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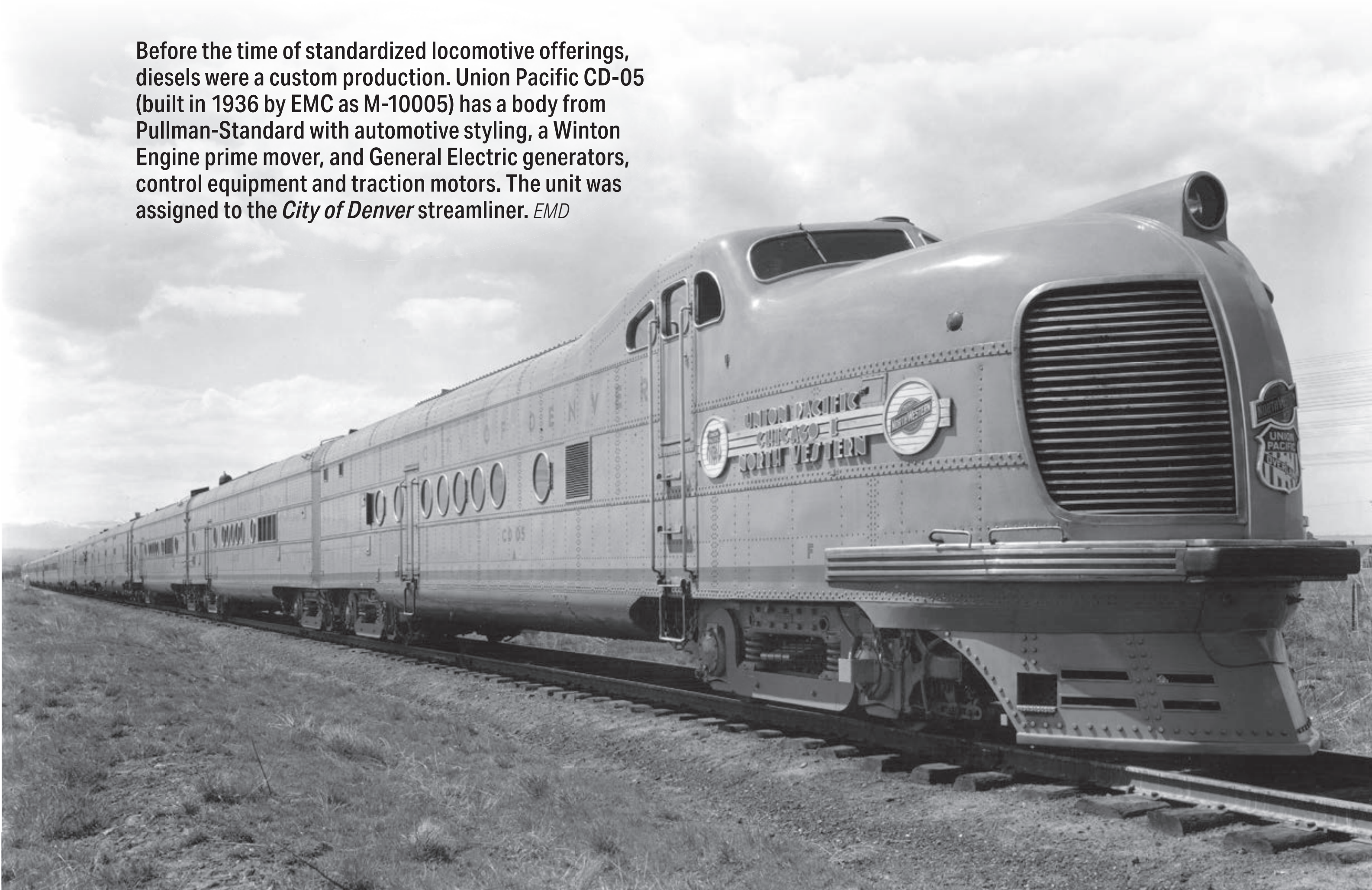


Before the time of standardized locomotive offerings, diesels were a custom production. Union Pacific CD-05 (built in 1936 by EMC as M-10005) has a body from Pullman-Standard with automotive styling, a Winton Engine prime mover, and General Electric generators, control equipment and traction motors. The unit was assigned to the *City of Denver* streamliner. *EMD*

FROM DIESEL ENGINE TO TRACTION MOTOR

DIESEL-ELECTRIC LOCOMOTIVES ARE POWERFUL, COMPLEX, FASCINATING MACHINES

Along with the engine itself, an array of systems and other components work together delivering power to the rails and pulling trains. In the following pages, we'll trace these systems, starting with the diesel engine and working through the generator and traction motors, then look at fuel, oil, cooling systems, and various ancillary and control equipment.

Understanding how these locomotives work will give you a better appreciation for how they're designed, how and why they evolved, and why railroads use them the way they do. If you're a modeler, this understanding will help you figure out what the various details on models represent and what their functions are in real life.

It's important to understand that this book is not a spotter's guide — it's not designed to aid in identifying various models or manufacturers' distinct details. The photos and descriptions throughout cover more than 100 years of diesel production, and illustrate representative components from all major manufacturers and many individual models. It would be impossible to show and cite every variation regarding the many components and features.

Entire books and volumes have been written about the technical aspects of engines, generators, and other individual locomotive components. This book is not intended to do that. Instead, the goal is to explain how a locomotive's various features and systems work, using nontechnical language that answers common questions — going into enough detail to provide a basic understanding of the technology.

We'll also show how the various components (and locomotives themselves) have evolved and grown in size and power since the early 1900s, with a look at horsepower, tractive effort, adhesion, and other operational factors.

There's also a chapter on electric locomotives, since they predated diesels and provided much of the groundwork for later diesel-electric development. We'll also review basic locomotive designs and body styles, providing brief histories of the major locomotive manufacturers.

This book focuses on road passenger

Workers lower a new SD40-2 body onto its trucks at EMD's assembly plant in La Grange, Ill., in January 1972. Diesel-electric locomotives house a number of systems that, working together, generate electricity, powering traction motors. The horsepower generated has moved trains for more than a century. *EMD*

and freight locomotives as well as switchers from major builders.

It does not cover small industrial diesels, turbines, or — other than brief summaries — genset or diesel-hydraulic locomotives.

My hope is that this book increases your knowledge and appreciation of diesel-electric locomotives. Turn the page and we'll take a quick look at the early history of diesel development, then we'll move into the literal nuts-and-bolts information with the engine itself.

CHAPTER 1

DIESEL-ELECTRIC EVOLUTION

Harnessing the internal-combustion engine — gas then diesel — put an end to the steam locomotive and revolutionized railroading

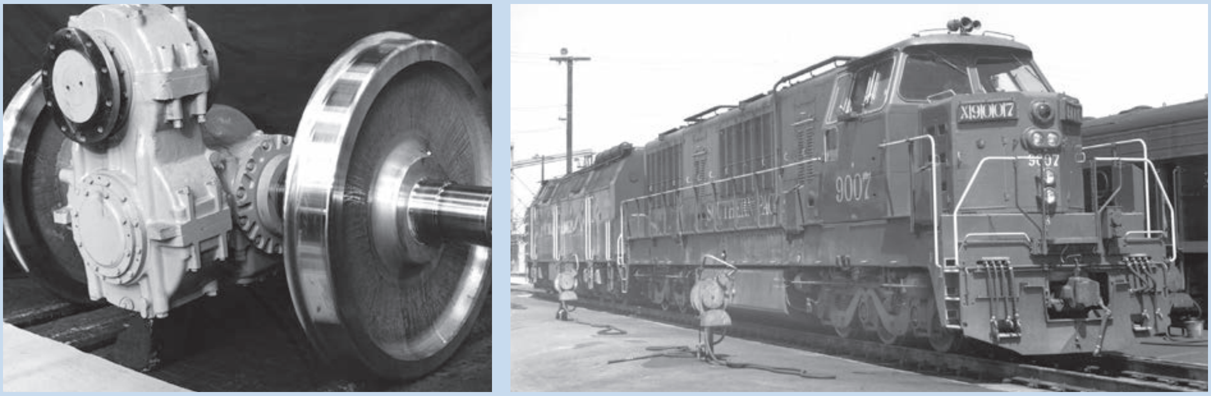
When Electro-Motive built E7 passenger diesel No. 504A (later renumbered 508) for Great Northern in June 1945, steam locomotives still outnumbered diesels 10-to-1. By the time of this 1967 photo, however, steam had been gone from U.S. and Canadian railroads for seven years. The streamlined, twin-engine E7, with 510 built, played a major role in bumping steam from passenger trains. *J. David Ingles*

The era of custom power cars was in full swing in 1936 when EMC/Budd built Chicago, Burlington & Quincy's *Denver Zephyr* power units *Silver King* and *Silver Queen* (No. 9906A, B). The 1,800-hp A unit had two 12-cylinder Winton 201A engines; the 1,200-hp B unit had a single 16-cylinder Winton. *Chicago, Burlington & Quincy*

DIESEL-HYDRAULIC LOCOMOTIVES

The 1960s saw an attempt to eliminate the electrical drive on locomotives, replacing it with a mechanical/hydraulic drive connection. In 1961 Southern Pacific purchased three 3,540-hp German Kraus-Maffei diesel-hydraulic locomotives, each powered by a pair of Maybach V16 engines. These were followed by 18 additional locomotives (including three for Rio Grande, which SP later acquired), plus three twin-engine diesel-hydraulics from Alco, model Century 643DH. All used hydraulic-mechanical transmission made by the German company Voith to transfer motion from the engine driveshaft to the axles.

Although moderately successful in service, the locomotives never advanced beyond experimental status. Uneven performance on mountain grades, higher-than-standard maintenance, the specialized nature of parts, and the coming of conventional single-engine diesel-electrics of 3,000- to 3,600-hp doomed the diesel-hydraulics to early retirements, and all were off the SP roster by 1968.



The German Kraus-Maffei ML-4000 was a six-axle, 3,450-hp, twin-engine diesel-hydraulic design. The hydraulic-mechanical transmissions, which replaced the generator/traction motor drive, resembled truck differentials.
Locomotive: Louis A. Marre collection, Jr; Transmission: Kraus-Maffei

Electro-Motive's FT, more than any other diesel-electric, ensured the demise of the steam locomotive. The four-unit, 5,400-hp demonstrator (1,350 hp for each unit), built in 1939, works on the Rio Grande during its cross-country demonstration tour. *R.V. Nixon*

By the early 1960s, as railroads were boldly advertising their hotshot piggyback trains and high-speed freight services — which were assigned the newest high-horsepower four-axle diesels — some in the industry thought the six-motor freight diesel was all but dead. The notable 2,400 hp of early six-axle, high-horsepower diesels (Fairbanks-Morse's H24-66 of 1953 and Alco's RSD15 of 1955) did not generate significant sales. Railroads looked at six-axle freight locomotives as suitable only for slow-speed drag service or for local service on lightweight rail, and didn't find the extra expense (and two additional traction motors to maintain) of six-axle units worth it for general service.

This changed radically in the mid-1960s with EMD's introduction of the 3,000-hp SD40 and 3,600-hp SD45 (and later SD40-2 and SD45-2). They, along with GE's U30C (3,000 hp), U33C (3,300 hp), and U36C (3,600 hp) gave the railroads powerful locomotives that worked well not only in heavy-haul and drag service (such as coal unit trains), but for longer, heavier fast priority trains as well.

As an example, at EMD, the '40- and '45-series six-axle diesels outsold the four-axle GP40/GP40-2 at a better than 3:1 clip. In fact, it was the low-horsepower (2,000-hp) GP38/GP38-2 that became the dominant four-axle locomotive: with 2,947 built, they outsold the 3,000-hp four-axle series by almost 600 engines. Four-axle sales continued fading by the late 1980s, with the last four-axle freight

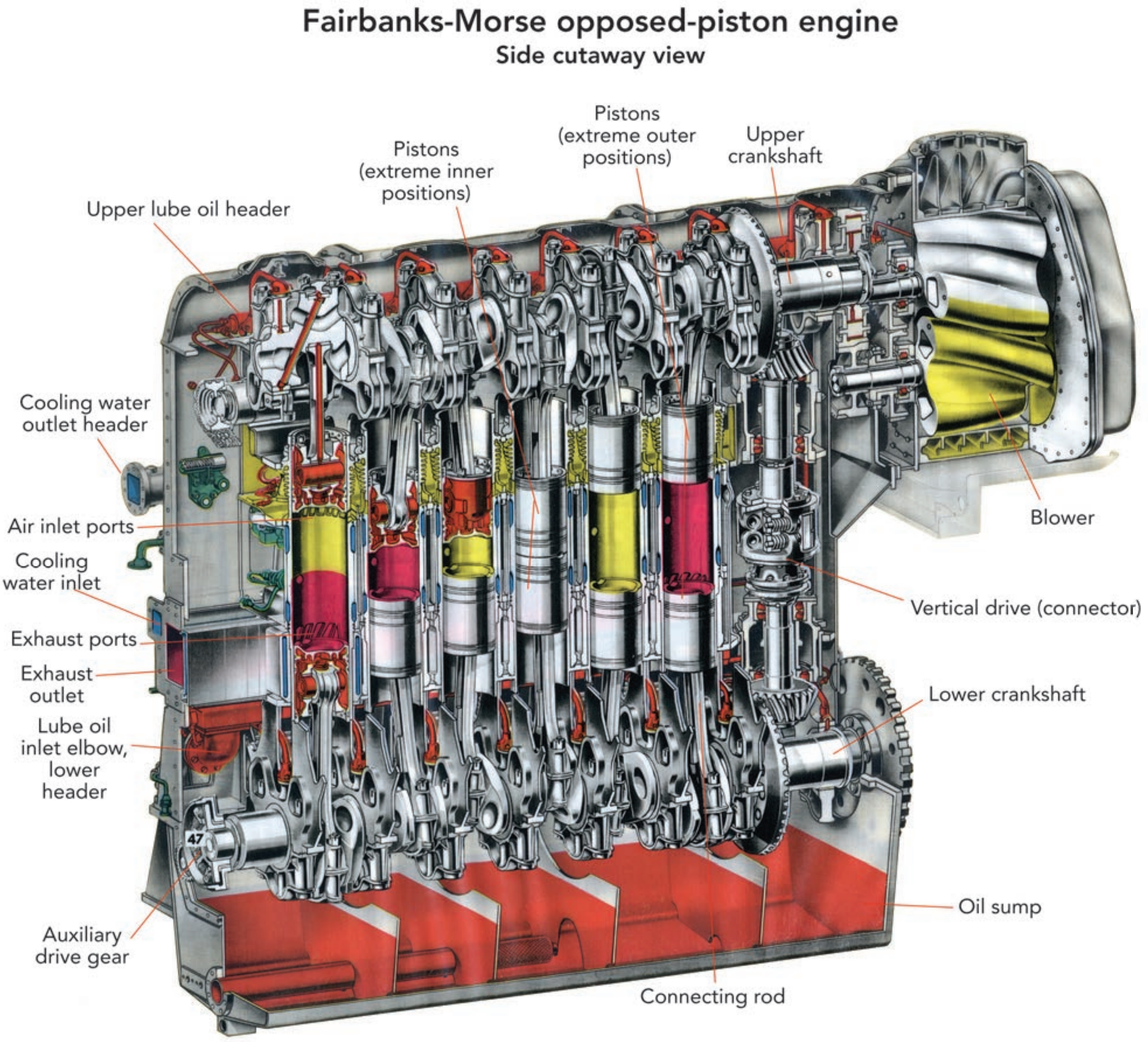
Alco gets credit for producing the first road-switcher with its 1,000-hp RS1 in 1941. The light-duty locomotive is basically an S1 switcher on a lengthened frame with road trucks and a short added nose. Great Northern No. 183 was built in 1944. *Alco* maintenance to the engine. Although OP engines worked well in submarines, ships, and power plants where they received constant care and maintenance, they weren't as successful on locomotives. See page 65 in Chapter 3 for more details on OP design.

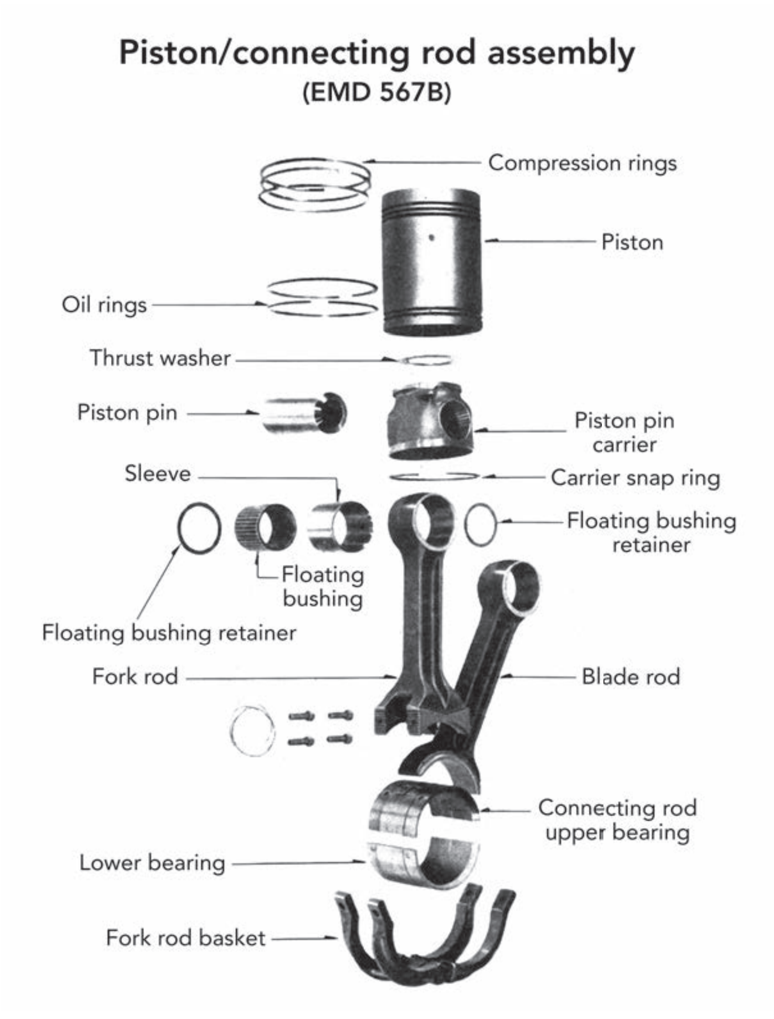
Four- and two-cycle engines

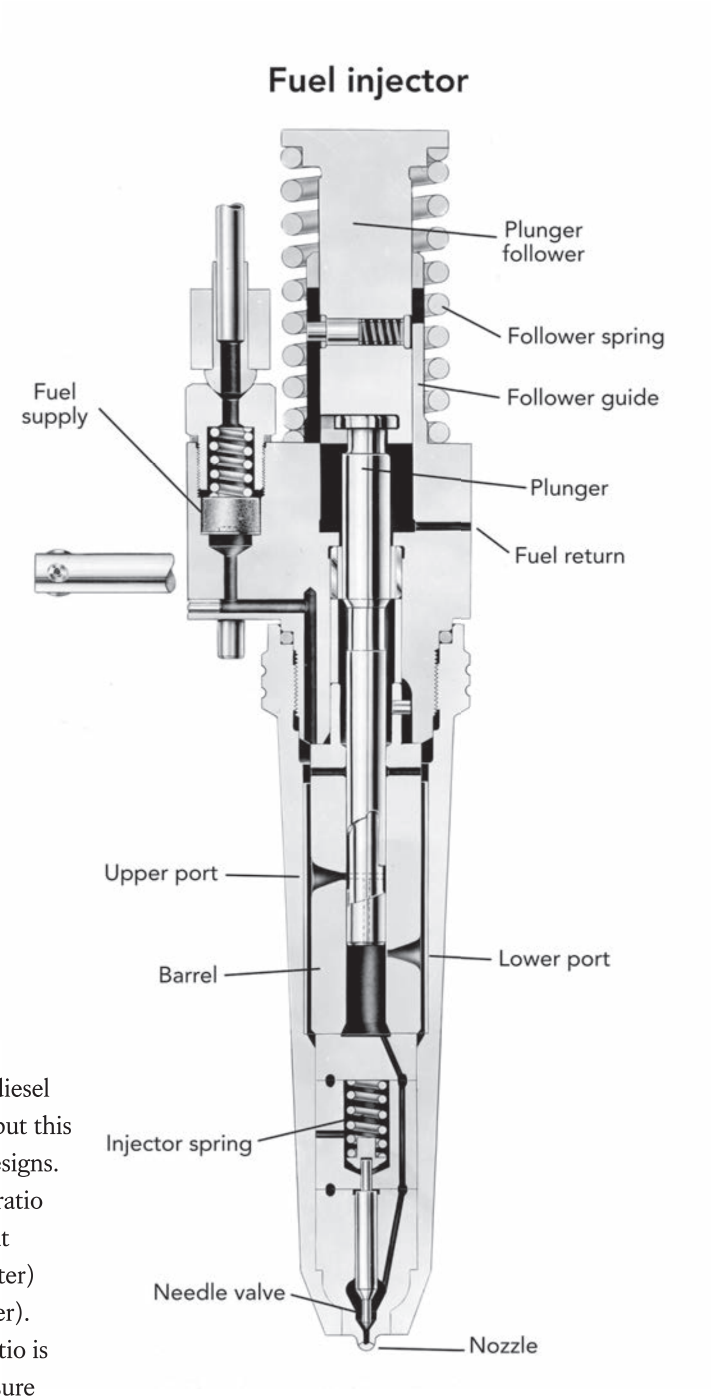
Diesel engines fall into two basic designs: four- or two-cycle. A four-cycle engine requires four piston strokes (two up, two down, with two revolutions of the crankshaft) to accomplish one power stroke. A two-cycle engine requires two strokes (one up, one down, one revolution of the crankshaft) to get one power stroke. Here's how they differ *(see the diagrams on page 34 and 35)*:

Four-cycle: The process starts with the intake stroke, where the piston descends and clean air is drawn into the cylinder through the air inlet ports. The piston then moves upward, sealing off the inlet ports and compressing the air as it reaches its highest position. Fuel is atomized and admitted by the fuel injector; the air/fuel mix burns, propelling the piston downward on its power

The Fairbanks-Morse Model 38 engine is an opposed-piston design, with two pistons in each vertical cylinder. *Fairbanks-Morse*







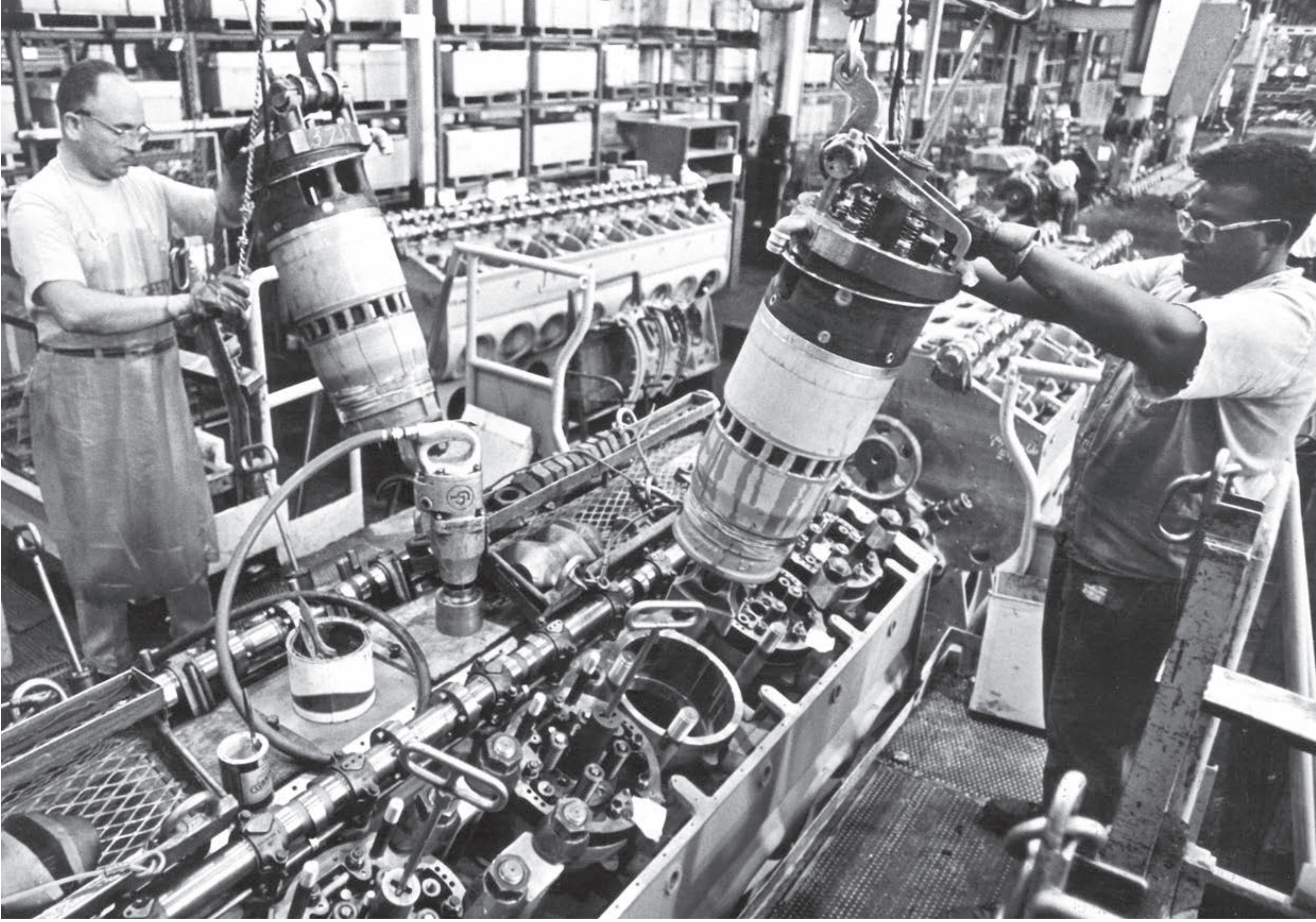
Above: The piston attaches to the crankshaft via the connecting rod. The blade rod nests in the fork rod, allowing the paired pistons in a V-style engine to work together at a single connection point on the driveshaft. This is the design from an EMD 567 engine. *EMD*

Above right: The injector pushes fuel into the cylinder just before the piston reaches top dead center. The needle valve is designed to atomize fuel to a fine spray ensuring complete combustion. This is an EMD design first used in 1959. *EMD*

A typical compression ratio for a diesel locomotive engine is about 15-to-1, but this varies among builders and specific designs. An engine's compression ratio is the ratio between the volume in the cylinder at its largest (piston at bottom dead center) and smallest (piston at top dead center). Compared to gasoline engines, the ratio is higher for diesels because of the pressure required for ignition.

Each cylinder has a cast-iron liner that is plated or hardened to enable the piston to slide smoothly within it. Having a separate liner means the inevitable friction wear is on the liner and not the engine block itself. Cylinder liners can be replaced or restored as needed, or when an engine is rebuilt or reconditioned. Cylinder heads serve as the top of the combustion chamber, and are also cast iron. The heads are subject to extreme temperature changes and pressure stress, and are water-cooled via cored passages. The cylinder head fits atop the engine block, with a tight seal needed at the joint, which is provided by the head gasket.

Pistons are made from cast iron, aluminum alloy, or aluminum plated with a steel cap. They have a series of grooves around their circumference at the top and bottom that hold piston rings, which provide the contact surfaces with the cylinder liner. The rings at top (compression rings) keep combustion air from leaking downward; the rings at the



Workers lower power assemblies into the cylinders of an EMD engine block. The assembly includes the cylinder liner, piston, connecting rod, and cylinder head (with valves and springs). *EMD*

bottom (oil rings) keep lubrication oil from leaking upward to the combustion chamber. The rings are designed to take the brunt of wear from the piston itself.

The rings require periodic replacing. Their wear can lead to a loss of compression (and thus power) and can allow oil leaks; more severe damage or failure can lead to a piston cracking or failing, which can damage the engine or crankshaft.

Steel connecting rods, as their name implies, connect the bottom of the piston to the crankshaft. They convert the up-and-down motion of the pistons to circular motion at the crankshaft. The piston/cylinder/connecting rod — the main components of the "power assembly" — operate at high speed and high temperature. All parts require tight tolerances (to a few thousandths of an inch) to work properly, and cooling and lubrication are critical. Most have grooves or internal passages that allow the movement of oil for lubrication and cooling (more on those systems in a bit).

The fuel injector is at the top of the cylinder, and its job is atomizing and spraying a precisely measured amount of diesel fuel into the cylinder at the proper moment when air has been compressed — just before the piston reaches top dead center. Because of the high pressure of compression, fuel must be forced in at even greater pressure (3,000 pounds per square inch and higher). This pressure comes from a fuel-injection pump (plunger) or unit injector. The coming of microprocessor control has led to electronic fuel injection in modern locomotives. The governor sets the amount of fuel (based on throttle setting), which is first admitted to the body of the injector; this fuel is then injected at the proper time.

This EMD SD60M, built in 1989, was among the first locomotives to feature desktop-style controls. The brake controls are at far right, with the throttle and reverser directly in front of the engineer. Conventional gauges are still used — computer screens are still a few years away. A cab signal is mounted between the windshields at left.
Union Pacific

the conventional control stand. The cab's left side featured a desk for the conductor, with a computer screen repeating the status of various systems.

Desktop controls, although sleek, met with mixed reviews from operating crews. Forward running is usually fine, with good visibility. However, doing reverse moves — not to mention switching — can be challenging. Some railroads continued ordering locomotives with conventional control stands; others went back to them after initially ordering desktop controls.

A redesign came when EMD released its SD70ACe in 2004. The advent of AC traction controls meant more (and more-advanced) computer systems. The new EMD stand had controls in a panel to the engineer's left like a traditional road switcher, but in a refined, streamlined design compared to earlier locomotives. Rounded corners and elimination of sharp edges made for a safer environment. The desktop front was retained, but for computer displays and a place for a clipboard and paperwork.

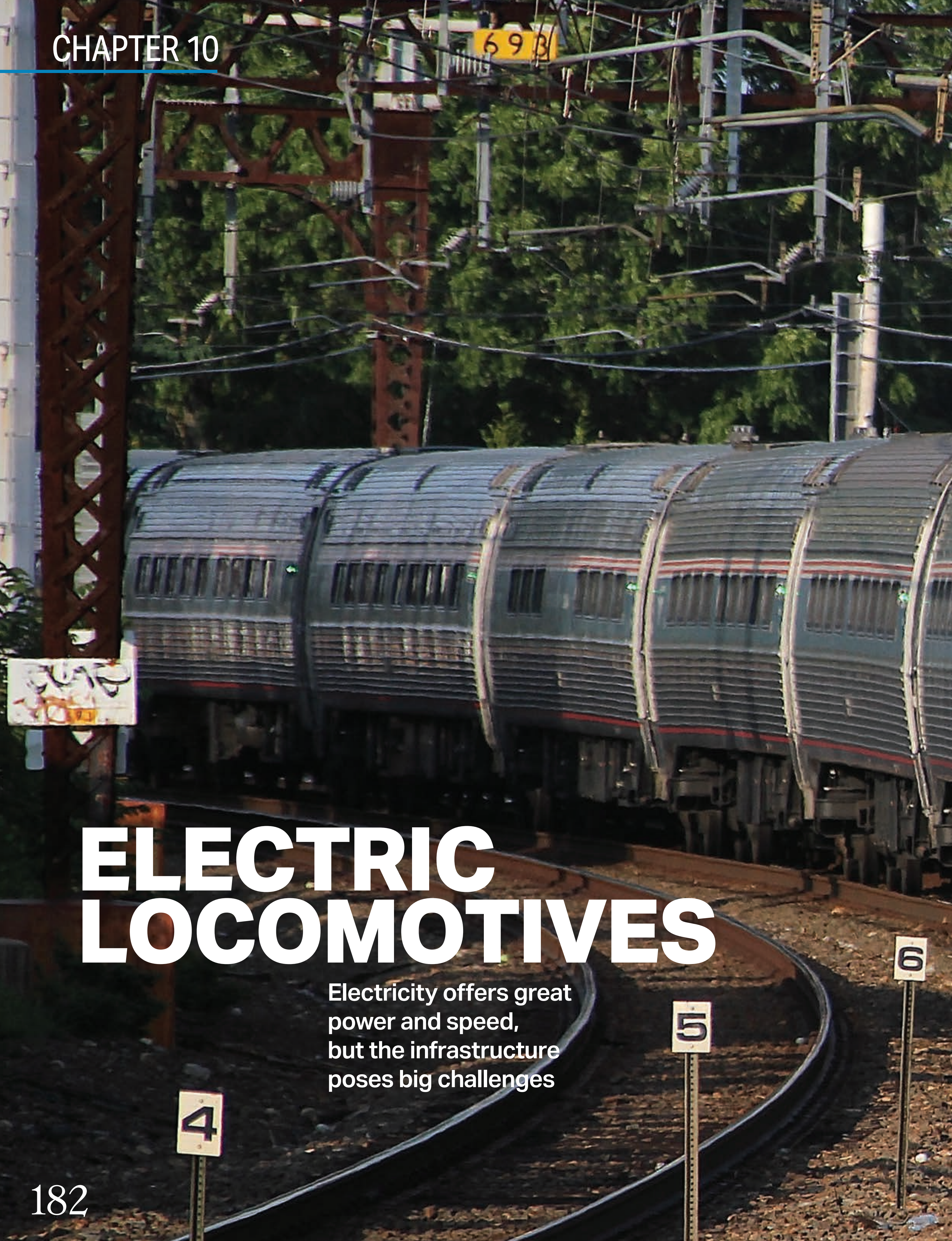
Another improvement on new locomotives was improving the view from the cab by angling the nose downward and adjusting the cab seats to allow better visibility. Even with the advent of low-nose road switchers in the 1960s, visibility was often not ideal, and impeded by the nose itself as well as controls placed along the front wall.

Computer screens along with desktop controls were common by the time this Union Pacific SD9043MAC was built in 1998. The coming of AC traction meant increased microprocessor controls. This view shows the conductor's desk and screen at left, and the door down into the nose (and toilet) at center. *Union Pacific*

Additional controls on modern locomotives have included a head-of-train unit (HOT box) that sends and receives information from the end-of-train device (EOTD or ETD), including brake pressure, motion status, marker light status, remaining battery, and communication status. This controller can send a command to the ETD to apply emergency braking if needed, and some systems allow the ETD to aid making service applications as well (see Chapter 7). New locomotives have this control integrated to the stand; it was a separate add-on for earlier locomotives.

The coming of positive train control (PTC), in service on most routes by the end of 2020, added another display to the cab (see more on PTC in Chapter 3). The system analyzes the locations of all trains and monitors train speeds and speed restrictions to avoid collisions and dangerous situations. Systems include Alstom's Incremental Train Control System (ITCS) and Wabtec's Positive Train Control Interoperable Electronic Train Management System (I-ETMS). The PTC display can be a simple digital readout, showing legal track speed, current signal indication, and current status, or include a full-screen display showing a track schematic and train statuses.

Yet another software package (and display screen) on some locomotives works to manage fuel use and engine efficiency.



CHAPTER 10

ELECTRIC LOCOMOTIVES

Electricity offers great power and speed, but the infrastructure poses big challenges

A Siemens Sprinter ACS64 leads an Amtrak train of Amfleet cars under catenary at Princeton Junction, N.J., in August 2019. The AC-motor ACS-64 is a modern 8,600-hp electric locomotive operating on Amtrak's Northeast Corridor. *David Lassen*

Electric locomotives, which take their power from an external source (overhead wire or electrified outside third rail), predate diesels. As heavy electric locomotives grew in power and size, their technological advancements in the 1920s and 1930s helped spur the development and evolution of later diesel-electric locomotives.

Streetcars and interurbans

The first electric railways were streetcars and interurban lines. Streetcars, as the name implies, run on streets and private rights-of-way within cities and urban areas. Street railways had been around — albeit horse-powered — since the early 1800s, with the first electric-powered cars appearing in Cleveland in 1884. Many cities soon adopted electric streetcars, and by the 1890s, interurban lines were being built to connect towns and cities. Interurbans were built on a private right-of-way or adjacent to a roadway, and usually connected directly to the streetcar lines in the towns they served. Interurbans were designed primarily for passenger traffic and, although standard gauge, were built with lighter (and cheaper) materials than steam railroads, with smaller/lighter rail, less roadbed and ballast (or no ballast), steeper grades, and tighter curves.

Streetcars and interurbans were self-propelled cars that were far less powerful than a locomotive on a conventional (steam) railroad. They operated as single cars, but sometimes pulled a trailing coach or a freight car or two.

Early streetcar and interurban systems operated on low voltage (500-600 volts) DC, generally from an overhead wire, with a trolley pole atop the car in contact with the wire via a small roller or shoe. Cars generally resembled passenger cars with an operator's stand at one or both ends. Power was routed through a controller and directly to traction motors that powered the axles. Along with self-propelled passenger cars, interurban lines sometimes used separate small locomotives (often steeple-cab design) to pull the few freight cars or work trains that needed to be handled.

Interurban lines were built to lighter standards than steam railroads. The self-propelled electric cars, with truck-mounted traction motors, led to the development of heavy-electric locomotives. This is along one of the last interurbans, the Illinois Terminal, at Gardena, Ill., in 1953. *Paul Stringham*