provide for safe and reliable tunnel operation.

The Canadian Northern R. R., in order to gain an entrance into Montreal, tunneled through a large mountain and equipped the tunnel and adjacent terminal for electrical operation.

The next and greatest example of electrical operation of a heavy trunk-line railroad is that of the Chicago, Milwaukee & St. Paul R. R., which in 1916 began the electric operation of 440 route miles on two mountain divisions. In 1920 this road put into operation 208 additional miles of electrification on the Cascade and Coast divisions, making a total of 648 route miles now operated by electric traction.

No statement of the development of electrification of steam railways would be complete without mention of the work done in connection with heavy suburban service on the Long Island R. R., which enters the Pennsylvania Terminal in New York City by means of tunnels from Long Island; also the West Jersey & Seashore R. R., operating between Camden and Atlantic City, N. J.; and the Pennsylvania R. R. electrification of that portion of the Broad Street terminal at Philadelphia which serves two of its important suburban branches, to Paoli and to Chestnut Hill.

Systems. The term "system of electrification" is used to define the kind of electric power used for the propulsion of the locomotives and motor cars. In the United States there are employed three principal systems of electrification, viz.: the direct-current, the single-phase, and the three-phase, the latter, however, having been employed in only one installation, that of the Great Northern R. R.

There are also subdivisions of these principal systems of electrification, such as high and low-voltage direct current, the straight single-phase, and one employing single-phase current on the working conductor and three-phase motors on the locomotives.

Each of the several electrification systems having been installed on important railroads and having proved successful through years of operation, and the results having been analyzed and studied, it has been demonstrated that each of these systems of electrification is practicable and reliable, and that a detailed study of the situation and an exhaustive analysis of all of the conditions surrounding any proposed electrification is necessary in order to arrive at the best solution of the problem. Therefore, today there are relatively few engineers who advocate but one particular system as being the only solution for any and every electrification project

The flexibility of electrical equipment and the apparatus of electric locomotives permits in certain instances the interchange of locomotives or multiple-unit cars between roads using different systems. Thus the single-phase locomotives and cars of the New York, New Haven & Hartford R. R., taking current from a high-tension overhead contact system when on their own rails, also operate over the New York Central R. R. electrified tracks and take power from the low-tension direct-current underrunning protected third rail. Direct-current locomotives could operate over tracks having an overhead contact system carrying single-phase current, if such locomotives were provided with converters or motor-generator sets. The fact that a single-phase series commutator motor is also a good direct-current motor makes possible the operation of single-phase locomotives on direct-current systems where such operation is necessary.

Relative Status. The mileage of electrified steam railroads (heavy traction service) in the United States and Canada amounts to less than 1% of the total mileage of railroads of these two countries. As the greatest accomplishments in electrification have been made on this continent, it would appear that in the 26 years since its first establishment the electrification of steam railroads has made but slow progress. Yet, when the time of accomplishment is considered and compared to the much greater period during which steam operation has been in use, it is apparent that considerable advance has been made. In considering the general progress of electrification it must be remembered that the steam locomotive has been developed through generations of railroad experience and has reached comparatively high standards of mechanical design and operating efficiency; also to displace this familiar type of motive power it is necessary to overcome considerable "mental inertia" on the part of the steam railway men.

Electrification having proven itself successful under the most severe conditions of railroading, such as tunnels, terminals and mountain divisions, the considerations that now determine its further progress are mainly financial, especially the question of securing the capital necessary to effect the change.

Prospects. Due to the financial considerations referred to, it is not likely that wholesale electrification of steam railroads will be effected for many years. What may be expected first is the gradual electrification of more terminals, mountain divisions, heavy suburban lines, tunnels and other strategic sections where the advantages of electrification are most marked. With increasing cost of fuel and increased density of traffic electrification of intervening stretches of main line will probably come, especially in the western mountain states, in the Appalachian mountain sections and the congested divisions of the eastern states. An outcome of the present super-power survey of the metropolitan and industrial district between Boston and Washington may be the acceleration of railroad electrification in that district.

An encouraging feature is that steam railway operators now realize that electric locomotives are not simply replacing steam locomotives as a form of motive power, but that they provide a new tool capable of doing much more work in a given time, a tool which, where fully taken advantage of, will revolutionize the present practices and methods based on the steam locomotive as motive power.

Abroad, financial conditions are retarding electrification even more than in the United States and Canada, except in those countries where the fuel shortage is so serious as to amount to a national peril. This is true in Belgium, France, Switzerland and Italy, where extensive electrification projects are being considered. Several railroads in England, South Africa and South America are now actively engaged in the work of electrifying portions of their more important lines.

STEAM RAILROAD ELECTRIFICATION, ECONOMIES AND OTHER ADVANTAGES OF.—A. Economies. The economies to be obtained from the electric operation of steam railroads have been demonstrated to be substantial in amount and include savings in the following items:

(1) Fuel for power, due to the higher efficiency of combustion in large power stations, the reduction in standby losses, and to regenerative braking.

(2) Maintenance of electric locomotives and the use of multiple-unit passenger cars.

(3) Reduction in the number and size of repair shops and the accompanying reduction in labor, most evident where the electric operation covers one or more steam-locomotive divisions.

(4) Reduction in the cost of train crew service per ton-mile, due to higher average speeds and heavier trains.

(5) Reduction in the number and size of fuel and water stations. None are required for electric operation except on a very small scale to supply fuel-oil and water for heating through passenger cars in winter weather.

The published records of several electrifications of steam railroads have shown a saving in coal varying from 25% to 60%. If a saving of 50% were obtained by the substitution of electric locomotives for steam locomotives on all the railroads in the United States, it is estimated that it would amount to 12% of the total coal production of the country.

Tests have shown that from 3 to 7 lbs. of coal on the tender of a steam locomotive is equivalent to one kilowatt-hour measured at the high-tension side of the substation (thus including the transmission losses). A modern power station will produce one kilowatt-hour for less than 2½ lbs. of coal; hence from test data a fuel saving of more than 50% can be computed under conditions favorable to electric operation. However, a word of caution should be said against placing too much reliance upon results of tests, even if they fairly well represent actual conditions. To be of comparative value, service records should extend over several years, and the data should be carefully collected and averaged to give results which may be expected in every-day operation.

Regenerative braking results not only in considerable fuel economy but effects a saving in brake shoes and wheel tires. Tests have shown that a train on a 2% grade has regenerated 42% of the power required to pull the same train up the grade. The records for a month on the Rocky Mountain electrified division of the Chicago, Milwaukee & St. Paul R. R. for both freight and passenger trains indicate that the regeneration was equivalent to 11.3% of the total power used.

The maintenance of electric locomotives per mile is less than for steam locomotives. In one instance, that of a heavy freight road operating in a mountainous district of Montana, covering 30 route miles (122 miles on a single-track basis), and operating 28 80-ton electric locomotives, the average maintenance cost per locomotive over a period of six years was 6 cents per mile. This covered the years 1914 to 1919, both inclusive. The cost of maintenance of steam locomotives on this same road prior to electrification was, in 1909, 16 cents per mile. In general, taking pre-war costs as a basis, the normal maintenance of steam locomotives ran from about 13 to 16 cents per locomotive-mile, while for electric locomotives during the same period it normally ran from 3 to 10 cents per locomotive-mile.

The reduction in number and magnitude of repair shops and necessary working force results from the greater mileage of electric locomotives, due to increased speed and less time out of service for cleaning, coal, water, inspection, repairs, overhauling and other causes peculiar to the steam locomotive. Electric locomotives are capable of performing from 400 to 500 miles per day for passenger service and about one-half these amounts in freight service. An authority on electrification recently stated that the electric locomotive is available for revenue work for 6000 out of the 8760 hours per annum, or 70% of the time, while the steam locomotive is available for revenue duty only 2500 hours, or only about 30% of the time. The repairs and overhauling on electric locomotives are comparatively simple matters, resulting in the requirement of only small maintenance forces and shop facilities. As an illustration, one armature winder and an assistant assures the operation of the 336 motors on the 42 electric locomotives on the Chicago, Milwaukee & St. Paul electrification, while the storage and repair facilities at the midpoint of the 440-mile initial installation formerly required for steam locomotives of 220 miles of route are sufficient for the storage and repair of all the electric locomotives required for the entire mileage. On this 440-mile electrification 42 electric locomotives replaced 112 steam locomotives.

Electrification has eliminated the necessity for shops and roundhouses at other points on the divisions. The only work done outside of the repair shops is light inspection.

The saving in cost per ton-mile and per train crew results from the greater locomotive capacity, the higher average speeds and the high availability-factor obtained with electric service as compared to steam operation.

The general results of the electrification on the St. Paul Railroad have been summed up by an official of the company by saying that it is quite within the facts to state that so far as that railroad is concerned it has forgotten that the continental divide exists. In other words, the electric locomotive, because of its almost unlimited tractive effort, has eliminated the ruling grades.

On the heavy Montana freight road first referred to, having 30 route miles electrified, the 17 electric locomotives first installed did the work of 28 steam locomotives. On this road, with few exceptions, the electric locomotives are operated in pairs, with one engine crew, resulting in a large reduction in expense for labor, yet handling greater tonnage than with steam locomotives. In the case of this road, it is stated that the annual net saving due to the economies of electric operation have exceeded 20% on the entire cost of electrification.

In the case of the Norfolk & Western R. R.—a heavy coal-carrying road operating through mountainous country including a long single-track tunnel—12 electric locomotives replaced 34 Mallet type steam locomotives. The tonnage per day in the direction of heavy traffic was increased from about 50,000 tons to about 65,000 tons. The resulting reduction in crew expense per ton-mile is very considerable. The operating speeds on 1% and 2% grades increased from 7 miles per hour to 14 miles per hour. The saving in round-trip running time is about 40%. On this road the single-track tunnel on a grade was the "neck of the bottle" with steam operation. Electrification has entirely removed this limitation and made possible a large increase in tonnage on the existing tracks. To obtain this increase with steam operation would have required additional tracks in the tunnel, as well as along the line, a very expensive undertaking in mountainous country. It has been stated that the cost of electric operation on this road is 12½% less than formerly, under steam operation, including all fixed and operating charges.

No coaling or watering stations are required in connection with electric traction; the expense of upkeep and operation of such facilities, which is a very considerable item with steam operation, is eliminated. For the heating of through passenger cars a small amount of fuel and water must be provided on electric locomotives during the winter months.

The running time between terminals with electric operation can be considerably reduced over that required when using steam locomotives. One instance has been referred to above. Another is that of the 30-mile electrification of the heavy freight road first referred to above. On this road, the average for three days of steam operation showed 1768 tons per train, time per trip 2 hours and 25 minutes. For electric operation one year later during three days of the same month of the year, there was handled 2122 tons per train, time per trip 1 hour and 25 minutes.

On the Chicago, Milwaukee & St. Paul electrification it has been found that the electric locomotives in passenger service can reduce the running time on long grades 30% or more. In the freight service it has been found that on one division where steam locomotives had required 10 to 12 hours to make 115 miles, electric locomotives can meet a schedule of from 7 to 8 hours for the same distance. Another instance on this road is that during the severe winter of 1917-18, it was quite customary to make up on the 440-mile electric run, fully 2 hours of the time lost by passenger trains on adjoining steam-locomotive divisions.

The greater part of the above discussion has related to the economies obtained in main-line electrification. Economies are also obtained in heavy suburban service, together with the absence of noise, smoke, gases, reduction in train delays and increase in station capacity. On the New York Central R. R. the multiple-unit electric cars in the suburban trains averaged 69,373 miles per detention during the year 1919, which may be considered a normal performance. The running time was also improved. The use of multiple-unit electric trains in suburban service reduces very much the switching at terminals, eliminates movement to and from round houses, and therefore, very materially reduces congestion at the terminal. Another instance of the advantages of the multiple-unit electric train operation in suburban service is that of the electrification of the Pennsylvania terminal in New York City and important suburban routes at Philadelphia. Here the capacity of the terminals, which was completely reached in steam operation, has been increased about 24% by the use of electric traction with multiple-unit trains.

With regard to switching service, especially in or near large cities, the elimination of smoke, gases and noise is a very important advantage of electric operation. The freight and passenger switching yards are often located in thickly populated sections and the undesirable characteristics of smoke and gas production, together with the noise of the exhaust and whistle, are intensified as compared with main-line operation. All of these undesirable features are eliminated with electric operation of switching service.

B. Other Advantages. The other advantages of electric operation, which do not of themselves result in a direct saving in train operation, but which accrue to the benefit of the railroad company or to the public, may be briefly enumerated below.

(1) Increase in track capacity, deferring the addition of tracks and the enlarging of terminals.

(2) Elimination of delays due to taking on coal and water, and from defective equipment; also from delays incident to steam-locomotive troubles in freezing weather.

(3) Reduced cost of painting structures due to the elimination of steam and smoke.

(4) Reduced cost of cleaning ballast due to the elimination of cinders and ashes.

(5) Conservation of coal, where water power is available for the generation of electricity, and a reduction in nonrevenue freight due to reducing the quantity of company coal consumed.

(6) Increased reliability of operation as evidenced by the greater train mileage per locomotive detention and a reduction in descending grade danger due to regenerative braking.

(7) Increase in property values adjoining city terminals and along the right-of-way because of the elimination of noise, smoke, steam and gases of the steam locomotives.

(8) The use of "air rights" over electrified terminals for the building of office and other buildings; also the possibility of two-deck terminals.

STEARNES CO.—133 W. Lake St., Chicago, Ill. Manufacturer of motor-driven fruit and vegetable peelers and parers and other hotel, kitchen and restaurant equipment.

STEARNS MOTOR MFG. CO.—Box 252, Ludington, Mich. Manufacturer of farm lighting and power plants. Business established 1909. President, J. S. Stearns; vice-president, R. L. Stearns; secretary and treasurer, E. E. Curtis; general manager, H. P. Wollensak.

STEATITE ELECTRIC PRODUCTS CORP.—Yorktown Heights, N. Y. Manufacturer of electric irons. Business established 1920. President and general manager, Samuel T. Moore; vice-president, Thomas D. Finizio. secretary, William J. Byrne; treasurer, James N. Strang; sales manager, Lester E. Moffatt. Main office, Yorktown Heights, N. Y. Factories, Yorktown Heights, Chester, Vt. Branch office, Chester, Vt.

STECHER CO., INC., THE CHARLES.—2301 Knox Ave., Chicago, Ill. Manufacturer of motor-driven machines, drills, etc. President and treasurer, Charles Stecher; vice-president, Emily Stecher; secretary, Charles F. Vogel.

STEEL.—Essentially an alloy of iron containing a small amount of carbon (usually not over 1.5%), capable of being cast directly in malleable form or of being hardened by sudden cooling. Small amounts of other elements may be present as impurities, and a definite amount of another element may be added to produce an "alloy steel" of a special property, as manganese steel, nickel steel, etc. Steel is usually manufactured from pig iron by oxidation and removal of the impurities contained therein, followed by readdition of carbon to the desire amount. The oxidation may be carried out in Bessemer converters, open-hearth furnaces, or electric furnaces. In the crucible steel process there is no oxidation, but materials of the desired composition are melted together in a crucible, yielding a high-grade product.

Electric steel can be made of equally high-grade, on account of the ease of control of the furnace atmosphere, temperature and other operating conditions. The electric furnace is especially well adapted for making alloy steels, since no difficulty need be encountered from oxidation of the alloying elements and the high temperatures necessary are readily attained. Of the steel produced in the United States in 1919, 77.7% was open-hearth steel, 21.0% Bessemer, 1.1% electric, and 0.2% crucible. The total production of steel ingots and castings was 34,671,232 long tons; that of electric steel 384,452 long tons. The United States production is roughly half of the world's production, Germany and Great Britain being the other two leading countries. The number of electric steel furnaces in the United States on Jan. 1, 1920, was 323, and in the world nearly 900.

STEEL, ALLOY, ELECTRIC FURNACE.—The electric furnace is very well suited to the production of alloy steel, because of the fact that the process may be carried on at high temperatures without the difficulty usually encountered from oxidation of the alloying elements. This permits the manufacture of alloys that were not possible before the introduction of the electric furnace and much progress has been made in recent years in this field. The steels produced have varying characteristics, depending upon the nature of the alloys. Such alloy steels as manganese steel, chromium steel, vanadium steel, silicon steel, silicon-manganese steel, nickel steel, and combinations of the above, and others containing tungsten, molybdenum, titanium, aluminum, etc., are successfully made for use in high-speed tools, automobile axles, engines and other parts, large guns, airplane engines and many other machine parts, etc., where the metal is subjected to severe stresses and often also to high temperature.

Manufacturers:

Andrews Steel Co., The, Newport, Ky.
Carnegie Steel Co., Carnegie Bldg., Pittsburgh, Pa.
Hammond Steel Co., Inc., The, 2600 Milton Ave., Syracuse, N. Y.
Milton Mfg. Co., Milton, Pa.
Trojan Electric Steel Co., 3401 S. Hoyne Ave., Chicago, Ill.
United Alloy Steel Co., Canton, Ohio.

STEEL CABINETS.—See Cabinets, sheet steel, panelboard, switch, etc.

STEEL CASTINGS.—See Castings, electric steel; Castings, miscellaneous steel, for motors and other electrical machinery.

STEEL CITY.—Trade name for conduit boxes and other products manufactured by the Steel City Electric Co., 1221 Columbus Ave., Pittsburgh, Pa.

STEEL CITY ELECTRIC CO.—1221 Columbus Ave., Pittsburgh, Pa. Manufacturer of conduit fittings and wiring devices. Business established 1904. President and general manager, W. I. Patterson; vice-president, A. H. Trimble; secretary and treasurer, Charles P. Trimble; sales manager, V. G. Fullman. Sales representatives, E. R. Bryant, Boston, Mass.; A. J. Bressan Co., New York, N. Y.; D. B. Scarborough, Philadelphia, Pa.; G. V. Carpenter, Buffalo, N. Y.; W. P. Ambos Co., Cleveland, Ohio; J. T. Pearson Co., Detroit, Mich.; J. P. Lane, St. Louis, Mo.; Ohio Distributing Co, Chicago, Ill.; Foster Callaghan, Birmingham, Ala.; H. C. Moran, Pittsburgh, Pa.; Wesco Electrical Supply Co., Denver, Colo.; Allied Industries, San Francisco, Cal.; Walter Ehman, Kansas City, Mo.; Hatheway & Knott, New York, N. Y.; R. S. Wakefield, Dallas, Tex.

STEEL CROSSARMS.—See Crossarms, iron and steel.

STEEL, ELECTRIC FURNACE.—Steel made in electric furnaces, or electric steel as it is commonly called, is a very high-grade product. Where the induction type furnaces are used, a charge of pure steel scrap and pig iron may be made into a steel similar to crucible steel. Other high-grade steels are made in the arc type furnaces from charges of cold steel scrap, covered with a slag containing a high percentage of lime, and brought to a high temperature. The reaction eliminates the impurities, such as phosphorous, sulphur, silicon, manganese and carbon, and the proper composition is obtained by the introduction of the necessary alloys. The physical properities of electric steel are usually superior to steels of similar composition made by other processes; this is due to its homogeneity and freedom from the traces of numerous impurities that weaken other steels. The electric steel output has rapidly risen during the last six years.

Manufacturers:

Bethlehem Steel Co., Bethlehem, Pa.
Canadian Brakeshoe Co., Ltd., 101 Belvidere St., Sherbrooke, Que., Can.
Carbon Steel Co., 32nd St., & A. V. Ry., Pittsburgh, Pa.
Chicago Steel Foundry Co., 3720 S. Kedzie Ave., Chicago, Ill.
Crowley Co., John A., 120 Liberty St., New York, N. Y.
Disston & Sons, Inc., Henry, Tacony, Philadelphia, Pa.
Hammond Steel Co., Inc., The, 2600 Milton Ave., Syracuse, N. Y. "Triton," "Taurus."
Ludlum Steel Co., Watervliet, N. Y.
Ryerson & Son, Joseph T., Corn Exchange National Bank Bldg., Chicago, Ill.
Trojan Electric Steel Co., 3401 S. Hoyne Ave., Chicago, Ill.
Union Drawn Steel Co., Beaver Falls, N. Y.
Union Electric Steel Co., Keystone Bldg., Reading, Pa.
United Alloy Steel Co., Canton, Ohio.
Vulcan Crucible Steel Co., Aliquippa, Pa.

STEEL FOR SPRINGS.—Steel for making springs is often an alloy steel. Some