the bogie frame and at the other end to the main frame of the locomotive. Both ends are fitted with rubber damping to reduce the transmission of vibrations. The role of the rod is to minimize tractive force stresses from the central bogie pivot and reduce adverse phenomena in the transfer of body weight to the bogies. Previously, the transfer of bogie-to-body forces was via a pivot in the bogie.

4. Operation

Nowadays, the purchase of locomotives is not only made by national or private operators, but also by leasing companies. The last solution applies to rail operators that need to acquire locomotives for periodically increased transport tasks (purchasing vehicles would be pointless). Therefore, leasing companies emerged using, for example, multi-system vehicles, which are not complicated to adapt to the requirements of individual rail operators.

4.1. Locomotive leasing companies

There are currently several locomotive leasing companies operating in the EU countries: Siemens and European Locomotive Leasing, MRCE / Mitsui Rail Capital Europe, Railpool, Alpha Trains, boxXpress, and Lokomotion.

4.1.1. Siemens and European Locomotive Leasing (ELL)

In late March 2014, the leasing company European Locomotive Leasing (ELL) signed a framework agreement with Siemens for the delivery of 50 Vectron locomotives with different technical parameters, i.e. for different customers [40]. In early June 2016, these two entities signed another framework agreement for additional 50 locomotives, which will be used to run trains on several traffic routes:

- from the Netherlands to Italy, via Germany, and Austria;
- from Germany via Austria and Hungary to Romania;
- on rail networks in Germany, Austria, and Hungary;
- the possibility to access the rail networks of the Scandinavian countries was included.

Except national safety systems, the locomotives will be equipped with ETCS. They have a power of 6400 kW and a maximum speed of 200 km/h. The installation of an additional diesel engine was also provided as an option. In February 2017, DB Cargo leased 10 Vectron DE locomotives from the manufacturer, and they are stationed at the locomotive depot in Halle.

4.1.2. MRCE / Mitsui Rail Capital Europe

Mitsui Rail Capital Europe, a locomotive leasing company, signed a contract with Siemens in July 2013 for the delivery of 15 Vectron locomotives in Variant B, i.e. designed to run trains between Germany, Austria, and Hungary. These locomotives have a power of 6400 kW and a maximum speed of 160 km/h. In addition to the required national systems, all vehicles are equipped with ETCS. Some of the locomotives will be produced in this way to allow easy conversion in the future, e.g. from AC to MS. In June 2014, MRCE signed a contract with Siemens to deliver another 20 locomotives with a maximum speed of 200 km/h for passenger traffic. MRCE signed the most contracts with Siemens for locomotives to run trains between Germany and Austria:

- in October 2015 – a contract for 10 locomotives in the AC version and 11 in the MS version (with the possibility to access the Italian rail network) and an additional contract for another 10 locomotives in June 2016; locomotives with the power of 6400 kW and a maximum speed of 160 km/h;
- in September 2017, a contract was signed for 10 Vectron MS locomotives, with the possibility to access the rail networks of Switzerland, Italy, and the Netherlands, with an option for additional 20 vehicles.

In September 2017, MRCE ordered 30 + 15 locomotives from Siemens (in addition to 66 Vectron vehicles ordered/received earlier), up to a total of 111 vehicles in its possession.

4.1.3. Railpool

The German company Railpool is one of the first leasing companies of Vectron locomotives, which ordered six single-system Vectron locomotives in December 2010 for both passenger and freight traffic in Germany and Austria. The first locomotives were taken delivery in December 2012. They have a power of 6400 kW and a maximum speed of 200 km/h. The locomotives were equipped with the following systems: ETCS, WTB (Wire Train Bus), and destination station displays. In May 2014, Railpool ordered five Vectron AC locomotives and, in 2015, another three locomotives of the same version. In May 2016, five AC locomotives were ordered to run trains on the rail network of Germany, Austria, Hungary, and Romania. They have a power of 6400 kW and a maximum speed of 200 km/h. The contract provides for the optional delivery of ten additional locomotives. To operate RE (Regional Express) trains Nuremberg – Sonneberg on the Ebensfeld – Coburg high-speed line, DB Regio has leased five locomotives from MRCE since December 2017, which were equipped with ETCS provided by Alstom.

4.1.4. Alpha Trains, boxXpress, and Lokomotion

Alpha Trains Luxembourg S.à r.l is one of the companies that lease locomotives (the aforementioned entity placed an order for six Vectron locomotives in mid-April 2016). The contract also provides for vehicle repairs and maintaining. Alpha Trains leased the vehicles to TX Logistik AG Germany, which operates the locomotives between Germany, Austria, and Italy. The contract provides for the procurement of four Vectrons, which was announced in early April 2017.

The locomotive leasing service is also provided by boxXpress headquartered in Hamburg, which purchased in August 2013 its first four Vectron locomotives to run trains between Germany and Austria. All locomotives are equipped with ETCS. In November 2014, four other locomotives were ordered, just as in October 2017.

In late January 2016, private company Lokomotion signed a contract for the delivery of eight Vectron MS locomotives to run trains between Germany, Austria, and Italy. In addition to the national traffic safety systems, the locomotives are equipped with ETCS and delivered in spring 2017. The locomotives have a power of 6400 kW and a maximum speed of 200 km/h (which also suggests the possibility of use with passenger trains).

Fig. 29. STH-owned Vectron DE 1247 905 with a freight train near Haiding station, Austria (15 March 2018) [photo by K. Steiner]

4.2. Germany, Austria, Switzerland

4.2.1. Austria

In March 2014, the Austrian rail operator Cargo Service – CargoServ acquired one AC locomotive with a power of 6400 kW and a maximum speed of 160 km/h. A single Vectron locomotive was also ordered by the Austrian operator Wiener Lokalbahnen Cargo GmbH (WLC). The locomotive, which was delivered in December 2014, is approved the permission to the rail networks of Germany and Austria.

In late January 2017, Siemens signed a framework agreement with ÖBB for the delivery of 200 Vectron locomotives, of which up to 50 will be in the MS version, up to 100 in the AC version, and up to 50 in the AC version with an additional diesel engine (Fig. 28). Furthermore, ÖBB contracted for the delivery of 30 Vectron MS locomotives that were delivered in the summer of 2018. The operator intends to operate similar locomotives (in addition to its rail network), also on the rail networks of Germany, Croatia, Poland, Slovakia, the Czech Republic, Slovenia, and Hungary. The locomotives with a power of 6400 kW and a maximum speed of 160 km/h were equipped with ETCS (Fig. 29, 30).


Fig. 30. WLC-owned Vectron 193 238 with a freight train near Haiding station, Austria (15 March 2018) [photo by K. Steiner]

Fig. 28. Vectron MS locomotive #1293 001 for ÖBB [photo by Siemens]

4.2.2. Germany

A German rail operator, mgw Service, signed a contract for the delivery of one locomotive, which was delivered in August 2014. Moreover, another locomotive was ordered in July 2016. The manufacturer delivered the Vectron DE 247 901 prototype locomotive to the Prüfcenter Wegberg-Wildenrath (PCW) research center in January 2015.

Another German operator, ENON, ordered one Vectron AC locomotive in May 2015 to lease to its subsidiary – Eisenbahngesellschaft Potsdam (EGP). In December 2017, ENON was taken delivery of another Vectron AC locomotive for its subsidiary – EGP.

Captrain Deutschland-Gruppe, a subsidiary of ITL Eisenbahngesellschaft, ordered three Vectron MS locomotives for operation on the rail networks of Germany, Austria, Poland, the Czech Republic, Slovakia, and Hungary. The first locomotive was delivered in August 2015 and the last in early 2016. The operator initially planned to acquire another three locomotives, as an option, but this plan was eventually abandoned in 2016. In late April 2017, ITL ordered another six locomotives for Captrain Deutschland-

Gruppe. Three locomotives delivered in 2018 received the national rail safety systems required on the rail networks of Germany, Austria, Poland, Hungary, the Czech Republic, Slovakia, and Romania, while three more locomotives delivered in 2018 additionally was equipped with the ATB safety system required on the Dutch rail network.

In September 2016, at the Innotrans trade fair in Berlin, the manufacturer and Railcare AG signed a contract for seven Vectron AC locomotives with an additional diesel engine. The contract also included repairs and maintaining of the locomotives for eight years. The purpose of the locomotives will be to pull freight trains on the rail networks of Germany, Austria, and Switzerland. The locomotives have a power of 6400 kW and a maximum speed of 160 km/h. The first rail operator that ordered Vectron DE locomotives was Infraleuna, which signed a contract for one locomotive in December 2016.

In August 2016, DB Cargo concluded a framework agreement with Siemens for the supply of 100 Vectron MS locomotives, 60 of which will be delivered shortly (Fig. 31, 32). The locomotives will operate freight traffic of the Rhine-Alps line on the rail networks of Germany, Austria, Switzerland, Italy, and the Netherlands (the locomotives will be equipped with ETCS), and from 2020 will also be placed in service on the Belgian network [24].

Fig. 31. Locomotives: Vectron DC owned by DB Schenker Rail Polska and HL 1877 owned by SNCB at VUŽ Velim, Czech Republic (26 April 2014) [photo by from the author's collection]

Fig. 32. Vectron MS #193 300 for DB Cargo [photo by Siemens]

In December 2017, Stern & Hafferl Verkehrsgesellschaft purchased Vectron-DE locomotive #247 905, which was officially presented earlier by the manufacturer.

An order for two diesel-electric locomotives was also placed by RDC Autozug Sylt GmbH, a German subsidiary of Railroad Development Corporation that is a U.S. entity headquartered in Pittsburgh. The delivery date for the locomotives was set for 2017 and 2018.

4.2.3. Switzerland

In late January 2017, the leasing company LokRoll AG, with the help of the infrastructure fund Reichmuth Infrastruktur Schweiz AG, ordered 18 Vectron MS locomotives, equipped with ETCS in addition to national safety systems. The purpose of these locomotives will be to run trains between Switzerland, Germany, Austria, and Italy. The locomotives with a power of 6400 kW and a maximum speed of 160 km/h was delivered by December 2017. The owner of the locomotives intends to lease all vehicles to SBB Cargo International for 15 years.

In March 2015, a Swiss rail operator, BLS Cargo, ordered 15 Vectron MS locomotives to run trains on the Swiss, German, Austrian, Italian, and Dutch rail networks. The first locomotives were taken delivery in the second half of 2016.

The Swiss operator Hupac decided to order eight Vectron MS locomotives for the Rhine-Alps traffic route. Deliveries of the locomotives should be made in the early summer of 2018. The locomotives have a power of 6400 kW and a maximum speed of 160 km/h [24].

4.3. Central Europe

4.3.1. Czech Republic and Slovakia

A Czech operator, ČD Cargo, decided to order five Vectron MS locomotives in April 2016 to pull trains between the Czech Republic, Slovakia, and Germany (although access to rail networks of other countries is not excluded) [24]. The power of the locomotives is equal to 6400 kW and the maximum speed is 160 km/h, which allows heavy trains to run without problems on the entire Czech and Slovak rail network, which is located in largely hilly or mountainous terrain (Fig. 33, 34). In May 2017, The order was extended by the operator to include three additional locomotives. In June 2017, ČD decided to lease eight locomotives from European Locomotive Leasing (ELL) for passenger traffic on the Prague – Dresden – Berlin route, with the vehicles ordered by ELL in a framework agreement dated June 2016. Another Czech rail operator that ordered similar locomotives is EP Cargo (1 locomotive in the MS version) operating mainly in the Czech Republic and Poland. In December 2015, a Slovak rail operator, Prvá Slovenská Železnicná (PSŽ), decided to purchase a previously leased Vectron MS locomotive – 193 820.

Fig. 33. Vectron MS #383 108 leased by ZSSK with an IC train at the train station Bratislava hl. st., Slovakia (22 June 2019) [photo by M. Graff]

Fig. 34. Vectron MS #383 050 leased by Unipetrol with a freight train at Ostrava Svinov station, the Czech Republic (30 September 2018) [photo by P. Štefek]

In November 2017, Slovak railways (ZSSK) decided to lease 10 locomotives from S Rail Lease to run IC trains between Bratislava and Košice (3 kV DC, 25 kV 50 Hz) [24]. Vectron locomotives are also leased by the operator RegioJet to run IC/EC trains on the Prague – Ostrava – Žilina – Košice, and Bratislava – Košice routes (ELL is the owner of the locomotives).

4.3.2. Poland

Vectron locomotives are placed in service on the PLK rail network primarily by their two rail operators – PKP Cargo and DB Cargo Polska, MS and DC versions, respectively [24] (Fig. 35, 36). The multi-system version was ordered in September 2015 with some 15 vehicles and delivered from early 2016 to summer 2017. The contract also provides for the maintaining, repair, and supply of spare parts for the locomotives over eight years. A clause in the contract for the purchase of locomotives also provides for the procurement of five additional units. PKP Cargo operates the Vectron locomotives when running trains on the rail networks of Germany, the Netherlands, the Czech Republic, Slovakia, Austria, and Hungary, while selected units have optionally installed traffic safety systems that are required on the rail networks of the aforementioned countries. Another operator, Deutsche Bahn Cargo Polska, ordered 23 Vectron locomotives in December 2012 for operation on 3 kV DC electrified lines. The manufacturer supplied the locomotives until 2015, which are used for running freight trains, although several units were briefly leased by PKP IC which was facing a shortage of locomotives to run trains with a maximum speed of 160 km/h. DB Cargo Poland decided to order another 13 Vectron DC locomotives.

Fig. 35. The Vectron DC locomotive leased by PKP IC with an IC train at Warszawa Wschodnia station (14 April 2011) [photo by M. Graff]

Fig. 36. The Vectron MS locomotive #EU46: 503+502 owned by PKP Cargo at Hegyeshalom station, Hungary (23 February 2016) [photo by R. Wyhnal]

Another Polish rail operator, Industrial Division, ordered one MS locomotive in February 2018, which will be placed in service on the rail networks of Germany, the Czech Republic, Slovakia, Austria, Hungary, Romania and Poland. In addition to the Vectron locomotives owned by PKP Cargo and DB Cargo Polska, Vectron locomotives owned by rail operators from neighboring countries – Germany, Austria, and the Czech Republic – are also placed in service on the PLK rail network.

4.3.3. Hungary

In March 2017, the Raaberbahn/GySEV operator signed a contract for the delivery of five locomotives, of which two were ordered in the AC version with an additional diesel engine and three were MS locomotives [24] (Fig. 37). A clause in the contract provided for the procurement of another four AC locomotives, however, this option was withdrawn by the operator in June 2017.

Fig. 37. GySEV-owned Vectron 471 500 with a freight train near Haiding station, Austria (15 March 2018) [photo by K. Steiner]

4.4. Southern Europe

4.4.1. Slovenia

Slovenian rail operator, Adria Transport, initially leased one Vectron locomotive. In January 2018, however, it decided to purchase the locomotive from the manufacturer – owner.

4.4.2. Italy

An Italian operator purchased Vectron locomotives exclusively in the DC version, indicating an intention for exploitation only in Italy or in Italy and neighboring Slovenia. The first rail operator was FuoriMuro, which purchased two locomotives in March 2012 to run freight trains between the Genoa harbor 60 km away and the *Interporto Rivalta Scrivia* container terminal. Another rail operator, Compagnia Ferroviaria Italiana (CFI), ordered two Vectron locomotives in February 2014, which were delivered in the second half of the aforementioned year. In September 2016, CFI signed another contract with Siemens – also for two locomotives, which were delivered by the manufacturer in 2017. The last private Italian rail operator, InRail, ordered three Vectron DC locomotives in July 2017.

The rail operator DB Cargo decided to lease eight Vectron DC locomotives for exploitation in Italy, where the lessor was UniCredit Bank's bank subsidiary – UniCredit Leasing, and the contract was signed in November 2015. The locomotives – with power of 5200 kW and a maximum speed of 160 km/h – were delivered to the operator in late 2016.

4.4.3. Bulgaria

In April 2016, PIMK, a Bulgarian rail operator, ordered one Vectron locomotive with AC medium power (5600 kW) and a maximum speed of 160 km/h. A second Vectron locomotive was ordered by the Bulgarian operator DMV Cargo Rail in February 2018.

4.5. Scandinavia

4.5.1. Finland

Vectron locomotives were also purchased by rail operators from Scandinavian countries. The first Scandinavian rail operator, VR, placed an order in December 2013 for 80 locomotives with an option for another 97 units suitable for operation on lines with a track gauge of 1524 mm and electrified at 25 kV 50 Hz. VR branded its Vectron locomotives as the Sr3 series. Due to specific requirements – harsh climate (Scandinavian winters), the design of the Vectron locomotives was modified, although it was an evolution rather than a revolution.

4.5.2. Sweden

A Swedish rail operator, Hector Rail, ordered five locomotives in July 2016 with an option for another 15 units in the AC version with power of 6400 kW and a maximum speed of 200 km/h, additionally equipped with a low-power diesel engine and ETCS system. As the SJ rail network use the same voltage as the DB rail network – 15 kV 16.7 Hz, or NSB, no major modification to the Vector locomotive was necessary. Adjustment to the 25 kV 50 Hz voltage allows operation on the Danish rail network. In March 2017, Hector Rail ordered another 15 locomotives, as originally agreed in the contract option.

The leasing company Emissionshaus Paribus Capital purchased two locomotives, which were taken delivery of in mid-October 2013. The purpose of both locomotives is to operate passenger traffic on the Swedish rail network.

4.5.3. Denmark

In mid-March 2018, DSB placed an order for 26 Vectron MS locomotives with an option for another 18 locomotives to be delivered by 2021. Denmark is a transit country located between Sweden and Germany, and much of the cargo is transported by rail, especially via the Øresund Bridge and Tunnel between Copenhagen and Malmö became operational. The multi-system locomotive will allow access to the neighboring rail networks – Sweden and Germany. It should be added that in the 1990s, DSB purchased Eurosprinter locomotives – EA4000 series (Bo'Bo', 25 kV 50 Hz) and EG3100 series (Co'Co', 15 kV 16.7 Hz + 25 kV 50 Hz) – of which a few remain in operation while the others were sold to other rail operators.

4.6. List of locomotives

Orders for locomotives are placed successively and these vehicles are delivered. By 2022, the manufacturer received orders for more than 1,800 locomotives, including more than 500 optional vehicles (Table 8). Table 8 provides a comparison of Vectron locomotives sold or ordered for individual rail operator or owners (as at Q1 2022).

5. Conclusions

The Vectron locomotives, designed and manufactured by Siemens, equipped with a three-phase drive system and of modular build, are in operation in passenger and freight traffic in EU countries and the USA thanks to their versatility. The facility of current conversion taken from the overhead line resulted in both single-voltage and multi-system versions, for 1,435 mm and 1,524 mm rail track gauges. The manufacturer also provided the possibility to install a diesel engine – either a high-power one in the case of a diesel version of the locomotive or a lower-power one in the case of a locomotive equipped with the last mile function (which enables an electric locomotive to run a short, non-electrified section).

The versatility of the Vectron locomotives means that they are completely sufficient for a leasing company to order a four-system version, in which selected functions (e.g. the ability to run at a specific voltage) or traffic safety systems are activated, depending on the current needs of the rail operator that leases or rents the vehicle. A comparison with the Taurus (ES64U4) locomotive – an earlier Siemens vehicle – shows that most retail operators choose to purchase locomotives not only when the vehicle has the right technical parameters but also at the right purchase price.

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Table 8

The comparison of Vectron locomotives sold or ordered for individual rail operators or owners; as at 2022

Year	Operator or owner*	Number	Option	Version**	Notes
2010	Railpool*	6	–	AC	–
2012	FuoriMuro	2		DC	–
	DB Cargo Polska	23	13	DC	intended for operation on the PKP network
	Amtrak	70		AC	U.S. passenger operator
2013	MRCE	15		AC	–
	CargoServ	1		AC	–
	boxXpress*	4		AC	–
	Paribus Gruppe	2		AC	–
	VR–Yhtymä Oy (VR)	80	97	AC	vehicles for 1524 mm rail track gauge
2014	CFI	2		DC	vehicles can be upgraded
	ELL	12 38		MS AC	–
	mgw Service	1		AC	–
	Railpool*	5		AC	–
	MRCE	20		AC	–
	boxXpress*	4		AC	–
	WLC	1		AC	–
2015	Siemens*	1		DE	vehicle delivered to Wegberg-Wildenrath test center
	BLS Cargo AG	15		MS	–
	ENON & EGP	1		AC	–
	ITL	6		MS	–
	PKP Cargo	15	5	MS	–
	MRCE*	11 10		MS AC	–
	Railpool	3		AC	–
	DB Cargo	8		DC	leased from UniCredit Leasing and placed in service on the FS rail network
	EP Cargo	1		MS	–
	PSŽ	1		MS	–
	SEPTA	15	3	AC	U.S. passenger operator
2016	Lokomotion*	8		MS	–
	ELL*	38 18	2	MS AC	–
	Alpha Trains*	10		MS	–
	ČD Cargo	5		MS	–
	PIMK	1		AC	–
	Railpool*	5	10	AC	–
	MRCE*	10		MS	–
	Hector Rail	2 18		AC	–
	mgw Service	1		MS	–
	CFI	2		DC	vehicles can be upgraded
	Railcare	1 6		AC	–
	Infraleuna	1		DE	–
	MRCE*	15		MS	–

Table 8 cd.

Year	Operator or owner*	Number	Option	Version**	Notes
2017	DB Cargo	4		DE	leased from Siemens
	SBB	18		MS	leased from LokRoll
	ÖBB	30 100 50	20	MS AC AC	–
	Raaberbahn (GySEV)	2 3 4		AC MS AC	–
	Unipetrol Transport	3		MS	–
	ITL	6		MS	–
	ČD Cargo	3		MS	–
	Hupac	8		MS	–
	InRail	1 1 1		DC MS DC	–
	DB Cargo	60	40	MS	–
	MRCE*	10 20	20	MS DC	–
	boxXpress*	4		MS	–
	ZSSK	10		MS	leased from S Rail Lease
	RDC Autozug Sylt	2		DE	–
	SHV	1		DE	–
	ENON & EGP	1		AC	–
2018	Adria Transport	1		MS	–
	DMV Cargo Rail	2		AC	–
	Industrial Division	1		MS	contract in progress
	DSB	26	18	MS	contract in progress
	MRCE	20 5		MS AC	–
	Srbija Kargo	16		MS	for operation on the rail networks of Serbia, Croatia, Hungary, Austria, and Germany
	LocoItalia	4	15	DC	–
	EP Cargo	1		MS	–
	Eisenbahngesellschaft Potsdam	4		Smartron	–
	RTB Cargo	3		MS	–
	ČD Cargo	4		MS	–
	EP Cargo	3	7	MS	–
	Infraleuna	2		Smartron	–
	e.g.o.o.	1		Smartron	–
	DB	< 100		MS	40 locomotives ordered under the framework agreement
2019	Slovenská plavba a prístavy (SPAP)	1		MS	–
	Advanced World Transport (AWT)	3		MS	–
	METRANS Rail	10		MS	–
	Paribus	17		Smartron	–
	Budamar	5		MS	–

Table 8 cd.

Year	Operator or owner*	Number	Option	Version**	Notes
2019	Industrial Division	5		MS	–
	BBL Logistik	1		Smartron	–
	Spitzke Logistik	1		Smartron	–
	Eisenbahnen und Verkehrsbetriebe Elbe-Weser	1		Smartron	–
	SüdLeasing	20	20	MS	leasing by SBB Cargo
	PIMK	3		Smartron	–
	E-P Rail	5		Smartron	–
	BLS Cargo	25		MS	–
	Laude	1		MS	–
	GYSEV CARGO Zrt.	1		MS	former Siemens test locomotive
	Railsystems RP GmbH	2		H	first Vectron hybrid locomotive
	RTB Cargo	2		MS	–
	Widmer Rail Services AG	2		MS	–
	GTS Rail	3		DC	–
2020	Mindener Kreisbahnen	2		H	–
	Bulmarket	2		Smartron	–
	BDZ	15		Smartron	–
	Unicom Tranzit	2		Smartron	–
	MMV Rail	1		Smartron	–
	Unipetrol Transport	4		MS	–
	DB Cargo	100	250	H	–
	RheinCargo	5		Smartron	locomotives numbering: 91 80 6 192 031-034, 045
	PCW	1		H	–
	Stern und Hafferl Verkehr	1	no data	H	a number of locomotives not disclosed
	Lotos Kolej	1		MS	–
2021	FOXrail	1	1	AC	–
	Stern und Hafferl Verkehr	3		H	–
	DB Cargo Polska	4		MS	–
	Raaberbahn Cargo	1		MS	–
	ITL Eisenbahngesellschaft	2		H	–
	ČD Cargo	2		AC	–
	Akiem	20		MS	the framework agreement, number of locomotives not disclosed
	Cargounit	1		Smartron	–
	ELL	2		MS	a former Siemens locomotive
	Railpool	20		MS	–
	Správa železnic	1		MS	designed to test rail networks of the Czech Republic and other countries
2021 / 2022	Cargounit	15	15	MS	–
	Paribus Capital	30		H	–
	National Authority for Tunnels	41		AC	for operation on the Egyptian rail network

Table 8 cd.

Year	Operator or owner*	Number	Option	Version**	Notes
2022	Railpool	70		MS	outside the framework agreement for more than 100 locomotives
	DB Cargo	50		H	order under the 2020 framework agreement four locomotives for Bahnbau Gruppe
	Alpha Trains	no data		AC H	the framework agreement, number of locomotives not disclosed
	MÁV START	90 25		AC MS	the framework agreement
	České dráhy	50		MS	first Vectron locomotive with a maximum speed of 230 km/h
	SüdLeasing	20		MS	leasing by SBB Cargo
	LokRoll 3 AG	35		AC	leasing by SBB Cargo
	ČD Cargo	10		MS	–
	MRCE	14		MS	–
	Akiem	65	no data	AC MS	outside the framework agreement, number of locomotives not disclosed
	DB Fernverkehr	21		H	order under the 2020 framework agreement with DB Cargo (2020)
	ITL Eisenbahngesellschaft	8		H	–
	Alpha Trains	15		MS	outside the framework agreement number of locomotives not disclosed
Total (confirmed orders)		**1,840**	**514**	–	–

[Own study based on operator and manufacturer data].

Operators or leasing companies:
1. CFI – Compagnia Ferroviaria Italiana,
2. EGP – Eisenbahngesellschaft Potsdam mbH,
3. ELL – European Locomotive Leasing,
4. MRCE – Mitsui Rail Capital Europe,
5. PSŽ – Prvá Slovenská Železnicná,
6. SHV – Stern & Hafferl Verkehrsgesellschaft (Stern und Hafferl Verkehr),
7. WLC – Wiener Lokalbahnen Cargo.

Traction type**:
1. MS: 1.5 kV DC (optional), 3 kV DC, 15 kV 16.7 Hz, 25 kV 50 H,
2. AC: 15 kV 16,7 Hz and 25 kV 50 Hz or only: 25 kV 50 Hz alt. 15 kV 16,7 Hz,
3. DC: 3 kV DC,
4. DE – diesel-electric,
5. H – hybrid.

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