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DEATH BY ELECTROCUTION? THE CHICAGO, MILWAUKEE,
SAINT PAUL, AND PACIFIC RAILROAD'S CHOICE OF ELECTRICAL
MOTORS OVER STEAM ENGINES IN MONTANA, 1914-1974

by

Robert W. Lynn

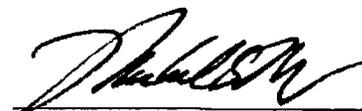
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Chairperson



Dean, Graduate School

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Death by Electrocutation? The Chicago, Milwaukee, Saint Paul, and Pacific Railroad's Choice of Electrical Motors over Steam Engines in Montana, 1914-1974

Chairperson: Michael Mayer 

The Chicago, Milwaukee, Saint Paul, and Pacific Railroad stands as a unique example of a western freight railroad that had electrical locomotives as its primary power source in the Rocky Mountains for over sixty years. This railroad suffered three bankruptcies in the same time period. Other railroads, ultimately more successful than the Milwaukee, utilized steam locomotives until this type of power became obsolete after the Second World War. One might conclude that the unusual choice of electrifying operations had something to do with the Milwaukee's bankruptcies. This thesis argues that an electrical rail system was hardly a foolish economic and engineering choice at the time, especially in cold and mountainous terrain in which the Milwaukee operated, and compares the mechanical and economic performance of late steam technology and early electrical motor technology, both used by the Milwaukee.

The railroad's choice of electrical power broaches several interesting points. Electrical, steam, and internal combustion power were in keen competition at the turn of the century. This competition was not exclusive to train locomotives. Cars, trucks, trolleys, and stationary powerplants were all available in a bewildering array of electrical, steam, and internal combustion versions. At least for train locomotives, electricity proved to be an efficient power source. The Milwaukee had electrical trains running by 1914, and for a short time this railroad possessed one of the most advanced transportation technology systems in the world.

Although the Milwaukee was ultimately an economic failure, the electrical trains it used played an important role in the development of diesel-electric technology, which dominates the American rail system today. Most modern diesel locomotives can trace their origins to purely electrical designs used by this railroad. Although this railroad had incurable financial problems, the electrical locomotives it used were an outstanding example of early twentieth century ingenuity.

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Introduction

The history of the Chicago, Milwaukee and St. Paul Railroad's tenure in Montana remains one of the more unusual tales in the nation's transportation history. While the railroad's finances were a dismal failure, its unusual system of direct-current powered locomotives running off of an overhead trolley wire was the world's most advanced rail technology at the time of its installation. Despite predictions of a short life-span and advancing diesel technology, the Milwaukee system endured for seven decades.

This thesis examines the Milwaukee's unusual choice to electrify over 400 miles of rail infrastructure in western Montana and northern Idaho, and the economic and mechanical implications of this choice.¹ Most observers conclude that the huge cost of installing and maintaining this vast electrical infrastructure is what drove the railroad to three bankruptcies and permanent demise in the late 1970s. This was not the case. If anything, efficiencies attained by the electrical system prolonged the Milwaukee's troubled existence.

Today, there is scant remaining physical evidence that such a railroad ever came through Montana, and what little evidence remains usually evokes a kind of pity and bemusement rather than any sense of wonder. Most people now living in Missoula do not know that the city was once served by a second railroad as recently as 25 years ago. People stroll along the south bank of the Clark Fork, ignorant of the fact that they tread on a right-of-way that once connected Chicago to Tacoma.

¹Although the railroad also eventually electrified portions of the line in Washington state as well, the Montana electrification was larger and need dictated that the Montana electrification proceed first.

More enduring is the Milwaukee's technological legacy. The Milwaukee's electrical fleet did not revolutionize rail transport (as the Milwaukee and GE had hoped it would), but it was a quantum improvement over steam and showed a surprising resilience in its competition with diesel technology. Although financially troubled, this railroad was once the pride of the American electrical community and left a lasting technological legacy for the modern American rail system. The now ubiquitous diesel-electric locomotive can trace its roots to the electric locomotives chosen by the Milwaukee in 1914.

Chapter One, "A Brief Operational History of the Milwaukee," deals examines the railroad's general problems both before and after electrification and its attempts to solve these problems. Although this is primarily a technological history, the Milwaukee's corporate history is relevant because economic and business factors shaped technological decisions. Consequently, this first section provides a general background of the railroad's troubled history, and offers a cursory examination of the Milwaukee's various financial crises, which show quite clearly that the expense of electrification was not the railroad's main problem. Rather, the bankruptcies resulted from the Milwaukee's relatively late decision to compete as a true transcontinental line. The company's late entrance meant a poorer route and a lack of free land, two advantages enjoyed by the older transcontinentals. This first chapter also looks at the general rail operating conditions in Montana and briefly introduces the electrical locomotives and power system that the locomotives used.

Chapter Two, "Engines and the Limits of Steam," describes the development of

the conventional steam locomotive, a technology that, while showing remarkable improvements in performance, remained fundamentally the same for 130 years. The story of the Milwaukee's opting for electrification is in large part the story of steam's decline in the face of competing technologies, as well as the increasing physical and financial constraints imposed on steam in the early years of the twentieth century. The final years of steam consisted of a series of refinements, and this work will examine some of the last attempts to improve the efficiency and performance of steam locomotives, such as streamlining, altering fuel, superheating, and other design modifications. Late steam's overall performance when compared to even the most primitive electric motors reveals the superior efficiency of the latter.

Chapter Three, "Motors," chronicles the development of commercially viable electrical power in mechanical form. Like the work of Isaac Newton, who once stated that he owed his brilliant career to standing on the shoulders of the giants who came before him, engineers working with the Milwaukee did not "invent" this technology. The electrical locomotives and all of their attendant infrastructure owed their collective existence to a number of gifted nineteenth century scientists and inventors, such as the famed Michael Faraday, Thomas Edison, and Nikola Tesla, as well as lesser known figures such as Frank Sprague and George Westinghouse. One of these five men developed virtually all of the components that the railroad used, such as high voltage transmission lines, alternating current transformers, generator sets, and the motors used for the locomotives themselves. The story of the Milwaukee's technology, therefore, is as much about the rise and eventual triumph of electrical technology in the late

nineteenth and early twentieth centuries as it is about the decline of steam power. How these early electric locomotives were operated is of additional interest, and this work will examine the four types of locomotives used by the Milwaukee in some detail.

Finally, this work deals with the first electrical system's ultimate replacement by the modern diesel electric locomotive. If the Milwaukee's motors could not exist without the work of the men mentioned above, it held equally true that the modern diesel could not exist without the pioneering work done by General Electric and Westinghouse on all of the Milwaukee's straight electric locomotives. Diesel performance has undeniably improved since the Second World War, but all of the basic design templates of the modern diesel - electric stemmed from work in trolley-type electrical traction from 1900-1920 – the era within which the Milwaukee sponsored the development of the most advanced rail system in the world. Although railroad technology advanced in the twentieth century, the industry itself declined. Accordingly, this thesis examines the rise of the modern American highway system and other trends deleterious to the American rail industry, particularly as these developments affected the Milwaukee.

To highlight the efficiencies of electrical motors versus engines, this work also examines advances in non-railroad technologies as well, such as powerplants for cars, boats, and airplanes. These examples highlight the advantages and disadvantages of competing technologies, and show that the choice Milwaukee officials made to electrify the Montana section of its line made technology and economic sense at the time. There was no one perfect solution for train locomotion in 1915, so any choice the Milwaukee

made had potential liabilities as well as benefits. Other large corporations faced similarly fateful technological choices, such as Henry Ford's decision to go with a gasoline powerplant for his Model T rather than a steam or electrical one. The Milwaukee's choice to electrify and Ford's choice of a gasoline engine each had advantages and disadvantages. In the case of Ford, he made the right choice. For every success story, however, there was at least one cautionary tale where a company made the wrong decision. The choice of a given technological system was not determined by purely technical factors; financial, cultural, and human factors (such as greed, intellectual or physical laziness, or pridefulness in one own's creations) have also played some surprising roles.

Finally, this thesis relates the history of the Milwaukee line to the secondary literature on the history of technology. Themes such as sea-change transitions from one technological system to another, how human and economic factors influence technology, and how technological icons such as Thomas Edison have fared at the hands of historians are but a few examples of the wide variety of writings that have been produced in this field. The Milwaukee's sundry choices and their consequences exemplify much of what scholars of technology have often said about electricity's larger impacts on American society in the twentieth century. The railroad was indeed a failure, but its pioneering work with electricity was a significant technological success story. Here, then, is that story.

Chapter I. A Brief Operational History of the Milwaukee

The Chicago, Milwaukee and St. Paul Railroad ultimately failed. Although many American railroads have failed, the Milwaukee was unique in that several hundred miles of its rail operations were electrified beginning in 1914.² The railroad's decision to electrify part of its line was unusual at the time. In pre-World War I America, opting for such an unproven system was quite bold, especially considering the line's location. Electric operations were considered best suited to heavily populated, high-traffic situations. A western, low-traffic railroad, such as the Milwaukee, seemed an unlikely candidate for such an experimental and costly project. One might reasonably conclude that the railroad's unusual technological path caused its eventual failure. Was the electrification an exercise in pursuing a false economy? The short answer is no. Electrification of the Chicago, Milwaukee, and Saint Paul Railroad's line through Montana, begun in 1914, possessed economic and mechanical efficiencies that it a more reasonable choice than other forms of motive power available at the time.³

In the early twentieth century, railroads had an increasing number of options for powering their locomotives. Each of these options had both costs and benefits. The Milwaukee Road, like many other American railroads from 1900-1980, utilized a variety

²Like many other railroads, the Milwaukee underwent several name changes over time. It changed from the Chicago, Milwaukee, St. Paul and Pacific to the Milwaukee Road after its second bankruptcy in 1945. Earlier works refer to the railroad as the "St. Paul," but after World War II, "Milwaukee" was more often used. In the interests of clarity, "Milwaukee" will be used throughout this work.

³Foreword by Jon A. Eliot, "Lie of the Century, A.K.A 'The Great Mistake,'" from Thomas H. Ploss, *The Nation Pays Again: The Demise of the Milwaukee Road: 1928 - 1986* (San Marino, California: Self Published, 1991.),v, vi.

of available traction power. Like all of the other railroads operating in the United States, the Milwaukee's management attempted to weigh, to a very fine measure, which combination of power and cargo was the most profitable. The Milwaukee's choice to electrify the Montana section of its nascent transcontinental line proved both economically and mechanically efficient.

While not an eighth wonder of the world, the electrified system in place by 1916 remains an impressive engineering feat to this day. The Milwaukee's electric locomotives, for a time, bisected some four-hundred thirty-four miles of some of North America's worst terrain, and were far more efficient and cost-effective than any steam fleet then available. For a few shining years, this line was the most modern rail system in the world. The only other major American electrification project on this scale was the Pennsylvania Railroad, and the Penn's layout in time, money, and material ultimately dwarfed the Milwaukee's. While the Milwaukee had fewer assets than the Penn, the size and difficulty of electrifying the area which the Milwaukee traversed electrically was more challenging.

Many historians consider electrification to be *the* watershed event in the social history of the United States. Much has been written about the early "luxury electrifications," such as J. P. Morgan's Residence in Manhattan.⁴ Such installations were undoubtedly high profile, little islands of modernity and made electrical pioneers such as Thomas Edison wealthy and famous. But the long-term trend was toward grittier,

⁴Jill Jonnes, *Empires of Light: Edison, Tesla, Westinghouse and the Race to Electrify the World* (New York: Random House, 2003), 107.

more mundane applications that improved transportation, basic industrial lighting and power, and water pumping for those without the financial wherewithal of individuals such as Morgan. Railroads' use of electricity exemplifies the heavy industrial application of this power source.

During the nineteenth century, there was a clear distinction between passenger trains and freight trains. Passenger trains were light; freight trains were heavy. By the turn of the century, however, passenger trains gained weight because safety legislation mandated the fortification of train cars. By 1910 a fifteen-car passenger train, up to code, weighed a hefty 1,000 tons.⁵ The diminishing physical distinction between freight and passenger traffic also reflected economic needs. A railroad could haul fewer long trains less often than several short trains in order to compete effectively. The logic was straightforward: since a greater number of passengers or a greater amount of freight could go on fewer trains, fuel and water costs went down, the per-trip cost dipped, and the railroad could pass savings on to the customer. Passenger service, with fast state-of-the-art locomotives, spotless, well-appointed cars, and more punctual schedules, certainly constituted a lucrative and image-enhancing endeavor in its own way.

The bulk of money to be made, however, was, and remains, in hauling freight. Regardless of the class of payload that a railroad line carried by the turn of the century, every line faced the problem of pulling increasingly heavy trains. Bigger trains meant increasing economies of scale in a brutally competitive market. However, this

⁵Robert L. Frey and Lorenz P. Schenk, *Northern Pacific Supersteam Era: 1925-1945* (San Marino, California: Golden West Publishing, 2000), 78.

necessitated more powerful locomotives. The technical problems imposed by this race for ever-bigger trains was especially acute for railroads that had to contend with mountainous terrain, either the Appalachians in the East, or the sundry mountain ranges in the West.

The Milwaukee's choice of motive power for its transcontinental expansion provides a grand example of electricity's wholesale insinuation into American society and commerce at the turn of the last century. Alone among the large American transcontinental freight lines, this company made a conscious, long-term commitment to electrical power, rather than utilizing electrical traction as an *ad hoc* solution to a specific operational problem, such as a lengthy tunnel.⁶ The Milwaukee made a deliberate decision to utilize electrical traction when other, ultimately more successful, railroads continued using steam until diesel-electrics became a practical option.

The electrical system the Milwaukee had in place by 1916, consisting of General Electric and Westinghouse locomotives, substations and overhead trolley wires, appears antiquated to the modern observer when compared to modern conveyances. Moreover, electric trains are most often associated with hauling passengers in urban settings, not long-haul freight traffic in the western United States. Most disinterested observers, upon hearing that freight trains operated on over 400 miles of electric trolley wire for over 70 years in Montana, doubt the wisdom of such a plan.⁷ This system that the Milwaukee

⁶The longest electrification project undertaken prior to GE's Milwaukee project was 160 miles in length, and most trolleys installed were for smoke reduction in tunnels and heavily urbanized areas. Noel T. Holley, *The Milwaukee Electrics: An Inside Look at Locomotives and Railroading* Edmonds, Washington: Hudman Publishing, 1999), 210.

⁷This skepticism is valid, because if electrification was such an efficient option, the major lines would have utilized this form of traction much more often when the

installed, however, was a quantum advance in motive power over existing steam locomotion, especially in the cold, mountainous environment in which the railroad operated.⁸ For one, motors were more efficient in fuel consumption, since they ran on “white coal” - hydroelectric power - rather than conventional black coal for a steam engine. Motors were also cleaner, quieter, and hauled more tonnage at higher speeds. Additionally, motors were much simpler mechanically, and had few of the maintenance problems that plagued steam locomotives. Finally, the Milwaukee was able to use its

technology became available after 1910. Instead we see a virtual absence of this form of locomotion in American railroading, especially in the western United States. Most assessments of the Milwaukee’s choice of electrics in such a remote, rugged, and sparsely populated setting note the unusual nature of such a choice. From “Those Classic Trains: Milwaukee Road Electrification,” available online at <http://www.northeast.railfan.net/classic/MILWdage5.html>, “[The] Milwaukee’s electrification is something of an odd fish. Unlike the two other major electrified systems (PRR and New Haven), the Milwaukee is a long haul route through rugged, thinly settled country to the northwest.”

⁸Two key problems for the railroad, ironically, were fire and ice. In 1910, cinders from a Milwaukee steam locomotive started a major forest fire in northern Idaho and northwestern Montana. This fire caused considerable loss of life and destroyed several hundred thousand acres of merchantable timber, as well as 16 of the Milwaukee’s wooden trestle bridges. The railroad was not held in any way liable for the fire. Nonetheless, the conflagration did little to enhance its public image. Although 1910 was a particularly bad fire year, similar episodes were always a possibility with steam engines. August Derleth, *Milwaukee Road: Its First Hundred Years* (New York: Creative Age Press, 1948), 193-94 and George Abdill, *This Was Railroading*, 166. The winter months posed no danger of fires, but subzero weather substantially curtailed any steam locomotive’s power. Trolley-powered motor performance actually *improved* in colder weather. This was especially evident in the Milwaukee’s “Rotary” snow plows used on the heavy, wet snow that fell in the Cascades. The rotaries were converted from steam to electrical power beginning in the 1950s. Their superior performance compared to existing steam plows was evident in a bad snowstorm of February 1954. A single electrical rotary operating in the Cascades effectively kept the track clear for the nine days that the storm lasted. Two of the three steam plows operating in the Bitterroots (where the snow was substantially lighter) failed during the same storm. Holley, *The Milwaukee Electrics*, 154. For more on cold weather performance, see the “Motors” chapter below.

trains as generators and to use the power either to propel another train or to “give” it back to Montana Power.⁹ In all of these ways, electrical power had mechanical advantages over the mountainous stretch of terrain through Montana.¹⁰ Because of these efficiencies, the overbuilt, primitive motors of 1914 were still more advanced in terms of performance than the much touted “super” steam locomotives pressed into service during the Second World War.

Mechanical efficiencies gained through electrification enable the railroad to operate at a lower cost in the Rockies. For example, electrification achieved significant savings, according to the Milwaukee’s own figures – almost \$12 million in the Rocky

⁹Bill Wilkerson, *Milwaukee Road EF-4 Locomotives* (Harlowtown, Montana: Times Clarion Press, 1998), 18. A more technical description of regeneration follows in the chapter on motors. From a financial and regulatory viewpoint, accounts of the situation that developed with Montana Power (MPC) owing to regeneration are at best muddled, and the author has yet to find a satisfactory explanation for this particular arrangement between the two entities. While not as transparently corrupt as the worst rebating abuses of the major railroads that precipitated the Interstate Commerce Commission (ICC) in 1887, the financial aspects were doubtless contrived to be as convoluted as possible, with the intention of bewildering the most diligent muckraker or ICC auditor. Some sources, such as Noel Holley’s *The Milwaukee Electrics*, 160, indicate that regenerated power not used for any nearby locomotive was sold back to MPC; others indicate that minimum purchase agreements precluded MPC from buying back any power or issuing a rebate. To date, no one has cared enough about the matter to explore the distinction. Rebates aside, the Milwaukee accrued massive savings in wheels, brake shoes, hydraulic line, and skilled labor by dispensing with conventional braking methods at all but the mildest conditions (under 3 miles per hour on a level grade).

¹⁰Interestingly, a significant portion of the railroad in eastern Washington was not electrified, presumably because the Milwaukee lacked funds to install electrical infrastructure all the way from Harlowtown to Tacoma. It is somewhat telling that the non-electrified “gap” from Avery, Idaho to Othello, Washington covered very flat terrain similar to that found east of Harlowtown. In other words, the Milwaukee applied the electrification where it was needed most, in the Rocky and Cascade Mountains. This thesis deals mainly with the Montana electrification, since it was more substantial in length and went in earlier than the electrical infrastructure in Washington.

Mountain Division for the eight year period between 1916 and 1924, or over a million a year on average.¹¹ Furthermore, in its 1928 investigation of the Milwaukee's finances, the ICC concluded that the "aggregate cost of operating those division by means of electricity has been much less than the cost of operating those three divisions by means of the older type of steam locomotives would have been."¹²

The ultimate failure of the line, therefore, resulted not from the company's choice to electrify its Rocky Mountain Division, but rather from its choice to construct a transcontinental expansion in the first place. Additionally, crushing debt, questionable management, changing economic and transportation trends, and overtly hostile competition from rival transcontinental lines in the region also contributed to the railroad's multiple bankruptcies. Much of the problem with the Milwaukee's expansion lay with its timing, and also with the fact that it was an entirely different species of railroad when compared to the other transcontinental lines. It was the last of the transcontinental expansions in American railroad history, and the Milwaukee's early growth was, in general, less spectacular and more risk-averse than the other transcontinentals.

Unlike the Union Pacific or Northern Pacific, the Milwaukee was originally a "granger" railroad, one with a preponderance of regional, farm-to-market traffic, in this

¹¹Interstate Commerce Commission, *Investigation Number 17021*, 651.

¹²Interstate Commerce Commission, *Investigation Number 17021*, 652.

case centered in the Upper Midwest.¹³ Ostensibly, the Milwaukee's first and foremost customers were the farmers, and the railroad had their interests closer to heart than the larger national lines, which farmers accused of predatory business practices. The other defining feature of a granger line was extensive installation of secondary track. Opposed to "trunk lines," secondary track covered Midwestern farm territory and made it possible for remotely situated graingrowers to get their products to markets in Chicago and all points east. This arrangement of track was common before the construction of decent farm-to-market roads resulting from the 1916 Federal Aid Road Act and the 1921 Federal Highway Act.¹⁴ A brief glance at a track map of the Milwaukee's Midwest operations verifies the pattern of secondary track. No unbending law of economics stated that granger lines could not attempt transcontinental expansion, but the Milwaukee would have done well to rethink its strategy in this case. As a late comer, the Milwaukee could not effectively compete with long-established continental lines.

The northwestern expansion forced the railroad to take on too substantial of a debt. Before the expansion, the company had a sound financial record. In 1905, for example, the line earned its interest requirements three times over, even after paying

¹³Ripley, *Railroads*, 214. Granger lines were generally much less heavily capitalized than the eastern "Trunk" lines. The pre-expansion Milwaukee was no exception, rated at \$30,800 per mile in 1906. By way of contrast, the Reading and Erie Lines – which both had double track – were listed at \$169,000 per mile in the same year.

¹⁴Eric Foner and John A. Garraty, (Editors), *The Reader's Companion to American History* (New York: Houghton Mifflin, 1991), 65.

dividends.¹⁵ During the years of the railroad's transcontinental bid for greatness, the company's debt roughly tripled.¹⁶ Similarly alarming figures exist for the long-term debt from 1905 to 1925, which nearly quadrupled from \$115 million to \$440 million. Equally important, the nature of the debt posed particular problems. The ratio of stock to funded debt in the company was roughly fifty-fifty in 1905. By 1925, stock represented roughly a third of the Milwaukee's wealth, a perilously low figure when compared to healthier contemporary competitors.¹⁷ Such figures, naturally, depressed the price of the stock itself, and the railroad found itself caught in a downward spiral, constantly having to borrow more and more money.

Part of the problem was that company officials grossly underestimated the cost of expansion. For example, the Milwaukee's President, Albert J. Earling, had originally projected expansion costs of roughly \$60 million at the most, a substantial sum in 1911. Final costs, however, amounted to a staggering \$256,968,126, although some disputed this as inflated.¹⁸ Interest payments on bonds that the Milwaukee was forced to sell over

¹⁵By way of contrast, the Milwaukee did not issue a single dividend from 1917 to the 1925 bankruptcy. Interstate Commerce Commission, *Investigation Number 17021, Investigation of the Chicago, Milwaukee & St. Paul Railway Company* (Washington, D. C. : Government Printing Office, 1928), 618, 626.

¹⁶"Funded debt issued in hands of public" stood at \$122,256,000 in 1900, and was \$356,157,000 by 1915. Derleth, *The Milwaukee Road*, 306. The Interstate Commerce Commission's examination of the Milwaukee's first bankruptcy draws similar conclusions (see below).

¹⁷The Hill Lines' capitalization was all well over 50 percent company stock in the 1920s. Interstate Commerce Commission, *Investigation Number 17021*, 626.

¹⁸Ripley, *Railroads, Finance and Organization*, 37. Ripley argued that the total debt was inflated by approximately \$100 million in order to conform to Washington State

the years constantly ate into the bottom line.¹⁹

Opting for electrification was an incidental expense of the decision to expand to the Pacific.²⁰ Only \$22,990,254 of this total went for electrification. A significant sum, but still less than 10% of the total expense. Furthermore, if one considers what was gained in terms of performance, it seems a bargain.²¹ Schedules tightened up considerably, and electrical operating costs were only 54 percent of pre-electric levels. A corporate report in 1925 pegged annual savings from electrification, after bond and interest payments, at one million dollars.²² As will be seen in the second and third chapters which compare these two technologies in depth, electrical traction was clearly superior to the contemporary technology, steam.

One of the problems of the debt incurred by the Milwaukee was the way in which it financed expansion. Fundamentally, there are two ways to finance a railroad's

Laws on bond sales. Essentially, something had to be added to the property investment side of the company's ledger in order to balance the total long term obligation of the company. Also, Washington State laws mandated that bonds could only be sold up to a level of double a company's stock capitalization.

¹⁹Holley, *The Milwaukee Electrics*, 210.

²⁰Although it is true that electrification could be more easily justified for heavier traffic lines, such as the Pennsylvania. See Alboro Martin, *Enterprise Denied: Origins of the Decline of the American Railroad, 1897-1817* (New York: Columbia University Press, 1971), 67.

²¹August Derleth, *The Milwaukee Road: Its First Hundred Years* (New York: Creative Age Press, 1948), is considered the definitive account of the railroad's finances and corporate operations up to 1950. See 198-99.

²²Holley, *The Milwaukee Electrics*, 210.

expansion: sales of company stock and sales of bonds.²³ In order to sell stock, the preferred method, a railroad required a good deal of genuine confidence in any proposed expansions. If the company's confidence faltered, there remained little chance that investors would purchase a share of such an enterprise. Realistically, however, a railroad depended on the flintier outlook of American and British bankers, and this meant bond sales. Alboro Martin, an expert on regulatory and financial practices in the Progressive era, explains the increased prevalence of bond-based financing at the turn of the century:

The relatively small proportion of the nation's wealth which was invested in exchange-listed corporate enterprises was overwhelmingly concentrated in railroads and the industrial enterprises which had grown up to supply the steel and the rapidly growing variety of equipment and mechanical devices which they required. In its monthly summary of stock price movements, the authoritative Commercial and Financial Chronicle listed thirty-eight railroad stock and twenty-two "miscellaneous" stocks. Of the latter group, three were municipal railways and the majority were dependent to a considerable degree on purchases by railroads. The few pages of stock prices, however, were preceded by page after page of bond prices, for debt securities still dominated equities in the nation's financial center. And most of these bonds were railroad issues.²⁴

Although all of the more successful railroads were rapidly expanding in the first

²³Until the mid-nineteenth century, common stock sales were the dominant method of financing a railroad's expansion. Bonds became more and more prevalent as the century progressed. Alfred D. Chandler, Jr. "Patterns of American Railroad Finance 1830-1850," 28 *Business History Review* 261 (1954).

²⁴ This work is a severe, yet erudite, critique of Progressivism's dilatory effects on the railroads. Martin holds that the rail companies were over-regulated, and that the long term development of rail technology that would have made the rail system more competitive with the nascent (but booming) network of American highways was systemically stunted by the government. Regulation, or a lack of it, remained a key factor in transportation in this period. Alboro Martin, *Enterprise Denied: Origins of the Decline of the American Railroad, 1897-1917*. (New York: Columbia University Press, 1971), 97.

ten years of the twentieth century, the Chicago, Milwaukee, and St. Paul was thinking especially big: a 1700-mile expansion from its then western terminus in western South Dakota to Tacoma. This obviously would require borrowing money, and many of the bonds sold by the railroad's financial agents would ultimately have European buyers. For example, Kuhn, Loeb, and Company negotiated a 1910 sale of \$50 million worth of Milwaukee construction bonds to a group of French banks.²⁵ With such a far-flung array of absentee investors and money handlers, none of whom were particularly interested in the daily affairs of a remotely situated American rail-line, the potential for questionable decisions rose sharply.

Indeed, the Milwaukee's management made a series of poor decisions that contributed to the railroad's financial woes. For example, the railroad overstated its income by five million dollars in 1910. The company did so in order to inflate the price of the stock. Essentially the company classified all interest, rents, and revenues resulting from construction as income – a highly dubious practice, but one that temporarily bolstered stock prices.²⁶ This type of scheme informed the Milwaukee's finances to an alarming degree.

The company's decision to undertake the expansion was a reflection of this bad

²⁵Martin, *Enterprise Denied*, 134.

²⁶William Zebina Ripley, *Railroads: Finance and Organization*. (London: Long, Green and Company, 1915), 23, 214. Ripley was the Nathaniel Ropes Professor of Economics at Harvard University, and in Alboro Martin's view, epitomized the well-meaning but misguided proponent of heavy federal regulation of the railroads. The company's stock rose from \$113 to \$133 a share in the 1909-1910 period, but the effect was temporary, and the stock fell well below \$113 by 1912.

management. In 1928, the Interstate Commerce Commission examined the Milwaukee's operations up to the first bankruptcy of 1925.²⁷ This document examined the Puget Sound Extension, electrification, and the railroad's finances. In the report, the ICC concluded that the Milwaukee's management developed the transcontinental expansion not because traffic surveys indicated another line was needed, but rather in response to maneuvers by both the Hill (Great Northern and Northern Pacific) and Harriman (Union Pacific, *et al*) lines.²⁸ The project, which moved both freight and passengers by 1909, represented 37 percent of the entire railroad's property investment, but continually turned in dismal returns considering the monetary layout. Returns were less than one half of one percent as late as 1925.²⁹ Simply put, hoped-for traffic never developed. The Board wrongly assumed that the Milwaukee could make good any cost overruns, and that the expansion would bring about the same spectacular early growth of the older railroads. The twentieth century railroad industry was much more static than it had been in the nineteenth. As a result, the railroad did experience the expected spectacular growth. Being twenty-five years behind the other transcontinental lines put the Milwaukee at a

²⁷The bankruptcies attracted additional attention as well. Attorney Max Lowenthal's best-selling expose of the Milwaukee's 1930s bankruptcy and reorganization, *The Investor Pays* (New York: Alfred A. Knopf, 1933), was especially damning.

²⁸Interstate Commerce Commission, *Investigation Number 17021, Investigation of the Chicago, Milwaukee & St. Paul Railway Company*, 618.

²⁹ Although all major railroads in this era suffered from similarly low returns. The key difference is that the Milwaukee spent a great deal more money in this period than did the Hill Lines. Interstate Commerce Commission, *Investigation Number 17021*, 619-20.

significant disadvantage, and the railroad's three bankruptcies are proof enough of this. No amount of borrowing and crash construction programs could turn back the clocks. As the ICC concluded, the decision to expand led inexorably to bankruptcy: "The record leaves no doubt that first among the causes of receivership was the failure of that extension to earn anywhere near a return sufficient to help the system carry the burden incurred in its construction."³⁰

The ICC also criticized the Milwaukee's minimum purchase arrangement with Montana Power. The railroad had a 99-year, minimum purchase, so-called "sweetheart" deal with the utility. However, with the railroad essentially paying for its power twice, the only one getting a sweetheart deal was Montana Power.³¹ This uniquely symbiotic relationship of a railroad with a major public service utility further differentiated the Milwaukee from the other transcontinental lines. The fortunes of the Milwaukee and Montana Power were much more closely intertwined than that of, say, Union Pacific and Standard Oil, or one of its major coal suppliers. The money the Milwaukee wasted on Montana Power was negligible when compared to its bond debt, but this arrangement certainly did not help matters in a situation where such overruns were so clearly not an affordable luxury.

The man who benefitted most from the circumstances electrification imposed on the Milwaukee and Montana Power was copper tycoon John Ryan. Ryan's role in the fortunes of the railroad are well known in the peculiarly esoteric field of railroad

³⁰Interstate Commerce Commission, *Investigation Number 17021*, 620.

³¹Interstate Commerce Commission, *Investigation Number 17021*, 646.

scholarship. Ryan had controlling interest in Montana Power, and was President of the planet's largest copper company. Additionally, Ryan held substantial amounts of the railroad's stock. Approached by fellow shareholder William Rockefeller to become a board director in 1909, Ryan accepted.³² Any substantial transaction involving copper, railroads, or electrical power in Montana (or in North America for that matter) had to get past John Ryan. Ryan's ultimate financial benefit from electrification would be a fruitful subject for a gilded age business historian to pursue, but failing that, it will probably never accurately be known. He is held up as an unfairly besmirched saint in the Anaconda Company's official histories; on the other hand, the mere mention of Ryan put local populist newspapers with an anti-Anaconda bent in high dudgeon. The truth probably lies somewhere in the middle. For his own part, Ryan categorically denied any sort of malfeasance and claimed that he studiously avoided Milwaukee board meetings dealing with electrification.³³ Ryan's alleged conflict of interest was not his only stint of notoriety; he stood accused of copper price fixing and pooling schemes during the First World War.³⁴ Whatever ethical shortcomings Ryan possessed, however, they hardly made him responsible for the bankruptcies. With so many other above-mentioned financial machinations going on in the same period, Ryan's "sharp" business dealings vis-

³²Ryan, with others, formed Montana Power in November 1912. Isaac F. Marcusson, *Anaconda* (New York: Dodd, Mead, & Company, 1957), 144. William, and later Percy, Rockefeller controlled substantial blocks of Milwaukee stock until the mid-1920s. Interstate Commerce Commission, *Investigation Number 17021*, 633-35.

³³Interstate Commerce Commission, *Investigation Number 17021*, 638.

³⁴Marcusson, *Anaconda*, 164-65.

a-vis the Milwaukee were hardly unique.

While over the long term electrification saved on operational costs, it nonetheless came at considerable initial expense. From 1915 to 1920, the railroad purchased 11,000 tons of copper from Anaconda Copper and 46 transformers and motor generators from General Electric.³⁵ And, a significant portion of the construction overruns went toward the purchases of land along the planned right of way, which effectively split the difference between the Great Northern's route on the so-called "High-Line" and the Northern Pacific, which followed the Yellowstone River for much of its course through Montana. The Milwaukee's route on the Great Plains section of its expansion was not markedly inferior, topographically speaking. More costly was the relative tardiness of the railroad's entry into the Musselshell drainage. By the time the Milwaukee entered the transcontinental game, the Musselshell Valley, while sparsely populated, still had its share of wheat bonanza farmers and ranchers who were not happy about sharing land and water easements with the Milwaukee, whatever the company's promotional literature said. The railroad had to settle, dearly, with several landowners in the Musselshell drainage before it could lay track.

Unlike the earlier transcontinental lines, with the exception of the Great Northern, the Milwaukee had to purchase right-of-way, rather than having it granted by the federal government. Unfortunately for the Milwaukee, free land for railroads had died in the wake of Trust Busting and Progressivism. The company's plight was further aggravated by the fact that its real competitors then in Montana, the Great Northern and Northern

³⁵ Holley, *The Milwaukee Electrics*, 210.

Pacific, had shrewdly anticipated the Milwaukee's expansion to the Coast, and had purchased the remaining vacant parcels on the route. They then sold the parcels to the Milwaukee at whatever price they saw fit. While without question a predatory practice, there was little the Milwaukee could do except purchase right-of-way at an exorbitant cost.

The Milwaukee did find ways to limit the expense of the line. Unlike all of the other transcontinental projects, the Milwaukee did not have to construct the line from a single point at the rail's head, which increased the construction's time and expense. Rather, the Milwaukee parceled the project out to four subcontractors, which began their respective rail construction projects from intermediate points in Montana, Idaho, and Washington. All concerned utilized both the Great Northern and Northern Pacific in freighting construction materials, such as rails and ties, as close to the immediate construction termini as was possible.³⁶ The speedy construction of the line was one of the few areas in which the railroad trimmed construction costs in its Pacific expansion. But even with such savings, the project cost almost four times the original estimate.

The Milwaukee's competitors enjoyed another advantage. The other lines, especially the Northern Pacific, shared many towns along the Milwaukee's eventual route. However, the Northern Pacific had the incalculable advantage of a twenty-year head start in the Rocky Mountain West, with industrial sidings in the logging and mining towns, such as Butte and Missoula, dwarfing the number the Milwaukee eventually installed in both number and physical size. The practical outcome of this disadvantage

³⁶Derleth, *The Milwaukee Road*, 182.

was that the usual location of the Milwaukee's sidings ran on the outskirts of a given town, and correspondingly limited service to prospective customers, a problem that hounded the line until its ultimate demise.

The competing lines also actively sought to disadvantage the Milwaukee. Railroads are not generally prone toward peaceful coexistence, and both the Northern Pacific and Great Northern used their senior status as transcontinental lines to gain certain advantages over the Milwaukee, such as the aforementioned buying land along the Milwaukee's planned right-of-way. The Milwaukee's problems did not end with the consolidation of these two lines, along with the Chicago, Burlington, and Quincy Railroad into the Burlington Northern in 1970. The entities making up Burlington Northern resented the Milwaukee's presence in the region and unabashedly did everything within the bounds of the law to drive it out of business, even before the 1970 merger.³⁷

Poor management was also an issue for the Milwaukee after World War II. Former employee Jon Elliot claimed that the Milwaukee's directors not only neglected the electrical facilities in favor of the steam (and later diesel) infrastructures, but also grossly favored the Milwaukee's pre-expansion network of track in terms of budgeting both capital and management talent. Elliot colorfully referred to this east-west schism in the company as a "Chinese Wall at Mobridge."³⁸ Chicago businessman Frank Quinn's was equally unimpressed by the Milwaukee's management. Quinn had been a major

³⁷Ploss, *The Nation Pays Again*, 88, 132-33.

³⁸Ploss, *The Nation Pays Again*, vi.

player making the “piggyback” system a workable reality, and had been forced to work with the railroad in the 1970s because of the ICC’s stated desire to have competition in the northwest after consolidation of Hill’s “Northern Lines” (Burlington Northern).³⁹ The Milwaukee became the government’s hope to keep “impermissible” monopoly out of the region.⁴⁰ Quinn’s assessment of the Milwaukee’s management was quite unflattering: “If I am smart enough to come up with a new system of running a railroad I am sure smart enough to not work with the worst financial, worst run and worst managed railroad in the U.S.”⁴¹

The Milwaukee’s history reads like a tragedy. The decision to build the transcontinental line sealed the company’s fate. From a technological standpoint, however, the Milwaukee’s transcontinental line was a marvelous success. Not only did the Milwaukee employ the most current construction techniques, it looked to the new motive force of the twentieth century, electricity, to move its freight. The notion was not a fanciful one. In contemporary plants and factories, electricity had supplanted steam in a

³⁹ Piggybacking had been contemplated as early as 1926 and theoretically combined the scales of economy of rail transport with the flexibility of truck hauling. Piggybacking, more formally known in the parlance of the trade as trailer-on-flatcar (TOFC), tend to haul finished rather than bulk goods. A 1980 corporate report pegs the relative fuel efficiency of a diesel-electric-towed boxcar at 340 net-ton miles per gallon, a piggyback unit at 167, and a 45 foot semi trailer at 63. Corporate cheerleading aside, piggybacking seems to have found a niche, judging by the rail traffic. Booz-Allen and Hamilton, Inc. for Transamerica Interway: *Piggyback: The Efficient Alternative for the 80's* (New York: Transamerica Interway Inc.; 1980), xiii, 44. Tuplin, *The Steam Locomotive*, 84-5.

⁴⁰Ploss, *The Nation Pays Again*, 84.

⁴¹Letter from Frank Quinn to Congressman Henry Hyde, August 21, 1990, from Ploss, *The Nation Pays Again*, Appendix Two.

number of applications. What had been a whirling maze of troublesome and potentially deadly belts and chains running off of large, centralized steam engines had been replaced by a greater number of more compact, and from the workers' and underwriters' perspective, much safer electric motors. While electricity did not end the need for maintenance, and the new technology had a number of early problems, electricity had clear advantages over steam on the shop floor. Moreover, the two major players in the then nascent electrical industry, General Electric and Westinghouse, thought that applying electromotive force to yet another field that had been the almost exclusive province of steam power had immense potential. With the land bought and the track laid, the task that the Milwaukee asked of electricity's state of the art was a formidable one.

Electrification had unquestioned advantages in terms of theoretical performance, but initial costs were much higher; moreover, the technology was unproven. Very large DC motors used in this fashion had never before been attempted. Steam had cut overhead costs as much as possible, and they were still ruinous. The hoped-for payoff would come in lowered maintenance and fuel costs, complimenting the Milwaukee's sensibility of lowered long term, but ultimately unfixed, costs. On whatever plane, the decision of the Milwaukee to use their trains as generators powered by potential kinetic energy (gravity acting on a massive object in a controlled fall) exemplified one of the great energy conservation schemes of the twentieth century. And yet, in all likelihood, the railroad did not electrify out of any sense of conservationism or conscientiousness. The new technology made sense because of its economic efficiencies.

The Problem of Terrain in the Rocky Mountain Division

When the Milwaukee Road first considered the transcontinental expansion, it intended to rely solely on steam for motive power because it was the only option available at the turn of the century. Despite 130 years of development and almost exclusive dominance, steam had severe performance problems, especially in cold and mountainous terrain. By 1915, however, electrical traction motors had become a realistic option. The terrain the new Milwaukee line had to cover over the Rockies made electricity an attractive option.

Historically, the American rail lines had taken an altogether different approach from those of other industrializing nations, opting for speed over more solid construction. The situation the Milwaukee faced in going to the Pacific Coast was common to all of the railroads in western North America. Distances the Great Plains and Rockies were much longer, grades more severe, and turns much tighter than anything attempted in Britain, the nation considered the longtime authority in constructing locomotives and putting in railbeds. When American rail surveyors encountered an obstacle such as a mountain, they would attempt to go around it if possible. British surveyors would go through the obstacle, whether practical or not. Perhaps the most telling example of the differing philosophies was the early British practice of using rail ties hewn from granite rather than wood. A similar distinction also applied to British and American steam locomotive design; British locomotives, while admirable products of the finest precision machine shops in the nineteenth century, were much less flexible on track and much more difficult for yard mechanics to service, because of various, apparently sacrosanct, English

machine shop traditions.⁴² Even a neophyte rail fan can spot the differences between British and American designs. The Milwaukee Road attempted, at least in public, to take a leaf out of the book of the British school of rail-laying. While not quite reaching the point of using granite ties, the Milwaukee their approach featured solid, quality construction the first time. Given the terrain, it did not pay to scrimp on materials. Worst of all was the problem of almost unrelenting grade any train going over the Continental Divide faced. Arguably, the Milwaukee received the worst route in this respect, because it chose last.

Grade is the enemy of any land vehicle's performance, particularly one as massive as a twentieth century train. Things happen more slowly when pulling a train than when driving a car, but making a mistake on a train obviously has more irreversible results. Perversely, climbing with such a vehicle is was easier than going downhill. Stopping a runaway vehicle of such a massive size, on steel rails, is a dangerous, complex, and

⁴²From Alfred Williams's classic *Life in a Railway Factory* (New York: Augustus M. Kelley, Publishers, 1969), 150-51: "There is a considerable amount of American made machinery at the works, and the percentage of it increases every year, though it is often far from being successful. At the same time, it must be conceded that our kinsmen over the sea are very clever in the designing and manufacture of tools and plant, and many of their ideas are particularly brilliant. The English maker of manufacturing tools follows at some little distance with his wares. These, though not actually as smart as the others, are yet good, honest value, the very expression of the Englishman's character. The chief features of American machinery are – smartness of detail, the maximum usefulness of parts, capacity for high speed and flimsiness, styled 'economy' of structure: everything of theirs is made to 'go the pace.' English machinery, on the other hand, is more primitive and cumbersome, more conservative in design and slower in operation, though it is trustworthy and durable; it usually proves to be the cheaper investment in the long run. One often sees American tackle broken all to pieces after several years' use, while the British-made machine runs almost *ad infinitum*." Williams's work also highlights the incredibly stratified world of the various British trade castes: "coalies," bricklayers, carpenters, various subspecies of machinists, and management.

sometimes futile endeavor. Even today, for a semi truck-sized vehicle on a 30 foot wide interstate highway, runaways are rare but always looming experience. One of a motorist's more sobering sights going east on Interstate 90's Homestake Pass out of Butte is a runaway truck ramp on the pass's east side, a massive incline with gravel at least a foot deep to arrest 80,000-pound trucks whose brakes have failed. The Milwaukee's route into Butte went over identical topography only a few miles from the Interstate, and a train makes a semi truck look like a sports car in terms of lightness and maneuverability. One can imagine the terror and powerlessness a crew with a 4,000 ton runaway train could potentially face under similar circumstances, but without the benefit of a runaway ramp. With all of mankind's current masteries over nature, in the country with the best industrial and transportation infrastructure on the planet, Homestake Pass on Interstate 90 is closed two or three times each winter, briefly, but still at considerable inconvenience to everyone involved: the drivers, the customers, and the underwriters, at a comfortable remove. Even today transportation is risky, but getting a train over any substantial mountains in the Gilded Age cost lives and money.

Even the primitive, light trains of the early nineteenth century posed unprecedented braking problems for designers and engineers. For the first time in history, the distance required for braking was beyond the driver's line of sight. Among other things, this necessitated a telegraph or other system of communication faster than the train.⁴³ By the time the Milwaukee undertook its transcontinental expansion program,

⁴³William L. Withuhn, (ed.), *Rails Across America* (New York: Smithmark Publishers, 1993), 73.

braking's many potential deficiencies were arguably the most serious hazard confronting train traffic over the Rocky Mountains. Grade could doom a train climbing or descending.

There are two major approaches to determining grade: degrees and percent.

Degrees are obviously measured with a protractor, inclinometer, or equivalent device, but rise/run in percentage is far more frequently used to express steepness. Thus, a rise of a half of a mile over the length of a mile had a 50 percent grade. Such severe grades are never encountered in railroading, with the notable exception of cog railways; 2.5 percent is considered the practical upper limit for a main line locomotive hauling anything over 1000 tons. Locomotives for grades more excessive than that are considered oddities. Geared locomotives on logging lines could handle grades of up to 10 percent, but this type of machine traded speed for traction, and cogged drivers with corresponding rails represented the extreme extension of this logic. Railroads and automobile roads almost without exception employ percentage measurements, because they have a greater amount of precision and are easier to use in civil engineering calculations. A four percent grade stood as the limit for performance, oddities such as geared locomotives and cogwheel railways aside. In both heavy-automotive and rail circumstances, a four percent grade is a potent obstacle to overcome. This might not sound like much, but moving a 4,000-5,000 ton train over such a grade remains a herculean task, even for today's machinery. Other grade examples include:

1.6 percent = 87.6 feet per mile.

1.7 percent = 89.7 feet per mile.

2 percent = 105 feet per mile.

Getting a train over a steep grade is not simply a matter of tacking more locomotives onto the front end. If railroads did this on a more frequent basis, there would be far more accidents than there now are. The tensile and compressive forces at work on the couplings of a train anywhere from a half mile to a mile long are colossal. Whenever possible, helper units were placed either in the middle of an ascending train, or failing that, dispatchers tacked pusher units onto the train's end. Operators understood this from the earliest days of rail commerce. Prior to the Westinghouse air brake, a train's usual two brakemen were always instructed to apply the primitive friction brakeshoes for each individual car from the ends of the train inwards. The brakeman made his way from car to car by scrambling along the top of a hurtling train. Prior to the airbrake's invention in 1869, the brakeman's job was thankless, underpaid, and incredibly dangerous. When it came time to slow the train, he was damned any number of ways even under ideal conditions: failure to apply brakes in the correct sequence, and with alacrity, could decouple a train; failure to apply enough pressure to the shoes would not sufficiently slow the train in time with the potential for catastrophe; over tightening the shoes resulted in flattened wheels, for which the brakeman would be fined \$45 each (the cost of the wheel, and coincidentally a month's pay).⁴⁴ Things improved considerably after the introduction of Westinghouse's design, which applied almost instant even pressure to all brakes remotely. Still, braking trains on a steep grade taxed the nerves of even the most skilled and experienced train crews in the western United States.

⁴⁴Keith Wheeler, *The Railroaders* (New York: Time Life Books; 1973), 182.

It was in this hazardous setting that the Milwaukee employed the industry standard: steam. For both freight and passenger service from Harlowtown and all points east, the railroad employed a wide variety of steamers. Although there was a 2510 feet difference in elevation between Mobridge, South Dakota and Harlowtown, Montana, grades on this stretch of the Milwaukee's right of way were well suited to using steam locomotives. To calculate the mean grade on this stretch, one takes the difference in elevation between Mobridge and Harlowtown (2510 feet) and divide this number by the distance (503 Miles = 2,801,568 feet) to get the grade, which is roughly an average of .08 to .09 percent. Contemporary steamers could handle this mild grade, but the situation worsened considerably west of Harlowtown. Indeed, the steepness of the terrain west of Harlowtown accounted for the railroad's selection of Harlowtown as the eastern terminus for the proposed electrification.

The railroad's path from Miles City to Harlowtown is the last gasp of the High Plains. From Miles City, on the Yellowstone River bottom, to Roundup, in the Bull Mountains (actually a series of sandstone hills), is one of the most forlorn rail sections North America can offer. U.S. Highway 12 follows the old Milwaukee Road grade very closely. The climb to the divide between the Yellowstone and Musselshell drainages is gradual but unmistakable. Sumatra, an old sheep shearing depot, is at the top of this divide. Sumatra's location and appearance are fairly bleak considering the exotic name, and the site consists of a motley collection of abandoned buildings. Roundup, the next town of any size, was at one time an important coal production center for all of the region's railroads.

Moving further west, the right of way comes to Harlowtown. Harlowtown was originally the result of the bonanza wheat farming era, named after the owner of a small upstart enterprise, the Montana Railroad, which eventually sold out its right-of-way over the Belt Mountains to the Milwaukee. The electrical trolley line began here, and the line first had to attack the relatively small Castle Mountains, followed by the much larger Big Belt Range. After summitting the Belts, a train would then descend down the narrow and winding Sixteen Mile Canyon into the Missouri River's main drainage. The town of Three Forks had a fairly large depot and steam repair facilities, and this was the last point of respite for a westbound train before it had to tackle the main spine of the Rockies. The grade from Three Forks to the next substation (necessary to keep the direct current voltage at adequate operational levels; see "Motors" below) at Piedmont was a relatively mild .3 percent, but the next 20 plus miles to the Donald summit were a harrowing two percent and taxed every bit of added performance that the electrics could give. The slope downhill into Butte and the nearby roundhouse at Deer Lodge was 1.66 percent – not so bad as the east slope but still a serious enough situation to instill respect and a sense of alertness in the train's crew. The stretch from Piedmont into Butte was known as a "helper district," because the severity of the terrain required additional electrical (and later diesel) units to move, and just as importantly, brake the train. The only other helper section in Montana was over the Bitterroot divide, with a maximum grade of 1.7 percent. Helpers were placed in the middle of the train, and the company took pains to instruct a helper's engineers that they were to concentrate on pulling the load behind them, rather than pushing the load in front of them, in order to avoid decouplings. Once safely into

Butte, however, a train had relatively smooth sailing down the Clark Fork of the Columbia River before having to climb to the Bitterroot divide.⁴⁵

The proposed electrical installation faced a formidably entrenched opponent in the existing steam infrastructure, even though the inadequacies of steam were becoming more and more apparent in the early twentieth century. Inertia often accounts for a number of the more perverse examples of why the machinery we use periodically defies common sense (especially in hindsight). A good example of inertia is the QWERTY keyboard's continued dominance in the face of superior keyboard layouts to explain this phenomenon. The QWERTY layout was the result of a desire deliberately to slow, rather than speed, the number of words per minute of even the most adept typist, in order to avoid double key strikes and other machinery jams.⁴⁶ The first mechanical typewriter that successfully "stored" the data in a double strike and kept the typewriter from jamming was not available until 1961, when IBM introduced the 72 Selectric, a revolutionary, and complicated, machine.⁴⁷

A layout that deliberately put the frequently used letters at the far points of the keyboard paradoxically improved the early machine's performance, and rewarded

⁴⁵For a far more detailed account of the towns along the right of way in Montana and Idaho, consult Steve McCarter, *Guide to the Milwaukee Road in Montana* (Helena, Montana: Montana Historical Society Press, 1992), 31-88.

⁴⁶Robert Pool, *Beyond Engineering: How Society Shapes Technology*, (New York: Oxford University Press, 1997), 159-60.

⁴⁷Simon & Schuster, *The Way Things Work: An Illustrated Encyclopedia of Technology* (New York: Simon & Schuster, 1967), 290. This particular typewriter uses several AC motors. IBM sold millions of this model after its introduction in 1961.

deliberate and plodding typing over fast, relatively imprecise keystrokes. No arrangement, however cunning, of cams and levers could match human hand eye coordination in the 1880's. Over the years, electric and electronic keyboards have rendered the QWERTY layout obsolete. Any number of keyboard arrangements have been proposed, but people have grown accustomed to QWERTY, and unknown numbers of QWERTY textbooks exist. The system has insinuated itself into an unthought number of instances in the life of anyone who uses a keyboard during the course of the day, and in the age of personal and business computers, that is quite a boast. The amount of effort that would go into making a change is not worth the trouble, according to efficiency experts who make careers out of feasibility studies. Office machine manufacturers would have to retool plants, instructors of the old method would be as ignorant as their students, computer programs would have to be rewritten on a massive scale, and all the rest. Given inertia and familiarity with a given system of machinery, proponents of any improved system sometime face an uphill fight. QWERTY has triumphed, by the intersection of several odd facts no one considered important when they first came to light.

Similarly, both steam technology and direct current wiring and machinery became entrenched in many unforeseen facets of life for many years - much longer even than QWERTY has been in our world to date.⁴⁸ Many of the decisions that railroads other

⁴⁸ The layout seems baffling to modern sensibilities, but simultaneous key strikes were a major problem, until the IBM Selectric, and then the advent of digital word processing. The QWERTY layout originally rewarded a deliberate, plodding approach, a legacy of mechanical rather than digital machines. The layout of a stenographer's keyboard, by way of contrast, took into account ergonomic and linguistic factors (a legacy of Isaac Pitman's Shorthand) much better than did any Remington or IBM product. QWERTY is widely invoked as an example for various agendas and is an all but

than the Milwaukee made, such as adhering to steam much longer than was practicable, reflected the “QWERTY principle.”

Direct current enjoyed a number of similar advantages, in terms of technological inertia, over the alternating variety. Early on, the chief enemy of a practical direct current transmission system was distance. A metallic wire conducting either direct or alternating current has two physical properties germane to resistivity and conductance: its diameter and length. Simply put, the longer a given wire, the higher its resistance; the greater the diameter, the lower the resistance. Edison’s heralded accomplishment of a practical, mass produced lightbulb orbited around these two facts and finding an efficient, long burning filament was not only a matter of the much ballyhooed world-wide search for the right material, but the less glamorous search for a proper mixture of the filament’s diameter and length.

The Milwaukee’s problem was that the circuit in question was hundreds of miles long, rather than the inch-long filament Edison’s team had toiled over almost forty years earlier. Granted, the science and art of electrical engineering in general, and DC circuits in particular, had come a long way, and much larger systems of DC circuitry were then in use. Still, these were small compared to what the Milwaukee was attempting. Although most of the passenger trolley lines in the United States used DC, they differed a great deal, both in degree and kind, from what the Milwaukee eventually adopted. The distances passenger trolleys were less than a tenth of what the Milwaukee would have to

hackneyed theme in technological history. See Robert Pool, *Beyond Engineering: How Society Shapes Technology* (New York: Oxford Press, 1997), 159-161.

deal with, and although the interurban trolleys carried freight often enough, the loads were nothing in comparison to taking a 4,000 ton train over five mountain ranges. Most inter-urban trolleys ran on about 500 volts; no one in 1910 had contemplated utilizing higher “electrical pressures.” The Butte, Anaconda and Pacific Railroad (BAP) used 2400 volts DC, the highest voltage attempted up to that time and sorely needed in view of the “industrial strength” loads of ore that Butte shuttled up to the smelter. Incredibly, because of the problems that using steam engines 16 hours a day had imposed, the Anaconda Company even considered scrapping the rail system altogether, and installing a 26 mile-long *conveyor belt* from the mine to the smelters for all of the ore. This was a case of thinking big if there ever was one and an excellent example of a company’s willingness to explore every fixed cost cutting avenue even remotely plausible.⁴⁹ Completed in 1913, the BAP’s electrification (yet another concern and project in which John Ryan played an integral part) was of great use to the Milwaukee’s electrical engineers; it not only demonstrated that moving freight in such a manner was feasible, but also did much of the pioneering in the peculiarly restricted field of industrial electric traction.⁵⁰ The Milwaukee already had committed to electrification by the time the BAP was complete, but it nonetheless closely examined the day-to-day experiences and hard

⁴⁹Charles R. and Dorothy M. Wood, *Milwaukee Road West* (Seattle: Superior Publishing, 1972), 67.

⁵⁰Unique among the BAP’s operational practices was the use of a GE 40 ton Tractor Truck as a pusher unit in especially severe grades. It was pure motor unit on four wheels, with room for the motors bolted to the truck assembly, and nothing else. Ira. L Swett, *Montana Trolleys - II Butte, Anaconda, & Pacific, Interurbans Magazine* (South Gate, California, volume 26 Number 4, Winter 1969), 114.

earned lessons that had accrued from BAP's transition and applied them in the construction of their own electric line.

One key difference that the Milwaukee opted for was a mean operational voltage of 3000 volts, which would vary by two hundred volts either way depending on circumstances at a given moment. The Butte, Anaconda, and Pacific had opted for 2400 volts, largely owing to the fact that higher direct current voltages were unavailable at the time.⁵¹ Because length greatly increased resistance in a direct current circuit, a single trolley wire 432 miles in length that did not have an appreciable drop in voltage would have required such enormous girth that this option was impractical. Direct current trolley wires then in use (approximately one-half an inch in diameter) required substations to convert alternating current transmission line power at regular intervals, to keep the voltages up. The mean distance between substations was 32 miles.⁵² This, then, was the electrical system the Milwaukee installed in Montana in the early teens – and that endured, with slight modifications, for the next sixty-odd years. While undeniably advanced for its time, such a system was expensive and, more important, unproven on

⁵¹Charles V. Mutschler, *Wired for Success: The Butte, Anaconda & Pacific Railway, 1892-1985* (Pullman, Washington: Washington State University Press, 2002), is an exhaustive examination of the BAP's operations. The main difference between the BAP and the Milwaukee was obviously one of scale – the Milwaukee's electrification was well over ten times the length of the BAP's. The BAP also did not have locomotives with regenerative braking and relied instead on Westinghouse brakes. But the railroad and GE were close students of the BAP's fleet's performance, since it had been installed a scant three years earlier.

⁵²Holley, *The Milwaukee Electrics*, 4,166. Telegraph lines, the earliest type of practical long distance direct current motor, also had substations, in the form of battery boosters, to achieve the same effect.

such a scale.

Steam, on the other hand, reflected almost a century of constant and practical improvements in 1910. Steam locomotives were also relatively cheap to purchase when compared to the thousands of tons of copper for lines covering the vast distances, which meant in turn tens of millions of dollars for the AC Transmission, DC catenary, the substations, and most visibly, the radical new locomotives. Further, a large and skilled workforce, most likely somewhat suspicious and resentful of the proposed electrification, was already in place for steam technology as well. The steam engines were much admired, as were the engineers who operated them. Pre-World War II America considered both airplane pilots and locomotive engineers the astronauts of the age. Virtually everything about steam was familiar and charismatic. Why was such a proven, beloved source of power being replaced by such a drab newcomer? The following two chapters will explain, in depth, first the older technology, steam, and steam's up-and-coming competitor, electrical traction.

Chapter II. Blood from a Turnip – The Limits of Steam Power.

It is dramatic testimony to the inexorable power of live steam and the strength of iron and steel that the steam locomotive was ever a practical vehicle. The demands upon it were almost ludicrous. First of all, it was very heavy (although the traction which resulted thereby was what made the flanged wheel, running on the low friction rail, practical in the first place), and in addition to its own lumbering self, it had to carry all of the makings of its power – coal and water– on its back, so to speak. Its width was strictly limited by the woefully narrow gauge of four feet eight and one-half inches which George Stephenson had imposed on the industry, and its length was only somewhat less critical. (Until articulated locomotives came into use, length was rather strictly limited by curvature of the track.) Within the narrow space that was available a firebox had to be provided, the limited size of which necessitated all sorts of compromises with efficiency of fuel consumption, smoke pollution, and employee welfare in order to get the highest possible rate of combustion out of it. These limitations would have been serious in a stationary engine, but the steam locomotive had to perform all of its functions while propelling itself along at speeds of fifty or sixty miles an hour.⁵³

When it first contemplated transcontinental expansion, the Milwaukee had but one option to pursue, and the choice was a venerable technology over two hundred years old: steam power. In spite of its dominance at the turn of the century, steam technology was clearly starting to show its age. This show of age manifested itself in the form of a series of increasingly refined and ingenious improvements, while attaining less and less back in terms of performance as these improvements continued. There were other problems as well. Steam, for many applications in 1900, saw increasingly realistic challenges from internal combustion, and more important for the Milwaukee, electrical motors. It would be instructive to examine in some detail the evolution of this technology, seemingly still in its prime in 1900, because the story of late steam technology's improvements show how complicated and expensive this source of power had become by the time the

⁵³Martin, *Enterprise Denied*, 63-4.

Milwaukee opted for an electrical system for its Montana operations in the 1910s.

Matching engines or motors to loads has been one of the richer fields of study for the past five centuries.⁵⁴ In many ways, organic engines, such as a horse or a human, are unexcelled in flexibility and responsiveness, but the power output is very low, especially on grades. Organic engines have done very well in our species' 10,000 year journey. Only in the last two hundred of those years have we successfully made synthetic mules – thoroughly powerful, durable, flexible, relatively cheap to operate versus competing forms of locomotion, and anthropomorphically stubborn in the face of adversity. The heavier an animal, the worse the efficiency on any slope – one arena where artificial engines do very well. The “engine” of any load-hauling animal, whether a horse, ox, dog, elephant, or person, is for all intents and purposes a fuel cell. As far as modern medical science has been able to determine, these vehicles “burn” carbohydrates or fat in a non-combustible, chemical fashion, turning them into electrical energy (of a sort, the electromechanical nature of neuron and muscle interaction is well-documented) and possess a marvelous feedback control device for steering and sensible regulation of fuel

⁵⁴There are two basic approaches to designing an engine or motor specifically for a given task. In engineering the first is known rather prosaically as “systematic parameter variation,” (cut- and-try). The other philosophy is an emphasis on basic theory and calculation prior to construction. (Bayla Singer, “Engineering Successful Innovation,” from Launius (Ed), *Innovation and the Development of Flight*, 145. Both philosophies can be seen in the various GE locomotives in the Milwaukee’s fleet. The earlier models were constructed in a time when little was known about electrical theory. They were certainly equal to the task asked of them, but the massive overbuilding of the motors reflected the relative ignorance of GE’s engineers in the teens. The Little Joe class locomotives were engineered to much finer tolerances after the Second World War because of advances in electrical theory.

consumption, courtesy of a mammalian nervous system.⁵⁵

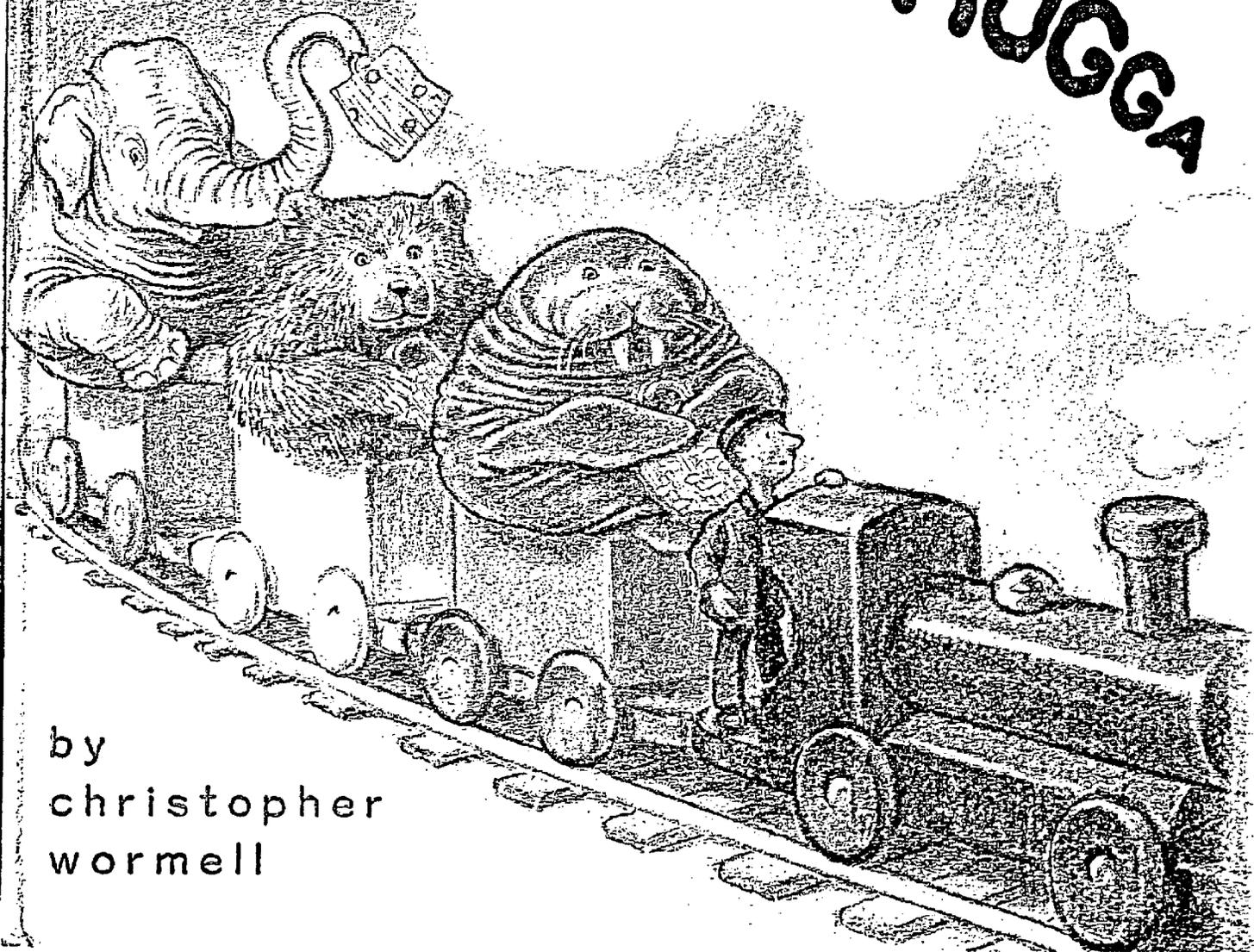
Even though humans, mules, and dogs are renowned for their toughness and endurance as cargo carriers, mammalian engines have their limits. However grossly inefficient, the first true steam engine, the Newcomen, was a large improvement over horse or man-turned pumps. The English mine owners did not choose Newcomen's engine out of a sense of progressive duty, or out of scientific or technological daring. They did so because it was ultimately profitable to do so. The board of the Milwaukee was governed by similar considerations.

Machinery is, rightly or wrongly, often maligned in this day and age, but there are few machines that mankind has contrived more evocative and possessing a quaintly human quality as a steam locomotive. Whenever a schoolchild is asked to draw a train locomotive, or to picture one in mind's eye, the invariable result is a choo-choo train, also known as a steam locomotive. Indeed, the anthropomorphizing of the steam locomotive was a commonplace in children's books of the last century, and still is a creative mainstay today.⁵⁶ (See Plate I, page 42).

⁵⁵Steven Vogel, *Prime Mover, a Natural History of Muscle* (New York: W. W. Norton and Company, 2001), 214-218. Vogel combines physiological analysis, physics and historical record in a very engaging fashion. There are many insights in this work regarding artificial engines, viewed in a biomechanical context, as well. In but one variation, modern fuel cells utilize the electrical charge that results from combining hydrogen and oxygen into water.

⁵⁶A more recent example is Christopher Wormell, *Puff Puff Chugga Chugga* (New York: Margaret K. McElderry Books, 2000), title page. Steamers simply had some intangible quality that inspired affection. One possible explanation is the sound of the steam engine's cycle under strain, which bears a remarkable similarity to the labored breath of a beast of burden's toil. Diesel and trolley electric locomotives were positively boring in their efficiency, and more modern locomotives offered none of steam's charm.

PUFF-PUFF, CHUGGA-CHUGGA



by
christopher
wormell

Plate I: While technically obsolete, the reciprocating steam locomotive still endures in the popular imagination. The very imperfections of steam technology make it appear more human. Christopher Wormell, *Puff Puff Chugga Chugga* (New York: Margaret K. McElderry Books, 2000), cover.

Most of the electric locomotives used by the Milwaukee Road, or modern diesel electric units for that matter, looked drab and utilitarian, even sterile, by comparison. The boxy features of most electrics stood in direct contrast to the circular qualities of the steam engine's boiler. The steam engine's circularity resulted not from aesthetic sensibility, but necessity. With the manufacturing techniques of the seventeenth, eighteenth, and nineteenth centuries, it was far easier to fabricate air and water-tight components, whether it was a barrel or a cylinder (both crucial for the efficient operation of a steam engine) with circular rather than linear and right angle patterns. The strength to weight ratio was higher, but this was only one factor; lathe work, both the boring and finishing of parts, was fundamentally circular.⁵⁷

It was far easier, in terms of body design, to weld or fasten with bolts or rivets sections of sheet steel perpendicularly than to use steam components which used airtight, circular designs. The main part of the body of a steamer was the huge circular boiler, necessarily made of high grade steel to withstand the tremendous steam pressures that a locomotive's pistons required. The outer boiler tube, which gave a steamer its unmistakable silhouette, was usually a one piece steel casting, up to 70 feet in length. An electrical locomotive's exterior, however, was little more than a roof of 1/4 inch sheet steel; adequate shelter to keep the crews and machinery dry, but something that did not require high-skill machining. The boxy shapes of the electrics were only one possibility.

⁵⁷Early steam pioneer James Watt recognized that true precision in cylinders – an increasingly vital factor – was available only through boring. Consequently, he contracted much of his later work out to John Wilkinson, the world's leading precision machinist at the time. Keith J. Laidler, *To Light Such a Candle: Chapters in the History of Science and Technology* (Oxford: Oxford University Press, 1998), 23.

Perhaps the most famous of the Milwaukee's electrical freight locomotives was not surprisingly its most aesthetically pleasing, the Bipolar. Among other distinguishing features of the Bipolar was its striking lines, which resembled a conventional steam locomotive far more closely than the other electrical types the railroad utilized. But the rounded front end of the Bipolar had nothing to do with the locomotive's performance. A square shape would have sufficed as it had in past designs; General Electric opted for something more classic in appearance – a good example of cosmetic atavism. Classic, circularly shaped designs were far better for boilers. Thus, most electrics looked unquestionably modern to the sensibilities of the average American in 1915. In all probability they also looked alarmingly alien when compared to the comfortable old steam engines.

The new motors did their work, hidden and conveying their mysterious force with “...no grinding, no jerking, no puffing, no pulling, no straining, no disturbed slumbers – just a keen sense of moving swiftly, of being propelled by power vastly in excess of requirements. You ride with ease – it is the very last word in transportation.”⁵⁸ This enthusiastic endorsement was putatively attributed to Thomas Edison, who toured the Milwaukee's facilities circa 1920, presumably in an orgy of mutual admiration, and the language bears the facile and breezy stamp of a Milwaukee Road or General Electric public relations flack, rather than that of the blunt, coarse, and often profane Edison. But the image is similar, if less articulately expressed, to the smooth, compact, and “occult”

⁵⁸William D. Middleton, *When the Steam Railroads Electrified* (Seattle: Kalmbach Publishing, 1974), 237.

power of Henry Adams's dynamo. The power of electricity and its attendant magnetic fields confounded educated observers unable to use the by-now familiar and intuitive concepts of Newtonian mechanics. Even an ecumenical observer as perceptive as Henry Adams (a self-admitted ignoramus when it came to practical matters) was unable to wrap his brain around the new physics. Adam's analysis of the new forces in nature, circa 1900 – the atom, the X-ray, and electromagnetic force – were strongly informed by religious language. That so blase an observer could be so awed should tell us something. Adams stated that the seven year gap between expositions he analyzed had elicited quantum advances in scientific progress.⁵⁹ Steam was like a comfortable, well-worn shoe when compared to electricity.

Considerable effort and nineteenth-century craftsmanship went into the design and construction of steam locomotives. With a technology as entrenched as the basic Stephenson layout, which dominated locomotive design for over 130 years, locomotive designers went to considerable lengths to wring additional performance and efficiency from steam plants. The Stephenson layout – horizontal cylinders, and a horizontal boiler – combined powerful traction and components that could be mass produced whenever possible. It had its limits, however.⁶⁰

The only alternatives to the Stephenson template that had been attempted in the

⁵⁹Henry Adams, *The Education of Henry Adams* (New York: Random House, 1931), 279-290.

⁶⁰Martin, *Enterprise Denied*, 62-64. One of Martin's key points in this work was that the railroads were stymied technologically as well as financially in the pre-World War II era.

previous century were bizarre indeed. The first was an “atmospheric” form of locomotion, which took its inspiration from the earliest steam technology, Newcommen and Watt engines. The earliest steam engines derived their power stroke from atmospheric pressure rather than steam acting on the piston. Watt and Newcommen engines were very low pressure affairs, and the twelve pounds per square inch pressure of the atmosphere did the heavy lifting. Steam was simply a cheaper means (rather than horses or oxen) of raising the piston in preparation for the power stroke. The breakthrough in applying this prime mover to moving freight required high-pressure steam acting on both sides of the piston.

The sole “atmospheric” railroad of any consequence was a short line operation in Ireland during the mid-nineteenth century. Air pumps (running off of stationary steam engines placed at intervals) evacuated the air from a tube positioned underneath the rails, and a piston attached to the locomotive was literally sucked from one pump station to the next (an interesting parallel to the DC substation scheme employed by the Milwaukee) and a colossally-scaled forerunner of the pneumatic “message tubes” employed by department stores and drive-through banks in the twentieth century. While an elegant and promising concept in principle, the plan failed because of constant problems with creating airtight seals in the running tube. The oiled leather used as gasket material was never equal to the task asked of it, and vulcanized rubber, let alone plastics, remained the stuff of science fiction at the time. The system also had practical upper limits to its size -- power of the atmospheric locomotive was directly proportional to the surface area of its piston, and while no figures exist, the train this system pulled was a featherweight in

relative terms compared to a 4000 ton North American “freight.”⁶¹ The future of locomotion obviously belonged to high pressure steam.

Although steam machinery in general had proved itself over three centuries of constant improvement, there were inevitable operational headaches attendant to using steam for locomotives. Although the steam locomotive underwent undoubted improvements in its 150 year history, the basic Stephenson layout remained the fundamental template of design, and improvements were small scale, along the lines of improved metallurgy (which led to higher boiler pressures), simplified valve design, and an increasing knowledge of steam’s physical properties (which led to superheating and compounding). All were marked improvements, to be sure, but none was fundamental in nature.

Of the virtually infinite number of modifications for the steam locomotive power plant in the twentieth century, there were essentially only two design modifications of a truly radical nature, and these applied to opposite ends of the performance spectrum: very heavy loads over steep grades at low speeds, and light passenger loads over flat grades at high speeds. For low speeds and heavy loads, the railroads opted for Ephraim Shay’s vertically bored, power-gear drive shaft “Slo-go” engines, but only under circumstances where steep grades, tight turns, bad track, low traffic, and heavy loads made conventional locomotives useless.⁶² In the United States, this meant service hauling

⁶¹For a fuller description of the atmospheric railroad, see George Basalla, *The Evolution of Technology*, (Cambridge: Cambridge University Press; 1988), 177-181.

⁶²James E. Benton, *4-10-2 -Three Barrels of Steam: A Complete Collector’s File of the Only Three Cylinder 4-10-2 Locomotive Built for Service in the U. S. A.* (Felton,

ore or more often timber. The output shaft spun rather than reciprocated, and drove the wheels through a bevel gear. The design sacrificed speed for traction, and the engines could handle grades that would have been impossible for a conventional design to surmount – up to 10% – shy of a cogged track, an impossible grade for an ordinary Stephenson-type vehicle.⁶³ (see Plate II, page 49).

The other major departure from conventional steam design was the application of the steam turbine, which had achieved great success in maritime applications. Eventually, however, a land-vehicle turbine engine proved itself even more of a curiosity than the geared locomotives. The typical steam turbine turned with speeds in the neighborhood of 40,000 rpm; even at the lowest speeds this meant employing reduction gears of very high ratios to convert the turbine's speed to usable torque. At low speeds, which trains of any weight invariably encountered when starting from a standstill, the turbine could move the load, although it consumed fuel voraciously. The turbine was therefore only efficiently suited to express passenger runs on flat terrain, such as the Midwestern prairies or the Eastern Seaboard. Only wealthier eastern railroads, such as the Pennsylvania, could afford to experiment with turbine locomotives in passenger service; the Milwaukee never acquired one. (See Plate II, page 49). Other railroads also attempted gas-powered turbines, similar to most modern helicopter engines. For all intents and purposes, this consisted of a very large version of a helicopter's gas-turbine engine

California: Greenwood Publishers, 1973), 2.

⁶³Brian Solomon, *American Steam Locomotive* (Osceola, Wisconsin: MBI Publishing, 1998), 109.

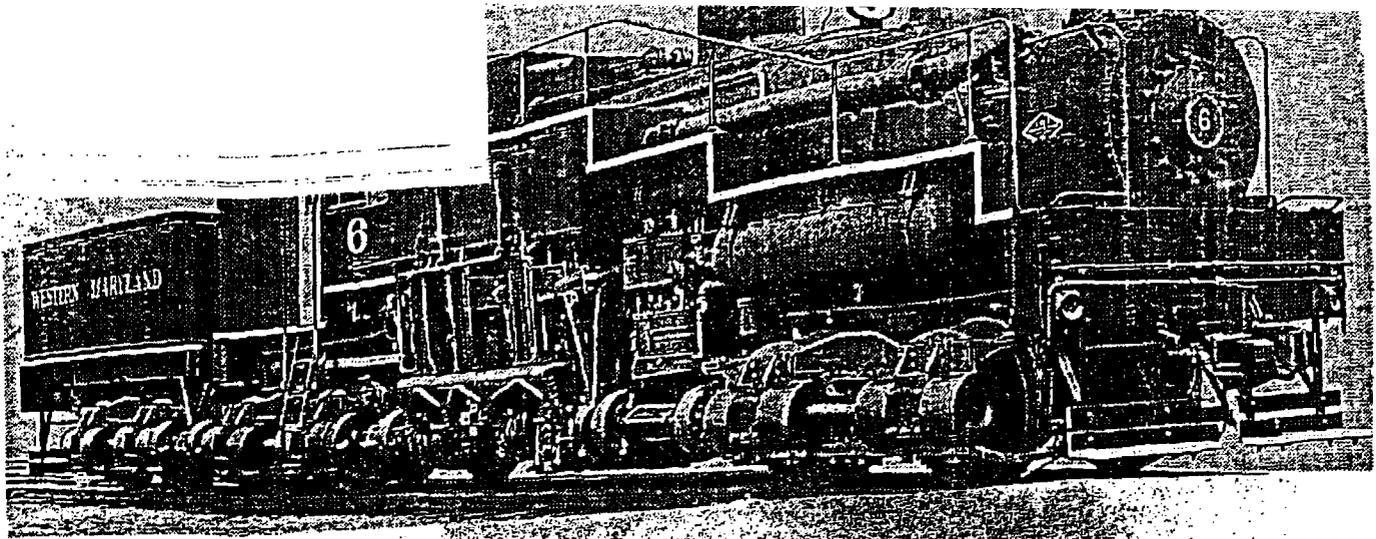


Plate II: The "Tortoise and the Hare": Late Steam Approaches to Improving Steam's Performance

Above: A 1945 Shay geared locomotive, using vertical cylinders. This design was slow, but provided a great deal of traction and could negotiate very tight turns. This type was used primarily for hauling timber on severe grades. Though the Milwaukee used several types of steamers, it never acquired a Shay.

Below: This 1944 Baldwin turbine locomotive, designed for the Penn, essentially took the opposite approach. Designers applied a steam turbine to power the four linked driving wheels. While a promising concept, the design consumed a wasteful amount of fuel and lacked power at low speeds. The only terrain suited for this type of locomotive for the Milwaukee was east of Harlowtown, and such a financially strapped corporation could not afford to invest in an untried and expensive concept.

harnessed to drive the direct current drivers on a land vehicle weighing 5000 tons --not a particularly promising concept. The design took every bad feature of land-based turbines and aggravated the situation with more heat, noise, and all-around inconvenience.⁶⁴

In the setting of a stationary power plant, five to six times the energy can be squeezed from a portion of coal with turbine technology in the form of electricity as it can from burning the same amount in a typical steam locomotive.⁶⁵ In light of this fact, GE locomotive designers attempted to mate both steam and gas turbines to mobile generators, with mixed results. It is no mystery why this particular mode of traction lost out to diesels. Some historians cite the fact that this particular type of power plant made its debut during the Second World War, when experimenting with fundamental design changes in any endeavor was not particularly fruitful ground, since proven designs held much more appeal than risky, experimental ones.⁶⁶ Unless the potential payoff was spectacular (for example, the devastating fruits of the Manhattan Project), why bother with experimentation in time of war? More importantly, diesels, reciprocation aside, were unbelievably robust and reliable prime movers. Turbines, with their high speeds and relatively delicate compressor fan blades could mean trouble, and tougher blades owing to metallurgical improvements remained something for the future.

Ultimately, the atmospheric railroad, turbine, and vertically bored engines were

⁶⁴Interview with civil engineer and rail buff Rich Mispion, December 12, 2002.

⁶⁵W. A. Tuplin, *The Steam Locomotive* (New York: Charles Scribner's Sons, 1971), 127.

⁶⁶Solomon, *American Steam Locomotive*, 140-41.

rather freakish exceptions to the Stephenson Layout's primacy in an era spanning 130 years, and the overall trend consisted of a series of incremental improvements on existing steam technology. These improvements (some of which took; some of which did not) included streamlining, superheating, altering the boiler fuel, compounding, using ball bearings, and converting from reciprocating to rotary engines. The Milwaukee's steam fleet in Montana employed at least some of these innovations. Each of these incremental changes will be examined in turn, because such attempts show clearly how desperate steam locomotive designers were to get increased performance out of a technology that had run its course.

Streamlining

Streamlining consisted of applying a smooth cowling to the otherwise irregular surface of a heavily riveted locomotive. Aimed at extracting increased performance, it produced negligible "efficiencies." Nevertheless, streamlining remained a popular technique, again because human considerations outweighed purely technical ones. A streamlined locomotive, simply put, looked good. Form supposedly followed function, but here form ultimately existed for its own sake. Even in the years of steam's decline, the rail lines that could afford to do so made major considerations for a locomotive that had attractive lines, at least when it came to carrying passengers, and in a practical sense, this usually meant streamlining, or a distinctive paint job, or both. The image of the streamlined locomotive, and streamlining in general, was an artistic mainstay by the 1930s as well as an avatar of industrial power and progress. Everywhere one looked, the

steam engine, for all its frailties in the hard-nosed world of commerce, refused to die, at least as an icon in the world's collective imagination, from the Little Engine That Could to Superman's proverbial strength – more powerful than a locomotive. The heyday of streamlining occurred in the 1920s and 1930s, and the result was a succession of elegant and beautiful machines that still have a grip on the popular imagination.

The state of the art of aerodynamics in the 1920s and 1930s was primitive by today's standards, where the pertinent variables are crunched through supercomputers. Even in the twenties it was widely known that streamlining a locomotive had more to do with its cosmetic enhancement and greater public relations than its performance.⁶⁷ Two factors were at play here. The first is the fact that for streamlining to have any real effect, the entire train, not the locomotive alone, would have to have been streamlined, from front to back, with some sort of cowling to be installed and removed at the appropriate time – not a particularly efficient, safe, or convenient ritual for either the passengers, engineers, brakemen, or conductors. Consequently, longer, heavier, more frequently separated freight trains were an even more unsuitable candidate for streamlining. Streamlining's lack of efficiency for freight and ordinary passenger trains was evidenced by the fact that rail lines streamlined only “flagship” or “glamor” (in other words, express passenger)

⁶⁷ Interestingly, the cowling of the first streamlined locomotives was actually riveted, giving it an “unfinished and clumsy look.” Designer Raymond Loewy, whose work defined the essence of streamlining in the 30's, suggested welding the cowl for a more seamless appearance. Loewy designed everything from toasters and trash cans (his first commission from the Pennsylvania Railroad) to heavy industrial plant such as locomotives. For a more detailed account of streamlining and Loewy's role, see Henry Petroski, *The Evolution of Useful Things* (New York: Alfred A. Knopf, 1993), 168-9.

locomotives and trains more or less *in toto*.⁶⁸ If it had cut costs appreciably, freight locomotives, and just as important, the freight cars, would have been streamlined as well, on every major rail line, and they were not.

More important, even if ideal streamlining could be effected, if one examines what happens to projectiles of various sizes moving at a speed of 56 miles per hour, it becomes quickly apparent that smaller projectiles at this speed suffer far more from drag than larger ones (such as a 3000 ton train with a frontal diameter of four and a half feet). The data in the table below only goes to 200 millimeters (about eight inches), but one does not have to be an aerodynamic genius to discern a trend:

⁶⁸W. A. Tuplin, *The Steam Locomotive* (New York: Charles Scribner's Sons, 1971), 141.

Table I: “Drag Tax” for Round Object at 56 Miles per Hour

Diameter of Stone Ball at 56 Miles per Hour	Drag Tax ⁶⁹
.20 mm	97.6%
.63 mm	90.8%
2 mm	73.1%
6.3 mm	48.4%
20 mm	26.3%
63 mm	9.8%
200 mm	1.3%

In spite of the restrictions imposed by this “drag tax,” with simple body design modifications, even a 750,000 pound machine appeared fleet and graceful, whether moving at 80 miles per hour or standing still. Streamlined or not, the harmony of hundreds of steel parts that intermeshed at dizzying speed, seamlessly, and almost hypnotically, was part of steam’s allure as well. Streamlining recently still has an almost achingly nostalgic effect, one that extends even to our own times (as evidenced by a current advertisement of the indisputably savvy marketing department of Daimler-Chrysler; see Plate III, page 55).

⁶⁹For an explanation of the math used in deriving the drag tax, see Steven Vogel, *Prime Mover, a Natural History of Muscle*. Pp. 272-73. Quite frankly I have no idea why the seemingly arbitrary figure of 56 mph (presumably the integer aided with Vogel’s calculations) is used, but this is happily right on par with near the practical average maximum speed a freight train would achieve in the Rockies.



Plate III: Madison Avenue remains fully aware of the visceral appeal of late steam technology. Above, a Daimler-Chrysler ad, rather overstating the capabilities of one of its products, from a 2002 edition of *The Atlantic Monthly*.

Superheating

Yet another attempt to squeeze more horsepower out of a Stephenson-layout engine was superheating. Unlike streamlining, superheating had everything to do with performance and left the power plant's exterior unchanged to all but the most expert observers. In superheating, designers were responding to the heavier, more infrequent traffic of the twentieth century's first two decades. The Milwaukee was particularly prone to feel financial pain from this trend. Agricultural traffic was especially depressed in the twenties; the Great Depression actually began about ten years earlier in the agricultural sector. Railroads looked into any avenue that cut costs, and one possible solution to this situation was fewer, but larger and more powerful, locomotives. The answer to this trend was a series of modernizations in steam engines, among them superheating. The practice was a series of incremental changes, rather than a radical one, such as the abortive application of turbines to heavy motive power on land. Specifically, the process of superheating heated steam issuing from the boiler without raising its pressure to avoid recondensation of the steam.⁷⁰ Engines thus achieved increased fuel economies and genuine increases in power. Most of the huge "simple" locomotives of the 1930s and 1940s (such as Union Pacific's *Bigboy*) were superheated.

Ball Bearings

Installing roller bearings was another example of incremental improvement: "In

⁷⁰ W. A. Tuplin, *The Steam Locomotive* (New York: Charles Scribner's Sons, 1974), 43-44.

the last days of steam (1930-1950), the Norfolk and Western Railway Company's Mechanical Department described a modern locomotive as one designed with a high capacity boiler, equipped with roller bearings on all engine and tender wheels, constructed with integrally cast steel frame and cylinders, utilizing improved counterbalancing techniques and possessing complete mechanical and pressure lubrication systems."⁷¹ Most railroads would have agreed with the Norfolk's assessment of ball bearings as a vital component for any competitively equipped piece of plant. Simply put, ball bearings reduced friction on the axles and made the locomotive easier to move. This simple but effective measure reduced maintenance and fuel consumption.

Altering Fuel

One area that seemed potentially fruitful was finding a material with more potential thermal energy than coal or wood, the long- dominant boiler fuels. Could improvements be made by selecting a fundamentally different type of product for burning? The layman would quite rightly think that changing the nature of a prime mover's fuel (however slightly) would do little to improve performance in the reciprocating steam engines of the turn of the century. From an engineering standpoint, however, even minor altering of engine fuel has paid off handsomely in many cases. For example, take the improvement in aviation gasoline between the First and Second World Wars. The Wright "Cyclone" engine, conceived in the late 1920's (and the powerplant for

⁷¹Robert L. Frey and Lorenz P. Schenk, *Northern Pacific Supersteam Era: 1925-1945*(San Marino: Golden West Books, 2000), 78. See also Solomon, *American Steam Locomotive*, 93. A favorite publicity stunt of Baldwin's was to have three harnessed women pull a bearing equipped engine weighing hundreds of tons from a standstill.

the famed B-29 Bomber) enjoyed eye-opening improvements in performance, almost solely based on the quality of the fuel:

Table II: Octane Content in Gasoline and Its Effect on Aviation Engine

Performance, 1929-1939 ⁷²

Year	Horsepower	Fuel Consumption (Lbs fuel/hp/hr)	Octane
1929	535	0.5	73
1930	580	0.5	80
1931	600	0.5	80
1932	650	0.5	87
1933	700	0.48	87
1934	780	0.46	87
1935	820	0.46	87
1936	1,000	0.44	87
1937	1,100	0.43	92
1938	1,150	0.41	92
1939	1,200	0.40	100

In this particular case, improved fuel more than doubled horsepower of the existing engines, while the engine's fuel consumption actually declined. While the payoffs were not usually as spectacular in the world of steam train locomotion, the advantages of a hotter burning, more compact fuel were obvious; therefore, the seemingly

⁷²Stephen L. McFarland, "Higher, Faster, Farther: Fueling the Aeronautical Revolution," from Launius (Ed.), *Innovation and the Development of Flight*, 114-15.

banal subject of boiler fuel became a matter of keen interest to anyone involved in railroading (or transportation and industry in general, for that matter). Through the course of the nineteenth century, much more became known about the various burning properties and efficiencies of wood, coke, all types of coals, and oil.

In the beginning, there was wood, or alternatively, coal. Although brutal, a nineteenth century fireman's job sounded deceptively straightforward. He shoveled coal into a locomotive firebox over a ten to twelve hour period. The job was not as uncomplicated as it sounds, however. In every other engine application, the fireman's job had been replaced by the fuel pump. In early twentieth century railroading, human labor was being replaced gradually, if not quite for purely humanitarian reasons. Mechanized fuel feeders picked up where human endurance gave out, and the proof of the upper limits of human performance can be found in the labor rules regarding the maximum size of firing grates to be tended to by firemen. After World War I, the federal government followed suit, mandating that any locomotive in excess of 240,000 pounds or having a fire grate of more than 70 square feet required a mechanical stoker, which for all intents and purposes was an Archimedes screw (a single helix enclosed in a cylinder, rotated on a lengthwise axis, used to lift both liquids and solids) pulling coal out of the tender.⁷³ The fireman's position also represented the last rung on a railroad's corporate ladder just below the rank of engineer.

The job taxed both body and mind. Not only was there the back breaking work of

⁷³William L. Withuhn,(ed.), *Rails Across America* (New York: Smithmark Publishers, 1993), 76. The Archimedes screw is arguably one of the most elegant (and widely used) devices contrived by this brilliant Greek (287-212 BC).

shoveling literally two-and-a-half tons of coal per hour over a ten hour shift; a fireman also had to be sure that he covered the grate evenly with coal and that the proper dampers and flues were suitably opened or shut. In addition, the fireman had to anticipate virtually every move that an (anecdotally obstreperous) engineer made. Failure to perform any one of the facets of his job properly meant trouble, and could jeopardize a fireman's always tenuous position. "Trouble" meant everything from a ruined firebox to failing to maintain an adequate head of steam and falling behind schedule. Many a fireman was physically broken by the time he could even be considered for an engineer's position.

Firemen as a group had a singular love-hate relationship with their "betters." There was something indefinably prissy and revolting, from the fireman's viewpoint, about engineers as a class. The stereotypical engineer came to work nattily dressed, and was more than willing to lord it over a fireman, yard crew, or anyone else he considered beneath him, which, according to other railroad employees, was anyone not on the Board of Directors. Indeed, most of the nineteenth and twentieth century railroads operated, and in some cases ossified, under a quasi-caste system. Firemen often envied engineers' pay rating and accompanying status (often rightfully earned) and relations between the two groups of men could be quite strained.

An historiographical aside: rail buff literature makes much of this relationship, and while the sentiment conveyed in many accounts undoubtedly reflected the experience of anyone who ever worked under a demanding or capricious engineer, the analysis of this management/operator tension is often obscured by a combination of overwrought prose and reverse snobbery. As one engineer recalled: "It was a caste system, pure and

simple. Once a fireman was exposed as an evolutionary throwback, of Neanderthal blood, and lacking of Anglo-Saxon credentials, how could he be entrusted with our grandest machines? What fraternal order would permit a missing link into its gentlemanly ranks? Which enlightened management could allow its corporate image to suffer by permitting beasts to doff the cap to ladies and children from the exalted cab of the steam engine”⁷⁴

⁷⁴Dennis Boyer, *Prairie Whistles: Tales of Midwest Railroading* (Black Earth, Wisconsin: Trails books, 2001), 16-17. Railroad buffs have even given their province of study a tailor-made name: Railroadiana. Like buffs in other fields, railfans concentrate on fact (significant or otherwise) for its own sake. They leave specialized analyses to the academics and general syntheses to pop historians. There are plenty of facts for buffs to seize on; they ruminate on everything from a locomotive’s horsepower to its assigned number, point schemes, and blow-by-blow descriptions of routes covering hundreds of miles. Buffs commit these facts, and others even more arcane, to memory. There are many outlets for the buff’s enthusiasm, from statistical sheets on locomotive performance, to collecting Lionel Trains (Direct Current, ironically enough). The quality of the writing by buffs varies. Some is quite well done; some is self-important, officious, breathless, obsessed with niggling details, and practically unreadable. John “Mr. Choo Choo” Elliot writes: “No one can write with authority on the history of railroading without making a pilgrimage to Old E 57 N (a GE EF-1 on display in Harlowtown)... so I say all you young squirts out there who are dreaming dreams and seeing visions about the great tomes you are to contribute to railroadiana, unless you can say you’ve made a visit to old E 57 B you are sounding an ‘uncertain’ trumpet.” Ploss, *The Nation Pays Again*, vii. The suggestion that no one knows anything about railroads at all unless he has visited Harlowtown, Montana (the author of this thesis, incidentally, has) speaks for itself.

Buff literature is also usually well-infused with a heavy dose of Norman Rockwell, making no pretense of objectivity. Brian W. Dippie’s wry essay on the conflict between buffs and academics over the dearly held subject of Custer’s Last Stand (“Of Bullets, Blunders, and Custer Buffs”) neatly encapsulates the issue. See Swartout and Fritz (eds.), *The Montana Heritage: An Anthology of Historical Essays* (Helena, Montana: Montana Historical Society Press, 1992), 275-85. Most of the buff writing on electric traction deals with the interurban lines of the east and Midwest, in part because electricity makes much more sense in high traffic, short-distance situations. Some electrical interurbans, such as Princeton University’s New Jersey Transit Branch, less officially known as the “Dinky,” have achieved a certain degree of bizarre esoteric fame. See Lawrence Biemiller, “Where the Only Station Stop Is Princeton,” *Chronicle of Higher Education*, 16 May, 2003, 48(A).

The historian who dismisses buff literature out of hand and scornfully ignores it loses a great deal of potentially useful information, since railfans are often former

Although many firemen did attain the rank of engineer, firemen were as a rule implacably hostile to engineers, and engineers warmly reciprocated the feeling. The tension between the two classes of laborers reflected the brutally difficult nature of the fireman's job, and the grimness of his usual prospects in the company. Throughout steam's two-century run, coal had become something more than simply a fuel. It was partially responsible for a relationship between two similar but separate castes of men, engineers and firemen. It would be another hydrocarbon, oil, that would challenge coal's primacy as a fuel system in the late steam era.

Oil fired steamers, heavily utilized by the Milwaukee Road, obviated many of the problems attendant to firing with coal. The only major design changes dictated by firing oil were in the firebox, which had to be reconfigured substantially. The fuel in question, "bunker" oil, was the residue left over from early twentieth century refining processes, after gasoline, kerosene, and the various grades of diesel had been fractionated off. Bunker oil was roughly the consistency and viscosity of modern asphalt and burned more efficiently than even anthracite coal. It did not catch fire easily, but when lit, bunker oil burned ferociously hot - hot enough to melt the iron in a coal fire grate in very short

employees. Dismissing first hand accounts, however clouded by time or influenced by personal experience, is bad historical practice. Bill Wilkerson's work was especially helpful for research purposes, and can generally be considered a primary source. This is not to say that many railroad buffs are not ridiculously territorial about their epistemological fiefdoms, and evince an almost perverse distrust of academics in general. Anyone who wholeheartedly believes everything he reads in "Railrodiana" literature needs to hone his skepticism.

order, hence the hasty adaptation of a modified fire box.⁷⁵

This modification was substantial, since oil was obviously a fundamentally different material from coal, so modifications had to be made owing to factors other than a high burning temperature. Very viscous at normal temperatures, it could not be fed through pipes under pressure. To make it flow, the fuel had to be heated to a 125 degrees; to burn it had to be at about 190 degrees. The oil had to be heated in its tender to just under 200 degrees, and was pumped under pressure into the firebox where it was atomized and sprayed against a (theoretically) red-hot brick that lined the firebox. Oil firing was more popular with individual firemen, for obvious reasons. It eliminated much of the previous toil of their job.⁷⁶

Some employees, however, viewed the shift to oil with less enthusiasm, seeing it as a threat to job security. Oil firing, by the very nature of its labor-saving tendencies, tended to eliminate the need for additional personnel, especially cleaning and maintenance personnel. The added weight of another extra body was not a significant factor in the immediate performance of the engine, but the added expense of one more soul on the payroll, cutting into the bottom line of the stockholder certainly was. Since oil was for a number of sensible reasons cheaper in the long run than coal, the railroads eagerly utilized it where they could. The move, like all other pursuits of increased

⁷⁵In terms of thermal potential, Bunker C produces 12% more heat per gallon than diesel fuel. (In other words, very hot indeed). “You burned a whitish orange flame and it was so bright you needed sunglasses to look at it. You could get instant heat with oil, much faster than coal,” according to Ralph Danley, fireman for the Milwaukee in the late 1940s. Holley, *The Milwaukee Electrics*, 175.

⁷⁶Holley, *The Milwaukee Electrics*, 172-77, 255.

efficiencies, came with a cost. Because machinery replaced skilled men, it made jobs more scarce, enhanced the caste nature and nepotism of a given line, embittered the unemployed and unwilling, and made the railroads a popular target for scorn in the editorial pages of the regional newspapers. The Milwaukee Road was no exception.

Whether firing coal or oil, an engineer could make life pretty miserable for a fireman if the engineer wanted. A potentially capricious engineer's every move still had to be anticipated. Especially with steam, there were so many variables involved in running the locomotive that it took the constant vigilance of two very competent men to avert risk to life, limb and property. Firing a coal locomotive was brutal work, but demanded a level of concentration that was anything but brutish. Coal could not be indiscriminately dumped on the fire grate; it had to be spread evenly, with a keen appreciation for that particular engine's (and engineer's) idiosyncracies. In fact, so demanding was this task that eventually the Railworkers' Union implemented a rule about Archimedes screw-based automatic stokers for any grate over seventy square feet, mentioned above. Later, "firing oil," even in the age of mechanical stokers, was no idle job. Obviously oil burning locomotives required men who had aptitude for boilers of whatever size, and practical experience with plumbing and pipefitting was certainly no handicap.

The Milwaukee was not the only railroad that took to oil. It provided significant efficiencies in fueling costs, and its supplies, straight from one of the legacy companies of Standard Oil, were seldom, if ever, threatened by labor disputes. The now legendary labor strife, such as Matewon, that surrounded North American coal mining and distribution in

the early twentieth century weighed heavily in many major railway's decision to opt at least partially for oil. Oil firing was one more attempt to wring every last efficiency out of a retrospectively dying technology and solve two problems, fuel costs and labor, with one change -- this time by altering the fuel. Again, the railroads made a decision based on human factors other than purely scientific ones.

Whichever fuel chosen by the Milwaukee, both had a common flaw: smoke in tunnels. The other transcontinental lines by and large decided to continue using oil and coal based steam as long as it was practical and profitable to do so. Only the Northern Pacific electrified lines, and then only in the direst of circumstances. This usually occurred where the combination of coal and oil fired steam locomotives (billowing clouds of blinding and toxic smoke) with lengthy mountain tunnels posed a nuisance to paying passengers, and, more important, a threat to the lives of employees. A series of deadly tunnel accidents in 19th century urban areas led to public outcry and subsequent legislation mandating the replacement of steam engines with electric or cable trolleys.⁷⁷ Most tunnels in the Rockies and Cascades for all of the transcontinental lines were very long and poorly ventilated. The Great Northern's Cascade Tunnel was especially lengthy

⁷⁷Cablecars represented serious competition, in the form of the "motor" concept, to early electrical power in high-traffic urban areas. The system consists of two stationary steam engines pulling an endless steel cable loop, generally about an inch in diameter. The cable cars used a sophisticated arrangement of pulleys, clamps and braking devices resulting in an elegant, and very expensive, form of light transportation that could handle severe grades (San Francisco comes most readily to mind). Electrical traction had most of the benefits of cable traction and cut fixed cost and maintenance expenses. Cable installation and maintenance was a major flaw in the cablecar system -- competently splicing damaged cable was a colossal job and major labor expense requiring round-the-clock service by crews of two skilled and two semiskilled men each. See George W. Hilton, *The Cablecar in America* (Berkeley: Howell-North Books, 1971), 77-79.

and dangerous, and the railroad once attempted to solve the problem by a bizarre modification of the smokestack on at least one of its engines.⁷⁸ (See Plate IV, page 67).

Later, interestingly, the Great Northern attempted to solve this problem with an alternating current system, with the 11,000 Volt, 25 Hertz current being transformed to direct current via a motor generator set on board the locomotive. This provided a good example of the myriad of viable design possibilities that electrification offered. The result was a locomotive significantly longer and heavier than the Milwaukee's largest class of electric locomotive, the Little Joe, and in fact the Great Northern's was one of the largest electric locomotives ever built.

In terms of steam engines fouling tunnels, or starting forest fires, there was little that could be done. The tunnels had to be shortened, cleaner fuel obtained, or massive ventilation systems installed, all anathema to management. Such solutions were *ad hoc* and ultimately unsatisfactory. The problem was a fundamental one; a different prime mover had to be used in tunnels, or tunnels would have to be altogether eschewed in future plans. Since the Milwaukee's route had 44 tunnels, the longest of which was some 8,800 feet, this posed a potentially significant problem.

Compounding and Articulation - The Mallet

Compounding was somewhat similar to superheating, in that it utilized increased scientific knowledge of steam's physical and thermal properties in the late nineteenth and

⁷⁸Abdill, George B Abdill, *This Was Railroading* (Seattle: Superior Publishing Company, 1958), 136. Prodigious smoke from steam engines in lengthy tunnels could suffocate a crew and passengers, blind the engineer to potential dangers, and at the least was a loud, hot, and accident-prone experience for everyone involved.



Plate IV: A Great Northern Railway 1902 stop-gap solution to smoke in its 2.63 mile Cascade Tunnel. The design did not sweep the world. George B. Abdill, *This Was Railroading* (Seattle: Superior Publishing, 1958), 136.

early twentieth centuries. While useful in some situations, compound locomotives were peculiarly ill-suited to operating in the Northern Rockies. Perhaps the most famous compound design was the “Mallet” class locomotive.

Steam engine designers realized that most of the steam going into a cylinder was used all too briefly and that allowing the steam to either go into a condensing line (in the case of stationary engines) or into the atmosphere (in the case of locomotives) was a waste of much of its potential expansion energy. The solution was to allow the steam, once it had done work on the first piston, to go into a second and even larger cylinder, and then into the atmosphere. The idea was to utilize the full expansion of a given portion of steam, and the practical result was increased economies of fuel consumption.

Mallets were also articulated, another key innovation. Because of the huge size of their boilers, they could not negotiate tight turns with a conventional design. Named for Swiss designer Anatole Mallet, this class of locomotive’s notoriety stem from his innovation of allowing the boiler to swivel on a huge pin a few degrees to the left or right on the locomotive’s truck. Rail and tunnels that had been open only to smaller locomotives were now accessible to a much larger powerplants.⁷⁹ Like the other major players in the industry, the Milwaukee made extensive use of the Mallet type.

In spite of the promised efficiencies, however, the Mallets were a liability to the Milwaukee. The Mallet enjoyed its heyday in the first two decades of the twentieth century, and while relatively efficient compared to earlier designs, the type had a number

⁷⁹Brian Solomon, *American Steam Locomotive* (Osceola, Wisconsin: MBI Publishing, 1998), 60.

of disadvantages. With double the cylinders to attend to, the locomotives were even more of a maintenance problem than conventional (known as “simple”) steam designs. They were also designed with tractive power and fuel efficiency rather than speed in mind. Mallets could move the increasingly heavy trains, but schedules tightened as the century progressed. Even then, most scholars maintain that the Mallets’ lack of speed was not a serious handicap until truck freight began to pose serious competition to rail freight, beginning in the twenties.

In addition, Mallets were also ill-suited to cold weather, which was a fatal handicap in the Milwaukee’s operating territory, especially if the locomotives came unequipped with superheating equipment. So low was the temperature of the steam as it evacuated from the second cylinder into the atmosphere that it immediately condensed and actually fell as unwanted rain on the locomotive. This obviously made life miserable for the crews, who contemptuously referred to them as “Slobbertacks.” Speeds were also low; crews considered 30 miles per hour a breakneck speed for a Mallet in Milwaukee territory. Not surprisingly, the Mallets were the first locomotives replaced by the post-war diesel-electrics in 1949.⁸⁰

All Refinements to No Avail - Water, Maintenance, Lubrication, and “Organic” Design

Even with the improvements that came from burning oil rather than coal, as well as the other above-mentioned incremental improvements, the most evolved steam locomotive was a very dirty, fussy machine when compared to the electrical variety. The

⁸⁰Holley, *The Milwaukee Electrics*, 180-184.

steamers in the Milwaukee's fleet could only run approximately one hundred miles before they required attention, and steam locomotives in general had to go in once a week for cleaning. The electrics were not only cleaner, they could also run for much longer periods without maintenance. Steam is nowadays often touted as a "clean" source of energy, but this would have been a bitter joke to the shopmen, firemen, and engineers responsible for the cleanliness of a locomotive at any point in its storied 130 year history. On the other hand, a steamer's thousands of parts which required the fastidious attention of scores of attendants represented job security to a number of skilled and semi-skilled tradesmen. Engineers and yardmen, while not to a man, generally greeted electrics, and later diesels, with suspicion and disdain. They called them "streetcars," and the term was one of opprobrium rather than endearment. "Streetcars" exemplified a trend of management's attempts to make any and all infrastructure less labor intensive. A diesel required one fifth of the manpower to operate. Thus, for a railroad's board of directors, perennially bent on reducing overhead, abandoning steam offered an attractive option.⁸¹ A steam engine required water to boil, a simple- sounding process; but if the PH of the water was too acidic, it could corrode the boiler's scores of fire tubes and other inner workings. Conversely, if the water was too basic, mineral deposits (lime) quickly formed, and hampered efficient running. Theoretically, in a small country such as England, water of both types could be rotated in and out of the boiler, each essentially counteracting the other. Another solution was the use of chemical additives to the water

⁸¹Lorenz P. Schrenk and Robert L. Frey, *Northern Pacific Diesel Era* (San Marino, California: Golden West Publishing, 2000), 27-8.

in order to make it PH neutral. European railroads used such techniques, but western American railroads, perhaps because of their larger operational scales and less sophisticated infrastructures, eschewed the practice of chemical additives for basic water. The yard crews could do little, except replace boiler tubes and other fixtures as they corroded, or more often, clean scale as it formed, a periodic but never-ending job.

In the western United States, the problem, more often than not, was water usually alkaline. Since it traversed South Dakota and Eastern Montana, the Milwaukee had more than its fair share of alkaline water to contend with, as did many other lines in the United States. Water quality varied greatly at the far flung points of any transcontinental line, and railroads used additives regularly only in steam's final days. The resulting scaling required periodic, labor intensive brushing and scraping of the boiler wall. An alternative, using different types of water, was more than a nuisance to yard mechanics. Nonmixed water, that is, water of one type, boiled much more quickly, while using mixed water caused delays⁸² Moreover, water that failed to vaporize properly could find its way into the cylinder, with the potential for an explosion.⁸³

⁸² W.A Tuplin, *The Steam Locomotive* (New York: Charles Scribner's Sons; 1971), 84-5.

⁸³ Steam engine cylinders are understandably designed to tolerate pressures for steam, not compressed water (which is in practical terms non-compressible). While steam locomotive cylinders are high pressured affairs, gases are a much more compressible material than liquids (a fact used to mechanical advantage with hydraulic machinery). Pure liquid in any engine cylinder is an invitation to disaster. Simon & Schuster, *The Way Things Work: An Illustrated Encyclopedia of Technology* (New York: Simon & Schuster, 1967), 512. However, in at least one instance, (The Republic P-47 Thunderbolt, powered by one of the most massive radial engines ever designed) water injection was used to enhance performance. Water cooled the piston and cylinder, as well as providing oxygen and pressure to the combustion process. This prevented combustion

The impressive number of moving parts that constituted a steam locomotive also required extensive lubrication. Up to 60 ports or reservoirs feeding lubrication points required daily oiling on a large steamer, and tending to this matter took an hour on the part of either the engineer or maintenance crew, depending upon how a particular railroad allotted its manpower. As a consequence, the hallmark of the overall drive to modernize steam locomotives was employing automatic lubrication whenever possible.⁸⁴ Suffice it to say that sundry maintenance costs cut heavily into the bottom line of any railroad.⁸⁵ First and most obviously, more maintenance meant more maintenance personnel, and cutting payroll costs was one of the few cost areas that retained a degree of flexibility for the Milwaukee's Board of Directors. Additionally, less maintenance implied greater reliability and less uncertainty. Like any other large corporation, the Milwaukee detested uncertainties of any kind and sought to eliminate them whenever possible. While charming, steam and the maintenance philosophy built up over the previous century were essentially obsolete by the First World War.

The electrics, and after them the diesels, were of an entirely different nature.

Squat, utilitarian, unlovable, they had no hope of ever making their way into the popular

of the unburned fuel. Premature firing of unburned hydrocarbon fuel is known as *knock*, and was an extremely vexing problem for aviation engineers in the "Golden Age" of aviation. A mere nuisance in cars, knock could destroy more delicately-constructed airplane engines, and was potentially fatal to pilots.

⁸⁴Robert L. Frey and Lorenz P. Schrenk, *Northern Pacific Supersteam Era: 1925-1945* (San Marino, California: Golden West Books; 2000), 78.

⁸⁵W. A. Tuplin, *The Steam Locomotive* (New York: Charles Scribner's Sons; 1971), 94. Tuplin pegs the figure at an educated (but still imprecise) figure of 30% of company expenditures for any given 19th century British railroad.

lexicon of children's books. They were, however, much easier to maintain than steamers, in part because the approach to maintenance and repair was modular rather than piecemeal. A steamer was an almost organic construction, but both trolley-electric, and the diesel-electric engines that replaced them (tellingly known as "units") were designed to compartmentalize problems. If a diesel threw a rod, or otherwise failed, the damage was relatively containable and easily repaired. Instead of having to dig around for a defective part, an entire piston and cylinder head, motor brush assembly, or similarly large modular component was replaced.

A notable example of modularization was Henry Ford's inspired adaptation of an earlier (ignored) British innovation of boring cylinder holes in an engine block, which was collectively sealed by the lump package of a cylinder head, rather than machining each cylinder assembly separately.⁸⁶ Cast and finished-bored engine blocks with cylinder heads are an arrangement still almost universally used to this day -- in car, train locomotive, aviation, and marine diesel engines. Incidentally, modular design has also enjoyed success in light industries such as bicycle manufacture. Both crank and wheel axles used to have separate ball bearings that had to be hand seated by the mechanic; now the axles and bearings are sold as a single unit cassette -- for the do-it-your-selfer, a more expensive but far less aggravating approach.⁸⁷

⁸⁶Allan Nevins and Frank Ernest Hill, *Ford: The Times, the Man, the Company* (New York; Charles Scribner's Sons, 1954), 462.

⁸⁷Henry Petroski, *The Pencil: A History of Design and Circumstances* (New York: Alfred A. Knopf, 1983), 12, is an absorbing look at the modularization of a more humble commodity. While not as glamorous as locomotive manufacture, pencils were an even more extreme, and in the end, similarly profitable example of this dynamic. (Few

The interest in efficiency carried over into maintenance practices as well. In the late days of steam, inspired by statistical management practices that at the time dominated American industrial thinking, maintenance crews conducted the routine replacement of parts, as well as major overhauls, according to a fixed schedule.⁸⁸ Rather than tend to a problem after it had occurred, preemptive servicing became a regular practice in the maintenance of steam, electric, and diesel-electric engines, land, air, and marine. This practice was known as the “belt system” and mirrored the Tayloristic philosophy and modular aspect of the assembly line process in many ways.⁸⁹

people ship many goods on rail by the hundred-ton, but who does not use a pencil?). Disparate products such as a million dollar locomotive and a nickel pencil are subject to the same (*very* general) trends in finished goods production. Petroski writes: “One oft repeated definition of an engineer is someone who does for one dollar what anyone can do for two, in the case of the mass produced pencil, the economic advantage is even more pronounced.” Baldwin and ALCO’s manufacturing processes, while sophisticated, were relatively simple and empirical compared to the amount of theoretical thought that went into an electrical system; GE’s manufacture of its electric locomotives for the Milwaukee took a more complicated, rationalized design approach with the goal of a (mechanically) simpler, more reliable product.

⁸⁸Railroads tended to be more resistant to Tayloristic philosophy than the lighter industries, arguing that rail activity was not “piece work,” (such as the manufacture of the Model T). Frederick Winslow Taylor, widely lauded as the “Father of Scientific Management,” saw his philosophy of breaking down manufacturing tasks into the most minute detail, and improving the floor layout and movements of each worker into the most efficient pattern, adapted by huge swaths of American and European industry during the Gilded Age. See Alan Nevins, *Ford*, 468-69. Similar attempts to purge inefficiency were made in the service sector, where the railroads obviously figured prominently. The Milwaukee’s electrics, with their emphasis on lowered maintenance anxieties and a corresponding rise in reliability, fit neatly into this world view. In general, however, railroad management collectively argued that no single scientific management panacea, such as Ford’s lauded Highland Park Plant, existed for railroading. See Martin, *Enterprise Denied*, 212-13.

⁸⁹W.A. Tuplin, *The Steam Locomotive* (New York: Charles Scribner’s Sons, 1971), 97.

The thinking was to prevent misfortune against the overall odds rather than to tend to specific problems when they arose, and to pull a whole “assembly,” and replace it, rather than to repair a specific part. But the ultimate de-skilling of a whole class of very able men that resulted was a tragedy of sorts. In addition to cutting overall maintenance costs, electrification and subsequent dieselization of many railroads also threatened yard mechanics and old time engineers, devaluing a set of skills acquired by long and acute study. Even the work of driving the locomotive was modularized. In the eyes of engineers, diesels especially reduced the role of the of the train’s “captain,” from a superbly accomplished mechanic who could think on his feet to one of a glorified gauge-monitor.

The Problem of Torque, and How Best to Apply It

Readily available torque of a wide variety of strengths is in essence a locomotive designer’s ultimate goal. When most people see a modern diesel locomotive and hear it described as “a diesel,” they reasonably assume that the engines are directly linked to the drive train, in other words, that the locomotives are gigantic Volkswagen Rabbits. This is in fact erroneous; for example, the Northern Pacific’s 1939 FT-Type diesel-electric locomotive had a V-16 engine, each piston of which was larger than a one-gallon paint can (16.5 inch bore, 10 inch stroke), which in turn powered alternating current generators (alternators).⁹⁰ The current was then put through a rectifier, which took the alternating

⁹⁰This was an experimental, two-stroke model. More efficient designs followed after the Second World War. Still, this particular locomotive performed respectably for a design in relative infancy. Lorenz P Schrenk and Robert L. Frey, *Northern Pacific*

current and transformed it into the direct variety, the more suitable type for traction motors.

Common sense would seem to dictate that the considerable energy the diesel engines produce be directly applied to the drive train. Why build something so electromechanically complicated?⁹¹ The short answer is that even these huge engines are equal to producing the required torque, at least not in the form a diesel engine first delivers it. The “output shaft” speed produced by even the slower-running diesel engines was too fast to move 4000 ton trains in a purely mechanical fashion. Interestingly, turn of the century designers fabricated prototypes of both diesel and carbureted gasoline direct drive locomotives, but knowledgeable observers generally labeled the concept a dud, even with a “light” train.⁹² All of the seemingly over-complicated design features on a modern diesel (more correctly referred to as a diesel generator) exist because of considerations of torque.

Perhaps a specific example, outside of railroading, of steam’s initial advantages over internal combustion, before the advent of a viable electric motor, would be useful. One of the more tantalizing “what ifs” of technological history is the eventual and total adaptation of the four-stroke carbureted gasoline engine for automotive use, over electrical and steam power plants. The outcome of this issue was hardly clear cut, as late

Diesel Era, 1945-1970 (San Marino, California: Golden West Publishing, 2000), 56.

⁹¹Very light European passenger systems have in fact used direct drive diesels to some extent. Simon & Schuster, *The Way Things Work*, 526.

⁹²David Page Morgan, *Diesels West!: Evolution of Power on the Burlington* (Milwaukee: Kalmbach Publishing, 1963), 26.

as 1920. Electrical cars ran a poor third in this contest. Admittedly, a few bus-sized vehicles ran off of trolley wires (See Plate V, page 78).

However, the electric cars offered at the turn of the century used anemic batteries and resembled little more than a glorified version of a modern golf cart in performance.⁹³ Electric cars of the early twentieth century were, without exaggeration, popular with well-to-do, little old ladies who drove to church on Sundays.⁹⁴ They set no speed or towing records; their chief advantages were quietness and ease of operation. The much-touted hybrid gasoline/electrical car that Honda now offers (price about \$22,000) uses a gasoline engine powered alternator, which puts the alternating current through a rectifier for use in a direct current motor arrangement, in tandem with a conventional gasoline engine transmission rather than a straight battery arrangement. The batteries are used for storage, rather than a direct power source, and Honda had moderate success with this design in 2002. However, in the setting of 1900 to 1915, the electric car's deficiencies were patent.

Steam cars, however, represented realistic competition to the eventual dominance of gasoline engines. Once again, the issue came back to torque. A gasoline or diesel engine runs most efficiently from 1,500 to 5,000 revolutions per minute, a broad range of speeds to be sure, but not particularly well suited to automotive use. The only time the drive train in a car even approaches its gasoline engine's bottom-end efficient speed of

⁹³Allan Nevins and Frank Ernest Hill, *Ford: The Man, the Times, the Company*. (New York: Charles Scribner's Sons, 1954), 203-04.

⁹⁴Michael Brian Schiffer, *Taking Charge: The Electric Automobile in America* (Washington, D. C. : Smithsonian Institution Press, 1994), 159.

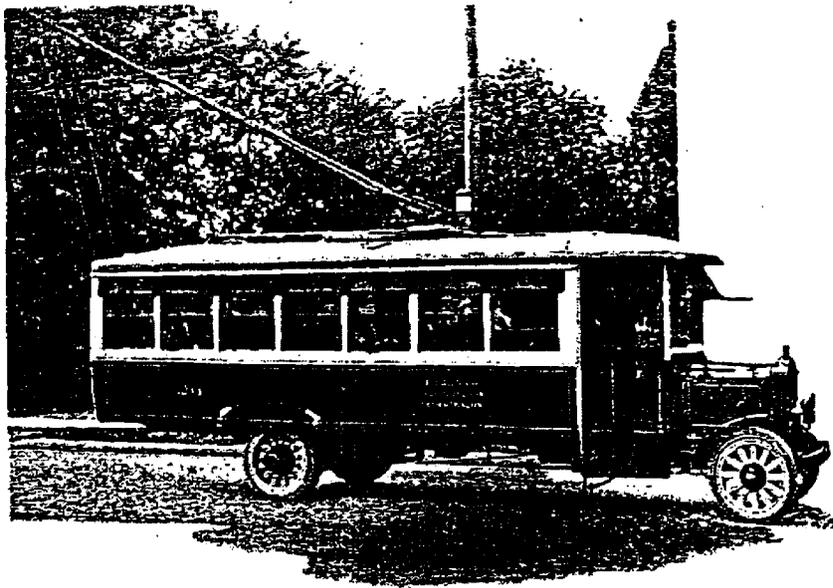


Plate V: A Westinghouse Trolley Bus, Circa 1915. Westinghouse Electric and Manufacturing Company, *A Brief Outline of the Development and Progress of the Electric Railway Industry* (East Pittsburgh, Pennsylvania: Eddy Press Corporation, 1923), 38-9.

1,000 rpm is at least 80 miles per hour. Translating the high speed and low torque of a gasoline engine's output shaft into something useful for moving a car requires reduction gearing. Anyone who has ever inadvertently "lugged" a standard transmission car and killed its gasoline engine can appreciate this engineering problem. When attempting to engage second or third gear from a standstill, the engine dies because the required torque of moving the drive train from dead stop is too great for the engine's running requirements. The solution is a transmission system that can take the high output speeds of a four-stroke engine and reduce them, through the operator's use of transmission gears, to lower speed and correspondingly higher useful torque from 0-1500 rpm.

High-end steam cars, such as a Stanley or a Doble, did not operate under such requirements. The two cylinder engine's efficient operational range encompassed a much broader spectrum when it came to moving the car's substantial curb weight from 0-125 mph. Because of the elasticity of steam and the high pressures that the Stanley's engine operated under (1000-1300 pounds per square inch), it could provide adequate torque under a wide variety of circumstances (from 0-125 miles per hour) no conventional transmission required.⁹⁵ In the last century, transmission problems have been a central problem in the maintenance life of any gasoline or diesel car. Moreover, transmission systems have always been notoriously complex. Even Henry Ford's planetary

⁹⁵Day, John. *Engines: The Search for Power* (New York: St. Martin's Press, 1980), 72-3. A Stanley Steamer made 126 mph in 1906 - at the time a world land speed record. A later fatal attempt at breaking this record ended in the Stanley crashing at a conservatively estimated 190 miles an hour. The cylinders had a bore of four and a half inches and a stroke of six and a half inches, and worked best at a pressure of 1300 pounds per square inch.

transmission, famed for its relative simplicity, was a complex piece of machinery.⁹⁶

Therefore, the sensible choice would seem to dictate something that avoided the problems of converting speed into work. With its valve reversing linkage, the Stanley's transmission was so flexible it could theoretically go as fast in reverse (up to 125 mph) as it could going forwards, just as a train locomotive could. While not a particularly advantageous in everyday automotive life, it demonstrated the Stanley engine's, and steam's, peculiar simplicity and versatility.

Many scholars, in fact, have persuasively argued that the most viable competitors to the noisy and complicated gasoline powered automobiles – the Stanley and Doble steam cars – failed because of marketing rather than performance factors. The Stanley Brothers and their product were the epitome of nineteenth century craftsman and salesmanship. They produced a machine for the select few who could match the Stanleys' customer screening process. Above all, customers had to have the financial wherewithal to purchase the steamer in one fell swoop. To buy a Stanley, one had to pay \$1500 cash, no mean feat in 1910 or 1920, and with no recourse to GMAC or Ford Motor Company financing plans.⁹⁷ The all time low price of the Ford Model T (with 15,458,781 units sold

⁹⁶Allan Nevins and Frank Ernest Hill, *Ford: The Times, the Man, the Company* (New York: Charles Scribner's Sons, 1954), 387. Interestingly, Ford Motor Company experimented with an electric battery powered motor attached to a Model T chassis. The project quickly languished. Schiffer, *Taking Charge*, 166.

⁹⁷Finance plans (installment payments) were the result of the average price of a car, a virtual necessity by the mid 'teens, coinciding with that time's average yearly income. Ford's competitors, in response to the popularity of the Model T, offered installment plans beginning in 1916. The Ford Motor Company quickly followed suit. Eric Foner and John Garraty, *The Reader's Companion to American History* (New York: Houghton Mifflin Company, 1991), 66.

from 1908 to 1927) was \$260 in 1923, down from the debut price in 1908 of \$850. Much of the discount came in the fact that the T's purchaser was expected to perform his own minor repairs, or find someone competent locally, rather than hold the Ford Motor Company in faraway Detroit responsible.⁹⁸ The Ford Motor Company thoughtfully provided a Question-and-Answer book for basic mechanical problems. It was unthinkable that the Stanleys would do such a thing. They had an unwritten, unlimited lifetime warranty on their product; if anything broke, the Stanley Company would fix it for free.

The point of all of this is that the power plant question for both cars and train locomotives remained wide open in 1910, and the choices confronting an individual consumer in the case of cars or the board of directors for a multimillion dollar railroad were not nearly so obvious as they appear in hindsight. No solution stood head and shoulders above the rest.

The weight of an automobile was paltry when compared to that of a 500,000 pound locomotive, much less that of the 3,000-ton freight train appended to it. But the same laws of physics pertained. This resulted no direct drive gasoline or diesel railroad engines built in quantity. Even in the twenty-first century, there are few direct drive gasoline or diesel railroad engines, and this explains why electrical power came into the picture back in 1914. The 20 gears required by modern semi trucks, with a typical load of some 70,000 pounds, gives some sense of the problems entailed in transmitting usable torque to a drive train. The amount of gearing that a 4000 ton train would require from 0-

⁹⁸Richard Tedlow, *Giants of Enterprise: Seven Business Innovators and the Empires They Built* (New York: Harper Collins, 2001), 157.

80 mph would make any automobile's transmission system look relatively simple. This explains the seemingly bewildering choice of going to the trouble to take the output power of a diesel engine and convert it into two types of electrical energy before applying it to the driver wheels. The recently released, much-hyped Honda gasoline electric hybrid has the same design principles as a modern diesel locomotive used by Montana Rail Link.

Thus, torque, in tandem with technological inertia borne out of steam's longstanding familiarity, made steam a formidable and seemingly perennial competitor to competing strains of motive power. The two cylinder bores on a Stanley were four-and-a-half inches wide, operating at anywhere from a thousand pounds to thirteen hundred pounds per square inch, and the engine obviously provided adequate power for the car in a variety of speeds. The cylinder bores on the Union Pacific's famed *Big Boy* were not quite four feet wide, and because steam boilers had constantly improved, operated at two hundred pounds per square inch, when all was running properly. This provided adequate torque to move a load of four to five thousand tons from a standstill to sixty miles per hour in a matter of minutes and without reduction gearing. Yet, although the machines represented eighty years of design refinement, their use still posed problems, particularly in rugged terrain.

In the days that the Milwaukee used steam over the Belts and the main spine of the Rockies, it was a costly (for stockholders) and nerve-fraying (for engineers and insurers) experience to take a train of any weight over the Continental Divide into Butte. The last of the transcontinental lines, the Milwaukee naturally inherited the most inferior and dangerous grade over the Main Spine of the Northern Rockies. The Milwaukee

acquired Mallets and Mikado class locomotives, the most efficient performers in the steam category, but any examination of what was involved in getting one up and down a severe grade would easily explain why electric (and later diesel-electric) locomotives looked so attractive, not only in terms of maintenance and braking, but also in terms of general performance under frequently miserable conditions.

Ascending the 1.66% grade east of Butte to the summit of the Continental Divide at Donald, seventeen miles away, moving a two thousand ton train, required three Mikado type locomotives, three engineers, three firemen, brakemen and a conductor. It also required tons of coal, thousands of gallons of water, and nearly two hours time – if all went well. Once through Pipestone Pass tunnel at the top, the train stopped while the retainer on the cars were set up to assist in the braking while descending the twenty-one miles of 2% grade to Piedmont. At this point, the two helper locomotives, with no more useful work to do, could either be cut off to return to Butte or continue on down with the train. The train, with the air brakes partially set to prevent losing control on the grade, proceeded slowly on down the mountain, with another lengthy stop or two to let the brakes and wheels cool. With the operation repeated at Haugan, Harlowtown, Cle Elum, Cedar Falls and Avery, the number of locomotives and crews needed to just keep the freight moving was fast getting out of hand. Add to this situation delays, bad weather, minor accidents, break downs, locomotives low on fuel and water, passenger train schedules that had to be kept, and the entire road could be kept in a snarl from one end to the other.⁹⁹ (See Plate VI, page 84).

The superior performance characteristics of the electric locomotives were intended to “unsnarl” this situation. How superior was the electric locomotive to its steam counterparts? Famed in Milwaukee buff circles are the various public contests between the electrics and the best designs that steam had to offer. Most impressive to the laymen were the various “pushing” contests between a Bipolar and a Mallet, or two Mikados.

⁹⁹Charles R. and Dorothy M. Wood, *Milwaukee Road West* (Seattle: Superior Publishing Company, 1972), 65-66.



Plate VI: Three steam locomotives (probably Mallets) clawing up the two percent grade at Pipestone Pass, westbound into Butte, one of the most arduous climbs and hazardous descents for steamers on the Milwaukee's line. Conditions on this pass were perhaps the most frequently cited example of steam's deficiencies. Holley, *The Milwaukee Electrics*, 34.

Intended to be dramatic, these contests, staged in the early 1920's, lived up to expectations. A Mallet steam locomotive at full throttle, belching steam and ash, could not budge the squat, quietly humming Bipolar, which gradually got the steam locomotive going backwards. As with all successful advertising, the Milwaukee used white lies; the Bipolar was also running at the electrical equivalent of full throttle (indeed, in excess of GE's guidelines for drawing amps, which could have burned up the motors. See Plate VII, page 86).¹⁰⁰

There were other spectacles as well. On December 9th, 1915, Milwaukee officials staged a promotional race between the GE freight motors and two "L" class locomotives plus a Mallet helper, eastbound over the divide from Butte. A reporter for one of Butte's newspapers gave a rather gushing account of the electric locomotives superiority over steam (note the anthropomorphizing –or more properly, "equestrimorphizing"– of the steam-powered engines):

The test consisted of starting from Butte a train of 3,000 tons, consisting of 48 loaded cars pulled by two electric locomotives, and the train was hauled over the grade quietly and apparently with the utmost ease at a speed of 16 mph, and proceeded on its eastern way without stopping. Following behind this train came another of 2,000 tons made up of 37 cars hauled by two "L" engines and pushed by a mallet locomotive. The steam horses toiled up the grade and the engines actually groaned under the strain placed upon them. The men at the throttles and the firemen shoveling coal were not trying to throw the race, but it was quite apparent that they had a pride in making the best possible show for their iron steeds, and steam was kept at the highest possible pressure, yet with the smaller tonnage the three locomotives made hard work on the grade and only managed to get

¹⁰⁰William D. Middleton, *When the Steam Railroads Electrified* (Seattle: Kalmbach Publishing,), 223. the *perception* was one of effortlessness. See also Noel Holley, *The Milwaukee Electrics: An Inside Look at Locomotives and Railroading*. (Edmonds, Washington: Hudman Publishing, 1999), 86.

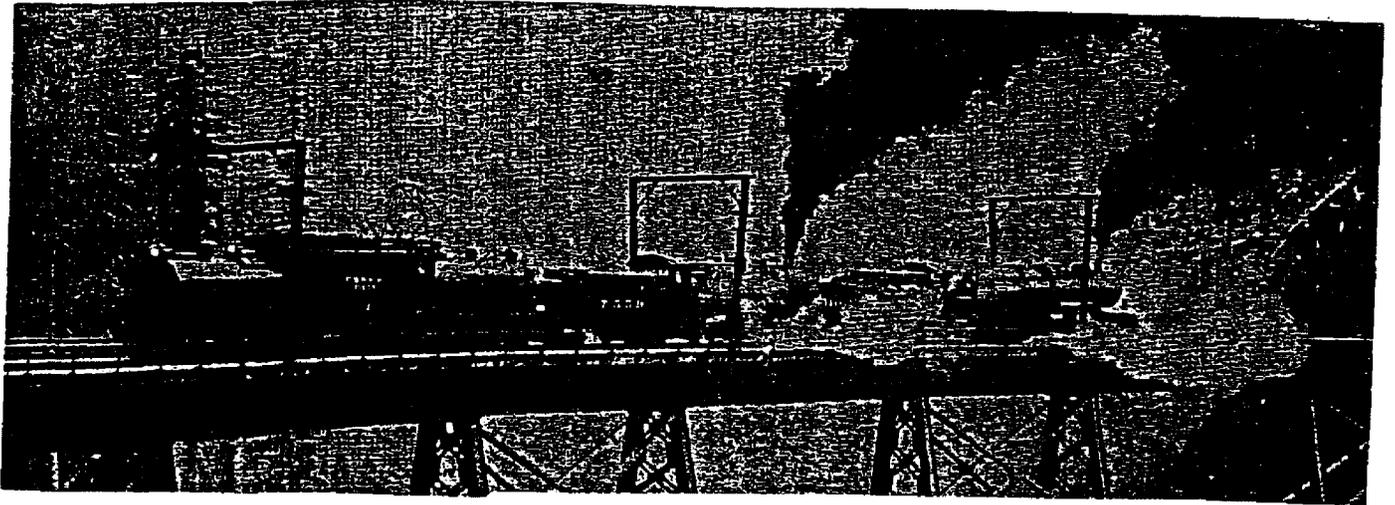


Plate VII: A 1914 "Pushing Match" between a Bipolar and a pair of Mallets. Holley, *The Milwaukee Electrics*, 223.

through Janney at a speed of nine miles an hour.

There was something almost pathetic in the game fight which steam put up against its new rival in the transportation field, but it was so visibly and completely outclassed that even a child could have picked the winner at a glance. Not one of the half hundred spectators could help feeling that he had witnessed the overwhelming triumph of a new power over an old and tried friend that had faithfully served mankind for many decades past.¹⁰¹

The selection of Mallets and Mikados (Class ‘L’) for these stunts was apt, because they represented the two most popular types of steam locomotives in the first forty years of the twentieth century. Baldwin’s 2-8-2 type Mikado, which varied in weight, combined a number of attractive technical features in a flexible package, and became the locomotive industry’s equivalent of the Ford Model T, with an estimated 14,000 units manufactured by Baldwin and Alco between 1890 and 1949.¹⁰² There are still Mikados in use today in various quarters of the Third World.¹⁰³ Smaller than the Mallet, the Mikado was a sensible combination of simple design, high power for its size,

¹⁰¹ Author unknown, *Butte Miner*, December 9, 1915, 1.

¹⁰² Annotation for various wheel arrangements in a steam locomotive is fairly straightforward. Called the Whyte System, the first number denotes the total number of wheels on the unpowered front guide section (the “bogey”), the middle number (or numbers) denotes the number of driving wheels, and the last number denotes the number of unpowered trailing wheels. Solomon, *American Steam Locomotive*, 17. The Whyte system is peculiar to American and British steam locomotives, and the numbering system for all other locomotives (known as the “International” system) differs somewhat. Here drivers are designated with a letter (A for one driver, B, for two, and so on) rather than a number, and notations are for only one side of the locomotive. Thus a Mikado would be designated as a 1-D-1 locomotive. Electric locomotives are designated under the “International” system, indicating the prevalence of electric trains outside of North America. Holley, *The Milwaukee Electrics*, 279.

¹⁰³ Brian Solomon, *American Steam Locomotive* (Osceola, Wisconsin: MBI Publishing, 1998), 53.

and flexibility.

Whatever the advantages of these two designs, steam (compound or simple) had one insurmountable problem operating in the Northern Rockies: cold weather some five months out of every year. Account after account in rail buff literature makes it clear that the huge boilers of any steam engine hemorrhaged heat into the surrounding air.¹⁰⁴ The Milwaukee's predecessor line in Central Montana, The Montana Railroad, which hauled freight and passengers over Judith Gap in the dead of winter, acknowledged the reality of operating in cold weather with "hand me down" locomotives leased from the Northern Pacific by not even bothering with the pretense of a regular schedule four months of the year.¹⁰⁵ A Milwaukee scheduling table from 1947 mandated a 20 to 30 percent reduction in gross tonnage at 20 below zero – not an everyday occurrence, but at least three weeks in January and February stood an excellent chance of having such bitterly cold conditions somewhere in the Milwaukee's sphere of operations.¹⁰⁶

Although railroads had no equivalent of the American automobile industry's Big Three, a few railroads, and locomotive manufacturers, had unquestioned primacy. Union

¹⁰⁴When stopped in these conditions, water condensing on the boilers found its way down to the wheels, and would actually freeze the locomotive to the track. Workmen (or ideally, another locomotive) would then have to dislodge the stuck train forcefully. Author Unknown, "St. Paul's Electrification System," *Literary Digest* (April 12, 1916), 1120-21.

¹⁰⁵Don Baker, *The Montana Railroad, Also Known as The Montana Railroad: Alias, The Jawbone, also Known as The Chicago, Milwaukee, St. Paul and Puget Sound, and The Chicago, Milwaukee, St. Paul and Pacific, and Finally as The Milwaukee Road* (Boulder, Colorado: Fred Pruett; Date unknown), 39.

¹⁰⁶Holley, *The Milwaukee Electrics*, 296.

Pacific, the world's first transcontinental railroad, was among the biggest of a handful of lines which could claim such status. The company's approach to steep grades and heavy, urgent freight contrasted greatly with that of the Milwaukee Road. One of the best-financed of the American railroads, Union Pacific adopted diesel electrics beginning in the early 1940s, but it still relied heavily on steam power. America's entry into the Second World War prolonged this reliance. The final evolution of the steam engine, and by consensus the ultimate evolution in steam design, was the Union Pacific's *Big Boy*, made by both ALCO and Baldwin. The moniker was no misnomer or idle pabulum ground out by the Union Pacific's Public Relations Department. The locomotive, although slightly outclassed in certain respects by the few remaining gargantuans that followed, became an avatar for steam power's ultimate evolution. Each weighed in at 772,000 pounds, had driver wheels over six feet in diameter, and measured 132 feet long. These engines were true performers, not just another example of mid-century industrial gigantism. Tellingly, they debuted in 1941, and a big component of their acceptance and heavy use by Union Pacific owed to the exigencies imposed the by the Second World War. The 4-8-8-4 locomotives were primarily designed with a combination of speed and power in mind. Because of the superheated "simple" design (rather than the "compound" design found in Mallets) they could pull heavy freights at up to 70 mph on level grade. ALCO's *Big Boy* was represented, for the most part, as a realistic compromise among speed, might, and the advantages of a tried and true technological system with a 120-year

track record.¹⁰⁷ World War II was hardly the setting for potentially unreliable technologies (unless the technology in question offered spectacular military payoffs, such as the two-billion dollar Manhattan project, the proximity fuse, or radar). The more mundane but hardly less important realm of moving stupendous quantities of goods left little room for experimentation.

Closer to the Milwaukee's sphere of operations, the Northern Pacific also utilized huge "simple" steam locomotives in the 1940s, its *Northern* and *Yellowstone* type steamers. The biggest simple steamer in the Milwaukee's fleet was the *Northern* type, a 4-8-4 that they began ordering from Baldwin in 1929.¹⁰⁸ While an undeniably huge machine, it was nowhere near the size of a Northern Pacific *Yellowstone* or the later Union Pacific *Big Boy* and was outclassed by its electric stable mates. The Milwaukee's acquisition of Northerns is an excellent example of its lack of slavishness to one particular type of motive force, even as late in the day as 1929.

More on Torque: Rotary versus reciprocating engines.

The everyday operational problems of various steamers also highlighted problems more general to steamers as a class. After some early stumbling, motor designers eventually found that the electric motor lent itself admirably to rotary configurations rather than reciprocating ones. Electrically-motored locomotives were a tangible example

¹⁰⁷Brian Solomon, *American Steam Locomotive* (Osceola, Wisconsin: MBI Publishing, 1998), 79-80.

¹⁰⁸Charles R. and Dorothy M. Wood, *Milwaukee Road West* (Seattle: Superior Publishing Company, 1972), 105.

of the superiority of rotary engines over the older, steam-powered reciprocating type. The trick was finding a very *powerful* steam rotary engine for locomotive use, which designers never developed. The continuing use of low load applications, such as marine and aviation engines, validated the turbine's use in certain applications, but turbines were not well-suited to locomotives. The loading on a ship's screw, even for a ship the size of the *Titanic*, was minuscule compared to that of starting even a modestly weighted freight train from a standstill.¹⁰⁹

Reciprocating engines are in one sense handicapped from the outset when compared to rotaries. The piston and its connecting rod in a reciprocating engine are subject to enormous forces in just one operational cycle. In a single-acting car engine, or a double-acting steam engine, the expanding gases acting on a piston ram it to and fro in the cylinder. The piston is accelerated, stopped, and accelerated with equal force in the opposite direction, hundreds or, when redlined, even thousands of times per minute. Especially at higher speeds, these forces can wreak havoc on engine parts.¹¹⁰ This results in abundant torque, but there are a number of undesirable side effects. The forward and reverse acceleration that a piston undergoes can fatigue all but the toughest of steel alloys. Failure of one of the piston's components could mean ruined piston rings, or more catastrophically, a thrown connecting rod, one of the worst possible eventualities for the running life of an engine. Other problems could plague reciprocating engines as well. For

¹⁰⁹For a good description of the advantages of rotary motion in certain (especially marine) applications, see Robert Landes, *The Wealth and Poverty of Nations: Why Some Are So Rich and Some So Poor* (New York: W. W. Norton & Company; 1998), 198-99.

¹¹⁰Simon & Schuster, *The Way Things Work*, 472.

example, the otherwise well designed *Northern* class locomotives utilized by the Northern Pacific had cylinders that were not integral to the frame; the powerful and violent motion of the pistons could (and did) work the bolts that connected the cylinder mounting to the rest of the engine loose. These bolts required constant attention, and in recognition of this fact subsequent Northern Pacific designs integrated the cylinder saddle, casted into the frame itself.¹¹¹

Manufacturers still take great pains in terms of design, engineering, and choice of component materials to avoid such catastrophic failures as a thrown rod whenever possible. In engineering's early days, this meant making pistons and rods excessively robust; as metallurgical and machining improvements came along, the components size decreased while toughness improved. The resulting engines worked and were marvels of the day, but at colossal costs. Steam locomotives, even at the height of their refinement, performed dismally in terms of thermodynamic efficiency. Pegged at an optimal 7%, a Mallet, or any other steam locomotive, appeared efficient only if one compared it to a Newcommen Engine of 1700, which burned free (waste) coal from the mines it

¹¹¹ Robert L. Frey, and Lorenz P. Schrenk, *Northern Pacific Supersteam Era: -1945* (San Marino, California: Golden West Publishing, 2000), 86. The grade from Mandan to Glendive was not excessively steep, but undulated scores of times in the rugged hills as a train moved in either direction, and this particular section of track was a constant thorn in the side of the NP's Operations division. Huge locomotives and improved combustion science were the route that the Northern Pacific chose, relying on a fleet of immensely powerful modern steam locomotives classed as Yellowstones and Northerns to move the 3000 ton trains. While unarguably charismatic, Yellowstones and Northerns were finally less cost effective than diesels for the same duty, and the NP ultimately phased them out.

drained.¹¹² The Milwaukee and other American railroads did not have the luxury of free coal or later oil.

With all of the stopping and starting, reciprocating engines are generally less efficient in fuel consumption, power-to-weight ratio, and virtually any other performance characteristic one cares to examine, all other things being equal. The Wankel rotary engine has a rounded triangle as its “piston,” but this piston goes round and round in one direction only. The following figures are for two internal combustion engines, and vividly demonstrate the superiority of rotary engines in lighter applications, such as passenger cars:

Table III: Efficiency and Economical Advantages of Rotary versus Reciprocating-type Engines

Wankel Rotary	Chevrolet 283 cubic inch V-8
1971 Manufacturing cost, \$ per	1971 Manufacturing cost, \$ per
Horsepower: 1	Horsepower: 2
Moving parts: 154	Moving parts: 388
Weight: 237 pounds	Weight: 607 pounds
Horsepower: 185	Horsepower: 195
Volume, cubic feet: 5.1	Volume, cubic feet: 23.2

In addition to being hard on the engine frame, reciprocating engines also mercilessly pounded track. Once dimples in the rails appeared, all locomotives tended to

¹¹²W. A. Tuplin, *The Steam Locomotive* (New York: Charles Scribner’s Sons, 1971), 82.

find a resonance in running, and the depressions became even deeper. The effect was similar to diving a car down a severely washboarded highway. The electric locomotives obviously could not undo damage caused by conventional steam engines, but at least they did not further aggravate the problem. Even conventional steamers, such as Mikados, heavily counter weighted their driver wheels in an attempt to avoid excessive pounding and increase smoothness at high speeds. Electricity offered uniform torque, which eliminated many problems considered unavoidable in steam engines. Bill Wilkerson, an engineer for the Milwaukee Road from the 1950s until its demise, concisely explained the mechanical advantages of a purely rotary motor, as well as the complications involved with reciprocating power:

For every revolution of the steam engine's driving wheels their pistons come to the end of their stroke four times with zero power. With the piston at the end of the cylinder there is no power until it starts back. For this reason American locomotives were set up with one cylinder on each side that were locked together by its connecting rod to the main driving wheels and the wheels were quartered on the axle. That means the right side was set 90 degrees ahead of the left side. By doing this, when the right side would come to the end of its stroke, the left side would carry the other side over until it could develop power again. For every revolution of the wheels, you had half power at 90, 180, 270, and 360 degrees ... The Bipolar developed continuous magnetic power for the full 360 degrees of rotation, and had smaller and more driving wheels.¹¹³

In addition, the reciprocating motion of a piston had to be converted into rotary motion for either automobile or locomotive engines. In cars, this was accomplished by a crankshaft. Most American locomotives' crankpins are on the outside rim of the driver wheels. In a double acting steam engine, the power of each cylinder, and by extension the

¹¹³Bill Wilkerson, *The Milwaukee Road Electric Passenger Locomotives* (Harlowtown, Montana: Times Clarion Press, 1998), 19.

torque of the driver, was also momentarily zero one time for each engine cycle (every 90 degrees of a driver's rotation), a complicated problem obviated in steam engines by making sure that the drivers avoided resonance by deliberately running each side of linked drivers out of sync with the other.¹¹⁴

Conventional designs of internal combustion engines operate under a similar handicap. Each cylinder of a reciprocating four-stroke engine produces torque for one fourth of its cycle, a two-stroke one-half, an electric motor, the whole cycle. No matter how ingenious the various modifications that designers contrived, an electrical rotary motor, such as the Milwaukee used, was a simpler machine.

Any problem a master mechanic faced when he had to service a steam machine the size of a Mallet was complicated by the number of interacting parts. This diminished any hope of prompt repair if anything should be found seriously amiss.¹¹⁵ The steamer was an undeniable triumph of interchangeability, but the men who maintained the machines often groused that anyone who ever designed a steamer never had to fix one. No matter how fastidiously constructed in 1800's, parts still had to be fine tuned a bit to actually work.¹¹⁶

¹¹⁴Bill Wilkerson, *Milwaukee Diesel Locomotives* (Harlowtown, Montana: Times Clarion Press, 1993), 2.

¹¹⁵Alboro Martin, *Enterprise Denied*, 67.

¹¹⁶True interchangeability was achieved much later than is widely believed. Another inaccurate elementary school tale of American industry was Eli Whitney's invention of "interchangeable parts." While Whitney's approach yielded unprecedented speed and relative precision, the parts were not truly interchangeable, and the story of stranger, blindfolded, effortlessly assembling a musket from randomly picked part was either rigged at the time, or a bit of apocrypha courtesy of Whitney or one of his subsequent admirers. Specialists in high dudgeon about Whitney's rather free use of the

But by the later half of the nineteenth century, parts needed much less “coaxing” with a hammer, file, or wrench to “make it fit.” Baldwin, Lima, ALCO, and the other locomotive companies could avail themselves of the finest precision machine tools in the world. Despite an unprecedented amount of precision, two seemingly identical parts could be inserted into an engine assembly, and have entirely different performance, and machining steam parts required less precision than internal combustion engines would come to require. The equation of steam locomotives with humans, or at least sentient life, was no accident. Each locomotive had its own personality, its own unique strengths and weaknesses (an ever elusive leak in the pipes, a subtle difference in the shape of a firebox, or perhaps a poor adjustment in counter weighting the drivers during assembly) that no yard mechanic, however gifted, could ever remedy entirely.

The Milwaukee’s use of a source of power best suited to rotary motion was a happy accident of the railroad’s opting for electricity over steam in the early years of the twentieth century. Rotary power was yet another incremental, but significant, engineering modification in the interests of increased mechanical efficiency. Reciprocating engines enjoyed entrenchment from the earliest days of steam technology; the first use for steam engines was pumping water. The first water pump designed featured an Archimedes screw (a rotary design) but had evolved into a reciprocating system of seals and valves within a piston. Later, steam-powered pumps featured plungers, indicating a

term in question represents more than semantic niggling; both he and Edison are now viewed as having at least as much skill at self-promotion as in the technical aspects of their products (which in no way denigrates their accomplishments). See Siegfried Giedion, *Mechanization Takes Command: A Contribution to Anonymous History* (New York: W. W. Norton & Company, Inc., 1948), 47-8.

reciprocating design, not a rotary one. The only place the first steam engines had a practical application was in pumping mines, where fuel cost nothing and water (used as both a coolant and a sealant) obviously was in superabundance. Eventually, however, rotary engines evinced their superiority in a number of applications, oil drilling and aviation among them. A cable tool rig, the forerunner of the modern rotary oil rig, basically pulverized the earth by reciprocating action, rather than boring a hole as a modern bit does. While rugged and dependable, cable tool rigs were agonizingly slow, sometimes dangerous, and retrieved less geological information than rotary rigs.¹¹⁷ In the seemingly unrelated realm of aviation, the performance of jets versus reciprocal power plants was patently apparent, even to those who had no expertise in the field.¹¹⁸

In short, rotaries did not have any of the problems attendant to reciprocating engines. Authorities on engines in all ages recognized this fact; it was familiarity with the reciprocating variety, from the earliest days of Newcommen and Watt, that kept

¹¹⁷*The Petroleum Handbook*, Compiled by the Members of the Staff of Companies of the Royal Dutch/Shell Group (London: Shell International Petroleum Company Limited, 1959), 74-77. Rotary drilling rigs employ a massive weight of “drilling mud” (a Portland Cement or Bentonite compound meticulously engineered for consistent viscosity) hydraulically sealed on top of the bit to avert the risk of a blowout. Blowouts are spectacular, inadvertent encounters with underground natural gas formations, and while a “gusher” is conventionally equated with success, they are usually wasteful and extremely dangerous. Because of increased speed, safety, and geological accuracy, rotary rigs altogether replaced cable tool rigs. Comparing technologies of the western American rail and fuel companies is not an idle sidebar; the Milwaukee’s prosperity, like all of the other western railroads, was directly affected by the ever-changing health of the region’s mineral industries.

¹¹⁸Expressing frustration held by all pre-World War II aeronautic engineers, noted aviation powerplant expert Ernest Simpson once referred to the reciprocating engine as “an invention of the devil.” James O. Young, “Riding England’s Coattails: The U.S. Army Air Forces and the Turbojet Revolution,” from Roger D. Launius (Ed.), *Innovation and the Development of Flight* (College Station: Texas A&M University Press, 1999), 264.

reciprocating engines so entrenched. This is why they were so widely used in the earliest days of automotive engines. In automobiles, only two types of rotary engines that have ever seen commercial use: the gas turbine and the Wankel type. Rotary engines have long enjoyed a predominance in aeronautics; helicopters have run on turbines since the mid 1960s; jet engines dominate large scale applications, and turboprops have made respectable inroads into the arena of smaller planes that have long been the province of piston-powered engines. Both aeronautic and marine engines are comparatively free of the loading problems that land vehicles encounter.

Clearly, by 1945, steam had reached its practical limits. The question the Milwaukee faced at the end of the Second World War was whether a diesel or straight electrical system would entirely replace a 130 year old infrastructure and tradition. Although steam locomotives remained in service until the early 1950s, steam had hung on only because of the industrial expediency of using steam's existing infrastructure during both World Wars. In spite of all of the stop-gap improvements, such as superheating, compounding, bearings, oil burning boilers, and the rest, the age of the direct current motor and its promised efficiencies, powered by either a diesel generator or an overhead trolley wire, was at hand.¹¹⁹ The following chapter examines in detail how electrical motors work, as well as why they are significantly more efficient than steam for what the

¹¹⁹ The Army Air Force demonstrated the universal importance of ball bearings by attempting to hit Nazi Germany's Schweinfurt Ball Bearing Plant, in daylight and at great cost, during the Second World War. This was one of the first truly "strategic" maneuvers of the nascent American Air Force. The thinking behind the raid reflected that virtually all of modern industry and transportation depended on ball bearings, and the Army Air Corps brass hoped that this campaign would paralyze Albert Speer's well-honed war machine.

Milwaukee required.

Chapter III. Motors

Electric motors are ubiquitous in the life of the average American. To prove this point, Donald A. Norman, who writes on technology, counted all the motors he could find in both his home and in that of his “simpler” parents, and came up with eighty-four and forty-three, respectively.¹²⁰ In certain aspects of performance, electric motors presented a quantum leap beyond what a steam engine could do. They were quiet, cheaper to produce, offered uniform kinetic energy, and could be manufactured in a far greater variety of sizes than any type of engine. The question of how best to power them remained to be settled. Reciprocating or turbine steam engines offered one possibility, but nineteenth century boilers, although proven overall, had a justifiable reputation for exploding. On the other hand, turbine blades turned by falling water rather than high pressure steam seemed the ideal compliment to electric motors. Damming and diverting water for both work and crop watering reached back into the remotest stretches of antiquity. Moreover, the Milwaukee’s territory also had particularly promising hydroelectric potential, rated at minimum of 2,749,000 horsepower in 1912.¹²¹

At 12,799 feet, Granite Peak in south-central Montana towers as one of the highest points in the Yellowstone River’s watershed. The lowest point of the Yellowstone River, where it empties into the Missouri River, almost exactly at the

¹²⁰Donald A. Norman, *Turn Signals are the Facial Expressions of Automobiles* (Reading, Massachusetts: Addison-Wesley Publishing Company, 1992), 144. The title is a bit precious, but otherwise Norman’s work is a very readable collection of technological essays.

¹²¹John D. Ryan, “Montana Power Company Bulletin Number 6 - The Montana Power Company: Is It a Monopoly?” (Butte, Montana: Montana Power), 1. Montana Power’s 1912 hydroelectric capacity was 433,000 horsepower.

Montana/North Dakota border, is just under two thousand feet. Theoretically, one could dump a glass of water from the pinnacle of Granite Peak and trace its eventual surface route to the Missouri, a drop of some ten thousand feet in just over 330 miles, as a crow flies. The snows that lash the Rocky Mountain front five months a year provide several million gallons of water annually. This theoretical glass of water generates a substantial amount of energy (for its size) during its fall to the Missouri, a fact that has been used to man's advantage for millennia. Mother Nature does the lifting; all one has to do is block and channel the water's descent. In spite of this hydroelectric potential, and its proximity to the Milwaukee's Rocky Mountain operations, no hydroelectric dam was ever constructed by Montana Power on the Yellowstone.

The Missouri, however, with a theoretical "head" almost as precipitous, and with even more water to work with, has been dammed from one end to the other. Some of the first dams constructed on the Upper Missouri, at Great Falls (as well as Thompson Falls on the Clark Fork), saw much of their energy converted and electrically "channeled" to the driver wheels on one of the Milwaukee's unconventional locomotives.

By 1914, the transmission of hydroelectrical power had become a reality, and the Milwaukee Road was able to transmit 100,000 volts of alternating current at the very outset of electric operations. Converting electricity into useful mechanical power was still a relatively new concept in 1914, however, and the Milwaukee was utilizing some very recent, hard-won advances in transmission. Only 35 years earlier, in 1879, the best that could be achieved by some of the world's best scientists was a feeble transmission system (capable of running a single small pump) that spanned only tens, not hundreds, of miles.

The city of Munich staged an event that the participants hoped would rival, if not surpass, the Crystal Palace events in London. Industrial expositions were all the rage in nineteenth century Europe and North America.¹²² Most of these events had one particular centerpiece exhibit, architectural facet, or machine that was supposed to epitomize and exemplify the event's spirit of technological progress, and celebrate the ingenuity and craftsmanship of the event's participants. The titanic Corliss Steam Engine highlighting the Philadelphia Centennial Exposition in 1876, or a similarly colossal dynamo at the Chicago Exposition of 1893 that so disquieted Henry Adams in "The Virgin and the Dynamo" were more than huge powerplants—they were avatars for the progressive notions of both expositions and the larger world.¹²³

The waterfall at the Munich Exposition was hardly as prepossessing a sight as the prime mover for Adams's Dynamo, but the small, artificial cascade symbolized a formidable accomplishment and portended something equally important: the kinetic energy of water falling high in the German Alps had been transferred electrically over a distance of some thirty odd miles and converted to equivalent work on the other end -- an electric motored pump powering the artificial waterfall in the exposition's atrium, and by the standards of the time, the transfer of energy was extraordinarily efficient. (See Plate VIII, page 103).¹²⁴

¹²²Henry Petroski, *The Evolution of Useful Things* (New York: Alfred A. Knopf, 1993), 181-2.

¹²³Henry Adams, *The Education of Henry Adams* (New York: Random House, 1931), 279-290.

¹²⁴Thomas P. Hughes, *Networks of Power* (Baltimore: Johns Hopkins University Press, 1983) 131-2.



Plate VIII: The Waterfall at the Munich Exposition, 1879. Power came from a water driven turbine in the Alps, an unprecedented 50 kilometers away. Hughes, *Networks of Power*, 132.

Electricity could not only be used for lighting the incandescent lamps that Edison “invented.” As the Munich exposition proved, it could also theoretically be utilized to power motors -- very large motors, in fact. Indeed, in the arena of traction motors, direct current still has a distinct advantage over alternating current, because DC motors can run at variable speeds and powers simply by altering the circuit’s resistance or reconfiguring the circuit layout. An alternating current motor can also vary speed and power, but not without an unwieldy arrangement of transformers. Since speed is directly related to the input voltage - direct current varies its voltage level through resistance- with alternating current voltage is constant until transformed through induction. A more technical description of the comparative strengths and weaknesses of AC and DC motors follows below.

The current powering the pump motor at the Munich Exposition was still a baffling phenomenon in 1879. While current was undoubtedly being used at this early stage, no one knew its exact composition. Conceptually, electricity is a very slippery subject, especially alternating current. Like electrical current, many of the other potent scientific theories postulated within the last five centuries are fundamentally counterintuitive. The Earth seems flat, but is spherical. We live on the bottom of an ocean of air that presses against our bodies (a fact utilized in all steam engines) but we do not notice it in our everyday lives. Air is synonymous with lightness and thinness. Relativity is one of the most admired, if least understood, scientific concepts formulated, but both special and general relativity run against common sense. Experiments have proven both types of relativity theories correct, for the most part. Although scholars of

scientific history and cultural historians often fondly (and vaguely) hold up Newtonian mechanics as an example of commonsensical absolutism, there was nothing commonsensical about these laws, or the calculus, at the time when Newton and Liebnitz formulated them. Anyone struggling through a freshman calculus or physics class would hardly describe these courses as exercises in common sense. They “make sense” in large part because three centuries of venerable intellects tell us they do.

Electrical current remains, to this day, difficult to understand, particularly the alternating variety. Fundamentally, “current” means the transfer of electrons through any type of conductor; electrical engineers and electricians use metallic conductors such as silver, or more commonly copper. Quite simply, there is no simple solution or analogy for electric current. The word “current” obviously demonstrates some similarity to motion in water, but the analogy strains; nothing in our everyday experience corresponds to it. This analogy breaks down even more when it comes to alternating current; when a man with as much acumen as Thomas Edison failed to grasp its basic tenets, there remains little hope in this endeavor for the vast majority of American society.

A unique wonder accompanied electricity, before it became a literal commonplace. The Milwaukee and GE were heading into mostly uncharted technological waters with the electrification in 1914, and one needs to understand some of the basic concepts surrounding electrical current to appreciate the size and intricate nature of this undertaking.

Utilizing Electromotive Force

Initially, static electricity was the only kind known to science.¹²⁵ However, with Volta's invention of the electric pile (the battery) in 1800, current electricity, potentially far more useful, became the preferred tool of experimentalists.¹²⁶ Electrical current is often explained in terms analogous to water flowing through pipes. While useful, this comparison breeds certain confusions of its own. Humanity has manipulated the forces of electricity and magnetism more ingeniously than any other, but its intricacies still remain very difficult to explain in concrete terms. Lightning and lodestone (otherwise known as the magnet) were the mysterious beginnings of electricity's observable effects, but mankind has really only utilized it for the past 300 years, one of the most recent utilizations of one of the forces of nature. Electromagnetism is an ultimately explainable but still mysterious force that baffles legions of would-be physics students to this day. If one equates water with electricity too slavishly, one will be waylaid by confusion, especially in the case of alternating current. For the purposes of this thesis, however, the water analogy will suffice.

Electrical current has three distinct properties. There is *voltage*, or the difference in the potential of electromagnetic force. In this water analogy, voltage would be the pressure behind the water in the pipe. Voltage was particularly difficult to conceptualize,

¹²⁵Benjamin Franklin's famed experiments all dealt with static electricity, such as lightning and Leyden Jars (a primitive capacitor, which is a storage device for a static charge). Franklin gave science the terms positive and negative to describe the equal but opposite charges. Jonnes, *Empires of Light*, 23-25. Since static electricity is not used in motors or generators, it is only mentioned in passing here.

¹²⁶National Electrical Manufacturers' Association, *A Chronological History of Electrical Development*, 15.

and as a result conceptual terms surrounding voltage are muddled. There is also *amperage*, or current strength. This would be the total “amount” of the analogous water. Finally, there is *resistance*. This would be the figurative “width” of the pipe through which the water flows. This elegant proportional relationship between the three constantly changing factors in an electrical circuit is known as Ohm’s law, where current equals Voltage divided by resistance, stated in formulaic fashion as $I=V/R$. Current is measured in amps, voltage in volts, and resistance in ohms. In electric traction, motors, either wired in series, in parallel, or in combinations thereof, provide (useful) resistance. Anything else, such incidental motor heat and resistance grids, take the current’s energy and dissipate it into useless thermal energy.

Alternating current presents additional complications. This type of current fluctuates between two extremes in voltage. Put another way, the current reverses direction at regular intervals. The frequency of the current is the number of times it reverses direction per second, so the standard 60 hertz cycle used in North America reverses direction 60 times a second. Alternating current is graphically depicted as a sine wave.

Other important concepts with implications for alternating current are induction and transformation. Induction in its simplest form occurs when a piece of metal is passed between two bar magnets. Since the metal passes through fields of electromagnetic force, a current is briefly induced. This is the basic principle behind both motors and generators. Induction is also an important principle for alternating current voltage transformation. If two separate alternating current coils are placed on a common closed

loop of metal, the voltage can be raised or lowered, with a corresponding lowering or raising of amperage, depending on the difference of the number of windings on each coil. Induction and voltage transformation was essentially discovered by Michael Faraday, whose work is discussed in some detail below. Since very high voltages are best for transmitting alternating current, but unsuitable for use in the home, residential electricity undergoes a number of transformations before it reaches residential users.

Any discussion of electricity in early twentieth century America would not be complete without mentioning the “Battle of the Currents.” This struggle bears on the technology that the Milwaukee used for over 70 years. When it replaced its steam fleet with an electrical infrastructure in the Rocky Mountain and Cascade Divisions, the Milwaukee utilized, to great advantage, both alternating and direct current, using each in the application for which it was most efficiently suited. No one would have thought such a successful hybridization of the two currents would have been possible a scant twenty-five years earlier. In the late 1880s and early 1890s, the individual corporate sponsors for these two types of currents were bitter rivals. The corporate proponent of direct current, Thomas Edison’s General Electric, and the corporate proponent of alternating current, George Westinghouse’s eponymous Westinghouse Electric and Manufacturing Company, opposed one another in an almost unrestrained manner.¹²⁷

¹²⁷The Battle of the Currents, as well as Thomas Edison himself, remain two of the most popular subjects of technological history. This seemingly dry topic contains some very human and sensational elements, among them jealousy, stubbornness, greed, and even a capital murder trial. Limited space and relevance prevent extensive examination of this topic in this thesis. The episode provides an excellent example of human factors outweighing technical ones in a putatively scientific debate. This war was no zero-sum game, and AC’s ultimate “defeat” of DC was neither immediate nor dramatic. Rather, it was incremental, and direct current’s elimination in most residential

It probably would have surprised either man that the last transcontinental railroad in the nation would use both types of currents. For Edison especially, using both types of currents in any application was anathema. Especially in the arena of motors, DC had a long time advantage, and this was especially true of traction motors, as we will see. Importantly for the Milwaukee, the inventor of the practical DC traction motor, a design used by the Milwaukee and even by today's diesel electrics, was Frank Sprague, a one time employee at Menlo Park.

The Gilded Age was a fecund time for inventors, and in many instances more than one "right" technological answer to an industrial problem existed. One of the many questions awaiting resolution in the late 1880s was the best type of electrical current to use in home lighting, in heavy and light industrial applications, and in light and heavy transportation. A colossal prize awaited the system that showed a clear superiority to the other. North America was ripe for electrification, contained the wealthiest market in the world for such a service, and its people were the most amenable to large-scale

and commercial applications occurred over the span of some forty years in most cases. Alternating current held undeniable advantages in transmission over distance, but especially in urban areas (universally the first electrified) distance was initially insignificant. See Robert Conot, *A Streak of Luck: The Life and Legend of Thomas Alva Edison* (New York: Seaview Books, 1979); Thomas P. Hughes, *Networks of Power* (Baltimore: Johns Hopkins University Press, 1983); Richard Moran, *The Executioner's Current: Thomas Edison, George Westinghouse, and the Invention of the Electric Chair* (New York: Alfred A. Knopf, 2002); Margaret Cheney, *Tesla: Man out of Time* (New York: Barnes and Noble, 1993); Laurence R. Veysey, *The Emergence of the American University* (Chicago: University of Chicago Press); Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970* (New York: Penguin, 1989); Michael White, *Acid Tongues and Tranquil Dreams* (New York: William Morrow, 2001); Jill Jonnes, *Empires of Light: Edison, Tesla, Westinghouse and the Race to Electrify the World* (New York: Random House, 2003); Robert Pool, *Beyond Engineering: How Society Shapes Technology* (New York: Oxford University Press, 1997).

technological change.

Edison also had a personal stake in seeing that the Milwaukee thrived. Even as late as 1914, with his beloved direct current falling ever more into disuse, Edison still did not shy from touting its glories. For all of his successes, Edison remained personally humiliated by his 1892 ousting from GE, which was largely based on his own obstinacy in wishing to retain DC for any and all electrical applications.¹²⁸ AC, in spite of its obvious successes in most applications, loomed in Edison's mind as a deadly and impractical menace. He cabled the Milwaukee's president Earling with the usual congratulatory testimonials, expected from one of his station: "One of the great achievements permitted by the wedding of science and business. I admire the nerve of the railroad's financial backers."¹²⁹ Edison also might have mentioned the Milwaukee's "wedding" of alternating and direct current technology, but he studiously neglected to do so.

Doubtless, a great deal of acrimony existed between these two pioneering electrical companies, and a substantial amount of scholarship is still being produced on the subject. The Milwaukee's choice to electrify its mountain operations, however, was a concrete and large scale example that debunked the notion of a system "war." The railroad made use of both varieties of current, since electrical traction was basically the last technology

¹²⁸Jonnes, *Empires of Light*, 240-42. The GE/Houston Merger, in which investors gave Edison his walking papers, was a debilitating blow to Edison's ego.

¹²⁹Carpenter Kendall, "The Handwriting on the Wall," *Milwaukee Railway System Employee's Magazine* (February, 1916): 1.

best suited to direct current. Indeed, if such a conflict existed, it was between the differing varieties of motive power, not only for train locomotives, but also automobile-size vehicles. Witness the episode in the 1905-1920 period when steam was a viable competitor to Ford and GM.

Steel mills, factories, and railroads can all use electricity of both types. Alternating current does enjoy an overall preponderance in modern society's more basic functions. Moreover, the design of an alternating current motor, lacking relatively intricate mechanical arrangement of a direct current motor, is now simpler to manufacture and therefore cheaper to produce.

In terms of sheer numbers of motors and transmission components, alternating current has seen more use the past century than has direct. But the Milwaukee stood as a concrete example of the argument that the direct current system held sway in certain sectors of the economy. While not quite as large as the other transcontinental lines, it certainly was not considered small fry. The scale of its 1925 bankruptcy was unprecedented.¹³⁰ Put another way, the railroad was a major consumer of the nation's electrical supply, especially in its early stages. The way it utilized both types of currents was not some theoretical laboratory curiosity. It was big business. Since the motors themselves were the heart and soul of the Milwaukee's system, and saved the company between one and two million dollars annually, some key developments of the electric motor's evolution should be examined.

¹³⁰The Milwaukee's slide into receivership in 1925 was the largest in the American transportation sector's history, up to that time. ICC Document No. 17021-*Investigation of Chicago, Milwaukee & St. Paul Railway Company* (Washington: Government Printing Office; 1925), 615.

The evolution of motor design is a story that spans almost 170 years. For much of this period, however, most motors were too weak and unreliable, and remained the playthings of laboratory scientists until the 1880's. By the time of the Milwaukee's purchase of the Little Joe (the most powerful and modern straight electric design that the railroad would ever use) in 1948, motors could be made in almost any size and power, and today's designs are even more impressive in terms of versatility. However, all of the massive motors the Milwaukee used in both the General Electric and Westinghouse locomotives had ancestors that, while ingenious, hardly inspired awe when it came to power or amenability to practical applications. In the early nineteenth century British scientist Michael Faraday (1791-1865) designed and constructed what was widely heralded as the "first" motor. Faraday's work with both motors and the phenomenon of electromagnetic induction would have important implications not only for the Milwaukee Road, but also virtually anyone who lived in an industrialized nation.

Michael Faraday was in a sense the Thomas Edison of his time. Unlike Edison, however, Faraday's most famous accomplishments dealt with electric motors, one area that Edison never truly mastered. Born in one of London's worst slums in 1791 and brought up in wretched Dickensian circumstances, Faraday was rightly considered the leading figure in the experimental study of electricity in the first half of the nineteenth century. He achieved this stature in spite of a relative lack of formal training when compared to later scientific luminaries, and rise to fame was also helped by his natural affability. Additionally, Faraday had the gift of intuition in the study of electromagnetism. In the period Faraday worked, the early nineteenth century, a lack of theoretical

knowledge was of little moment to a man with Faraday's innate ability.¹³¹ While mathematics was astoundingly advanced and a useful tool in astronomy, surveying, and other applied sciences, when it came to formulating mathematical equations to explain electrical phenomenon, empirical observation and educated guesses from someone of Faraday's acumen were more than equal to the primitive state of electrical theory (to a certain extent, this axiom also applied to Edison some fifty years later). This tension between applied theory and empiricism is one of the fundamental hubs in technological history.

The origin of this first practical "motor" is a matter of dispute, mainly stemming from semantic and technical hair-splitting. Most cite Faraday as the figurative father of the motor, but this contrivance, built by Faraday in 1821, was a rather delicate laboratory curiosity. In previous experiments with direct current, Faraday had taken a small magnetized needle and put it adjacent to a wire carrying current. One of the needle's poles rotated, and Faraday realized that a single magnetic pole (which is an impossibility) could be made to rotate around a current carrying wire indefinitely, as long as current flowed in the wire. Intrigued, Faraday then resolved to construct a device that would solve the problem of isolating a single pole on any magnet. This consisted of a small bath of mercury, an excellent electrical conductor, into which he placed upright a small bar magnet, insulated from the mercury, with one pole above the top of the bath. Faraday

¹³¹ Keith J. Laidler's work *To Light Such a Candle: Chapters in the History of Science and Technology* (Oxford: Oxford University Press, 1998) is a masterful examination of Faraday's accomplishments, asserting that he was easily the equal of Einstein, Bohr, and other Nobel Prize winning physicists. Laidler argues persuasively that Faraday would have won at least six Nobels, had the prize existed during his lifetime. See pages 156-58.

completed the arrangement by attaching a free-moving wire to a frame above the basin, and dipping one end of this wire into the mercury. When current was put through the wire and the mercury, the wire moved. If the poles of the magnet reversed, the wire rotated in the opposite direction. Although Faraday was merely trying to demonstrate experimentally that circular lines of force existed in current flowing through a wire, it was also the world's first instance of electrical energy being transformed into mechanical energy. Faraday had invented the motor, albeit an impractical one. (See Plate IX, page 115). However unlikely it may seem, the huge and powerful motors used by the Milwaukee to such great effect can trace their origins to this delicate device.

The Milwaukee would also utilize another of Faraday's discoveries: Induction. The alternating current generated and transmitted by Montana Power and put to such impressive and efficient use by the Milwaukee Road had to be transformed a number of times before it could be used by the locomotives. Although Faraday did no real work with alternating current, his initial observations on induction in 1831 made the efficient transformation of alternating current both understandable and readily workable by the beginning of the twentieth century.¹³² (See Plate X, page 116).

¹³²Laidler, *To Light Such a Candle*, 131. Like Faraday's first motor, his experimental apparatus for the first induction experiments was also a deceptively simple arrangement belying a complex concept. It consisted of nothing more complicated than an iron ring wrapped by two separate coils of insulated wire. Since Faraday only had direct current batteries at his disposal, current was only induced from the "primary" to the "secondary" winding when Faraday *started* or *stopped* the current. In other words, current is only induced from one coil to another when there is a *change in the level* of the current. Subsequent research would reveal that since alternating current changes (when it reverses its direction in the coil windings) induction would also occur, and consistently. This is why AC is so amenable to transformation, and is also why induction never occurs in a direct current while it is running in its circuit. Voltage and current levels are easily manipulated by varying the number windings in each coil. Meleaf, *Electricity 1-7*, 3-74.

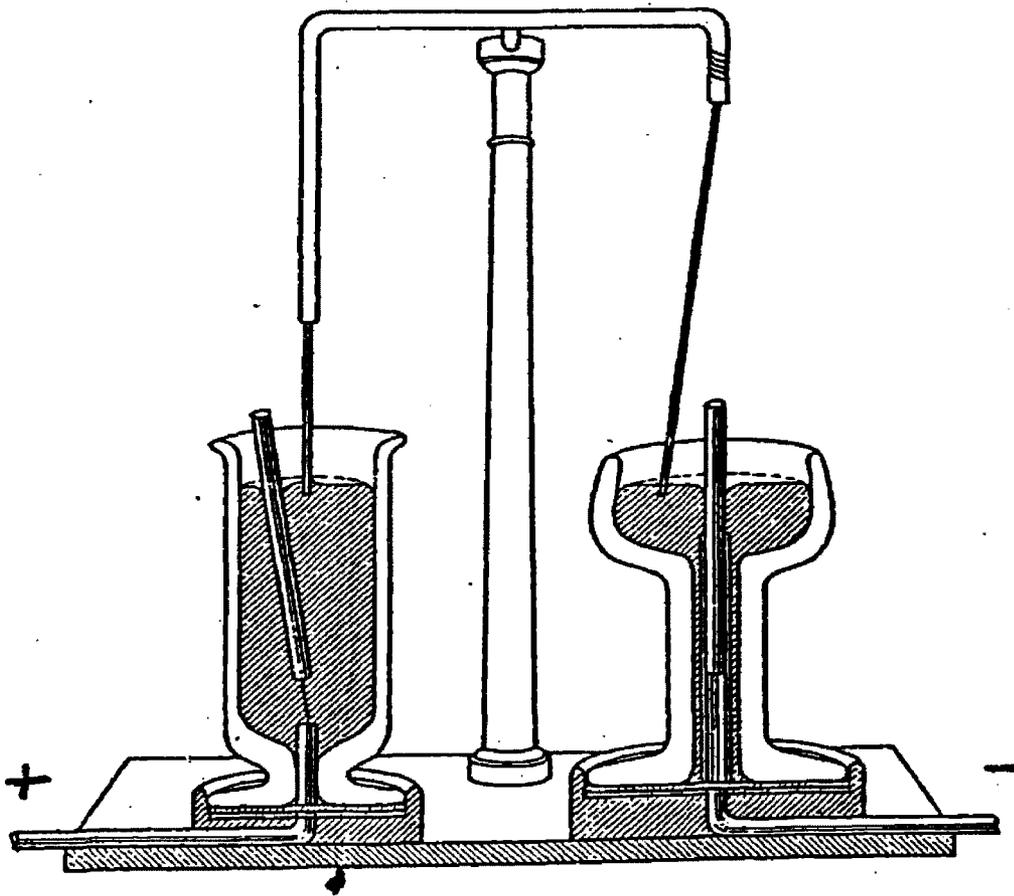


Plate IX: Faraday's 1821 Protomotor. Laidler, *To Light Such a Candle*, 133-34.

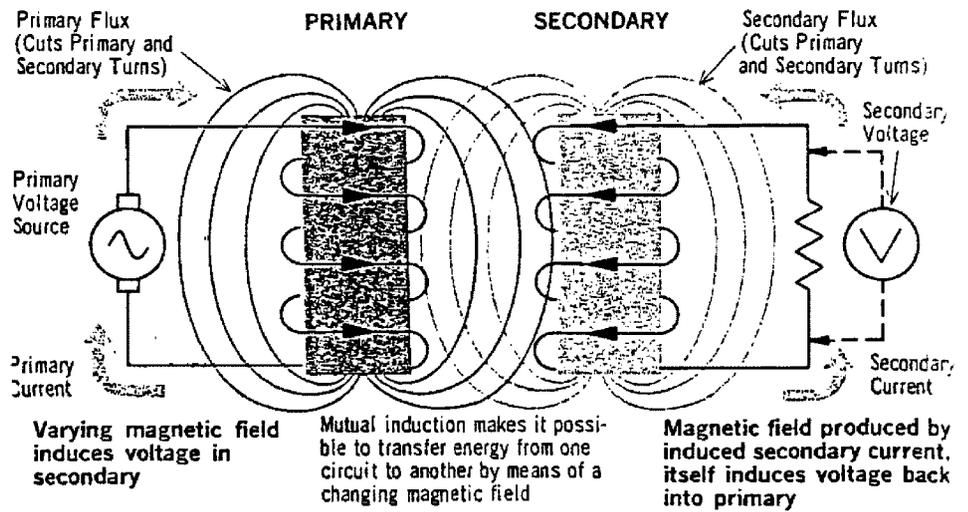
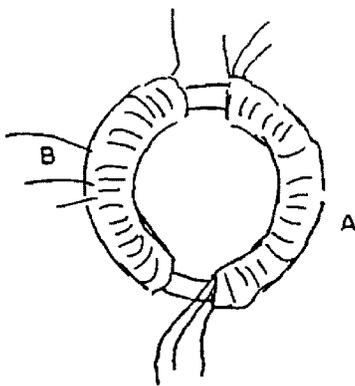


Plate X: Faraday's 1831 sketch of the apparatus he used to discover induction, and a schematic diagram of the forces at work when induction takes place. In this case, the number of windings on both coils is the same. To manipulate voltage and current, the number of windings on the secondary coil must vary from the number of windings on the primary-coil. Induction schematic diagram from Harry Meleaf, *Electricity 1-7, 3-74-75*.

The AC current that originated from the dam turbines at Black Eagle and Thompson Falls was generated at 2400 volts, transformed to 100,000, and transformed yet again to 2300 volts for AC synchronous motor/DC generator sets in each of the 13 substations in the Rocky Mountain Division. Thus, the Milwaukee, like many other early twentieth century corporations, were eagerly making use of a hard-won series of advances in electrical engineering that could trace their beginnings to Michael Faraday's laboratory in the 1820s.

More robust, practical motors followed Faraday's. Interestingly, many of these earliest motors attempted to mimic the reciprocating motion of the dominant prime mover of the time, the steam engine. Again, we see the phenomenon of entrenchment and inertia (the QWERTY principal) of an older technology acting as a design template for a newer one, even if the results were awkward and inefficient. A motor designed in the 1850s by inventor Charles Grafton Page provided an example. Page's design consisted of a pair of solenoids which were intermittently fed with direct current. When current ran through the solenoid, it attracted a cast-iron "cylinder" which was attached to a conventional flywheel system.¹³³ (See Plate XI, page 118).

The tiny size of Faraday's first motor was ultimately a tribute to electricity's versatility and amenability to engineering modifications. Electric motors started small and grew very large; steam engines started very large. The first Newcomen engines had

¹³³ Sigvard Strandh, *A History of the Machine* (Gothenberg, Sweden: Nordbok, 1979), 156.

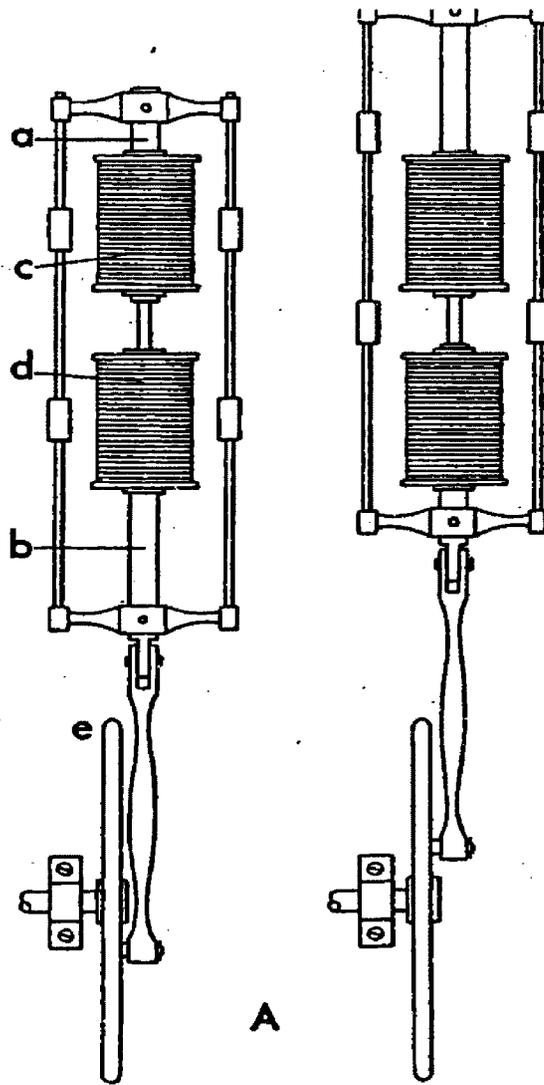


Plate XI: Atavism – The Grafton-Page Electric “Piston” Motor, circa 1850. Sigvard Strandh, *A History of the Machine* (Gothenberg, Sweden: Nordbok, 1979), 156.

bores well over six feet.¹³⁴ and now can be made unbelievably small.¹³⁵ (See Plate XII, page 120). From the standpoint of designers and engine wrights, it is much easier to start small and scale up than it is to start large and miniaturize. The 70-year transition from vacuum tubes to transistors, ending with the silicon chip is but one example of dearly bought miniaturization. However humble, the huge motors used by the Milwaukee can trace their ultimate ancestry to Michael Faraday's contrivance of 1821. (See Plate XIII, page 121).

Faraday's ingenious arrangements of Mercury and wire would eventually have no practical limit on their size. While the power of the Corliss steam engine exhibited at Philadelphia in 1876 was immense, only some thirty years later an electric motor could conceivably be constructed to match it, horsepower for horsepower. What happened in the century between Faraday's small curiosity and motors capable of hurling a 1,500 ton passenger train at speeds of up to 90 miles per hour?

One key was the invention of the *commutator*, a pivotal component of any direct current motor. Although its origins remain somewhat obscure, the commutator is exemplary of nineteenth-century mechanical ingenuity.¹³⁶ The commutator's function is

¹³⁴Leonard C. Brun, *The Tradition of Technology: Landmarks of Western Technology in the Library of Congress* (Washington: Government Printing Office, 1995), 228.

¹³⁵William C. Fitz (Ed.), *Steam and Stirling: Engines You Can Build* (Traverse City, Michigan: Wildwood Publications, 1980), 49.

¹³⁶The commutator seems to have been developed independently in both France and England, about a decade after the debut of Faraday's 1821 motor. National Electrical Manufacturer's Association, *A Chronological History of Electrical Development from 600 B. C.* (New York: National Electrical Manufacturers Association, 1946), 22-3.

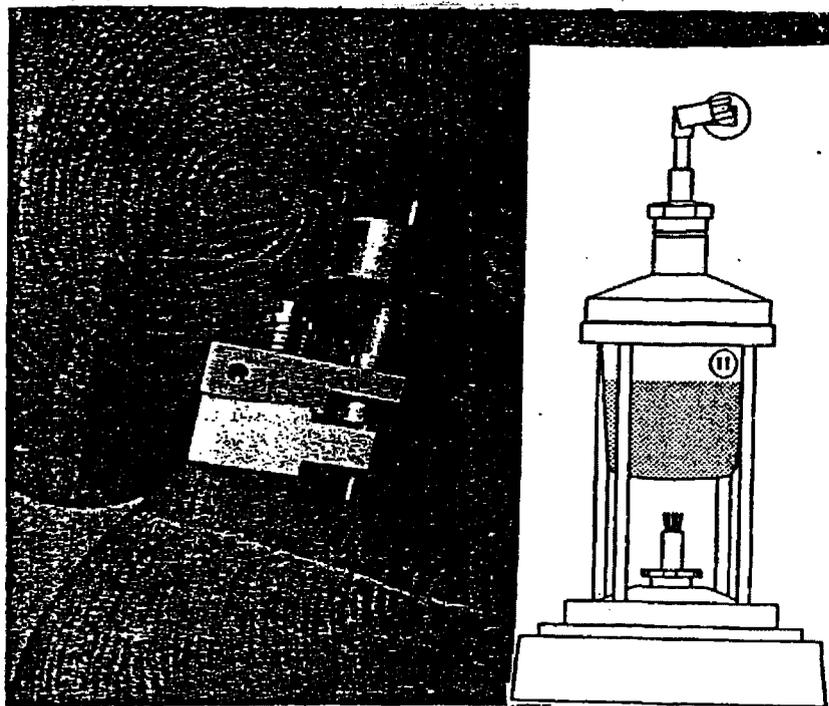
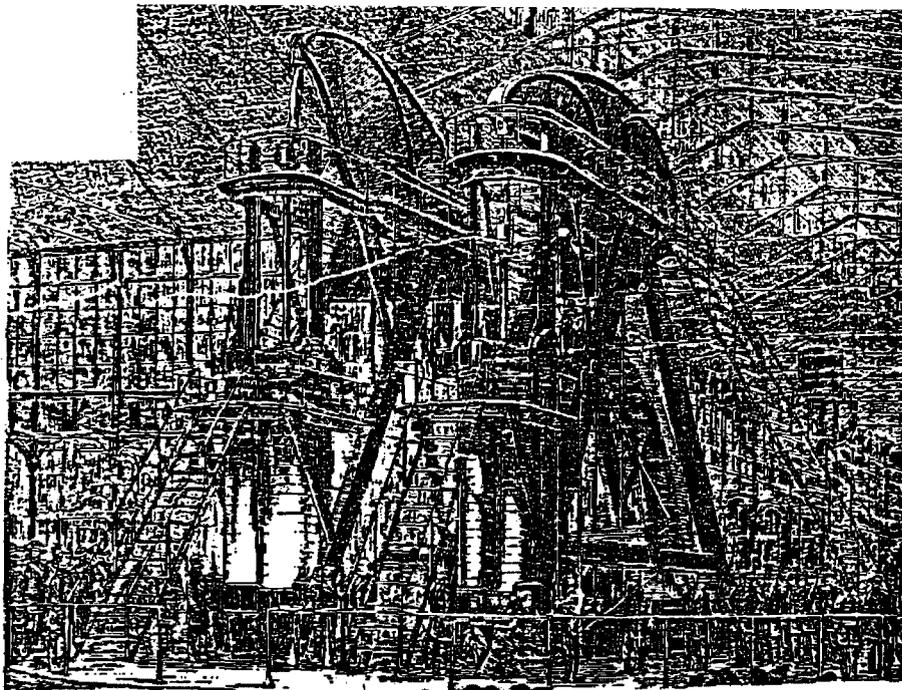


Plate XII: Range of Sizes in Steam Engines: Nineteenth and Twentieth Centuries -From "Heavy Industry" to "Hobby."

Above: The Corliss Beam Engines of the 1876 Centennial Exposition at Philadelphia. Leonard C. Brun, *The Tradition of Technology: Landmarks of Western Technology in the Library of Congress* (Washington: Government Printing Office, 1995), 228.

Below: A "Thimble Boiler" Hobby Engine. William C. Fitz (Ed.), *Steam and Stirling: Engines You Can Build* (Traverse City, Michigan: Wildwood Publications, 1980), 49.

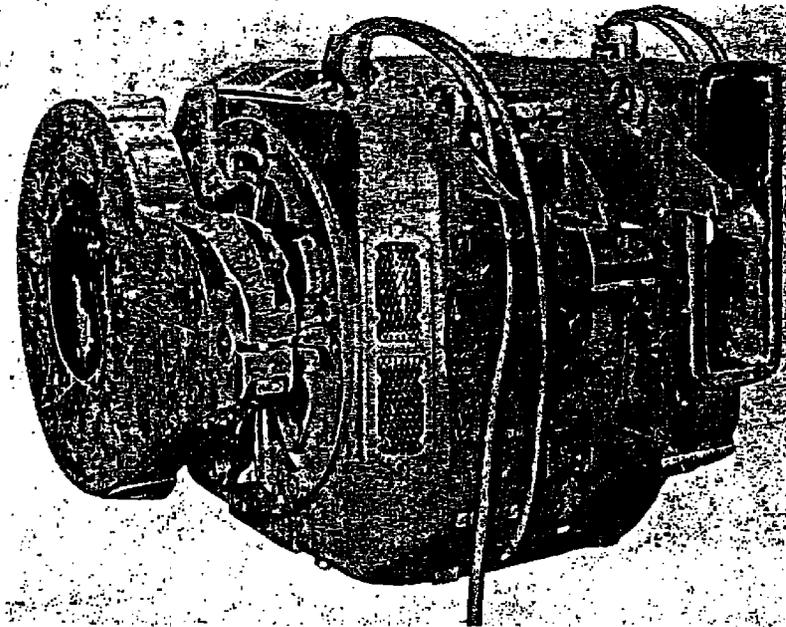
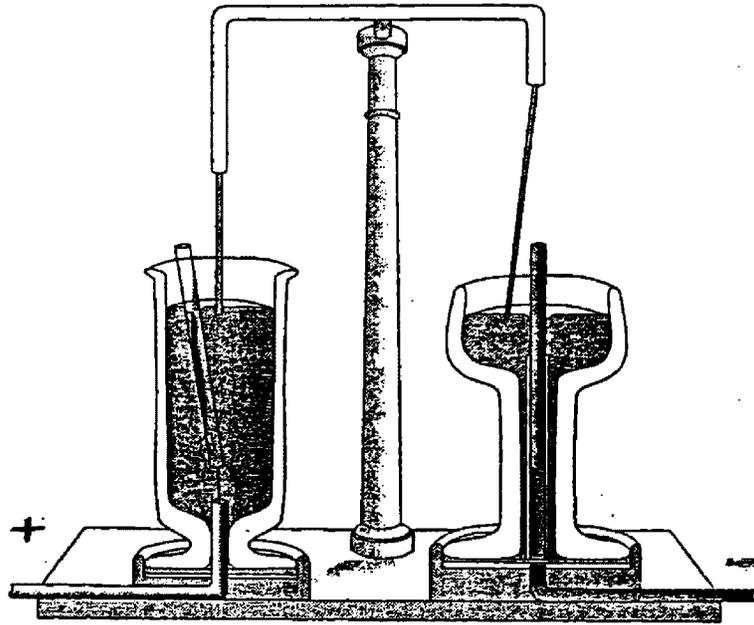


Plate XIII: Range of Sizes in Motors, Nineteenth and Twentieth Centuries - From "Hobby" to "Heavy Industry"

Above: Faraday's 1821 Protomotor. Laidler, *To Light such a Candle*, 134.

Below: A GE 253 A 3,000 Volt Commutating Pole Motor used in the EF-1 and EP-1 Locomotives. Wood and Wood, *Milwaukee Road West*, 133.

to take the alternating current that any generator produces, and mechanically turn the alternating current into the direct variety. The commutator was developed to alleviate a vexing obstacle to a practical rotary motor. Three out of the four primary ingredients for a simple DC motor are two bar magnets placed with the attractive ends facing one another, yet placed far enough apart that they do not contact one another. A “T” shaped bar, with a wire coil wrapped about the top of the “T.” Each end of the coiling wire is then run down the side of the “T.” When current is supplied to the wire at the base of the “T” from a battery through contacts (known as brushes), the “T” (more correctly known as an armature) is magnetized. If the armature is oriented correctly with the magnets, both the “north” end of the stationary magnet and the “north” end of the movable armature face one another, and repulse, causing the armature to move. Without a commutator, however, the motor promptly stalls because the attractive ends of the armature and the magnets now face one another, essentially locked in place magnetically.¹³⁷

In its simplest form, a commutator consists of two hemispherical rings of a conductive metal, usually copper, each insulated from the other. These rings are in contact with the brushes and the split in the rings ensures that the armature reverses its magnetic polarity every half turn. This ensures that either end of the armature is repulsing, rather than attracting, against the magnet it faces. (See Plate XIV, page 123). In

¹³⁷The same can be said of direct current generators (dynamoës), which also rely on commutators. In the simplest case, a metal loop is rotated between the poles of a horseshoe magnet, the current induced, however, is alternating, because of the constant rotation of the loop through the magnetic field. In this case, the commutator ensures that, every time the current in the loop reverses polarity, the brushes are switched from one half of the commutator to the other, converting the alternating current to direct. Harry Mileaf (Ed.), *Electricity One-Seven* (Rochelle Park, New Jersey: Hayden Book Company, Inc., 1977), 6-74.

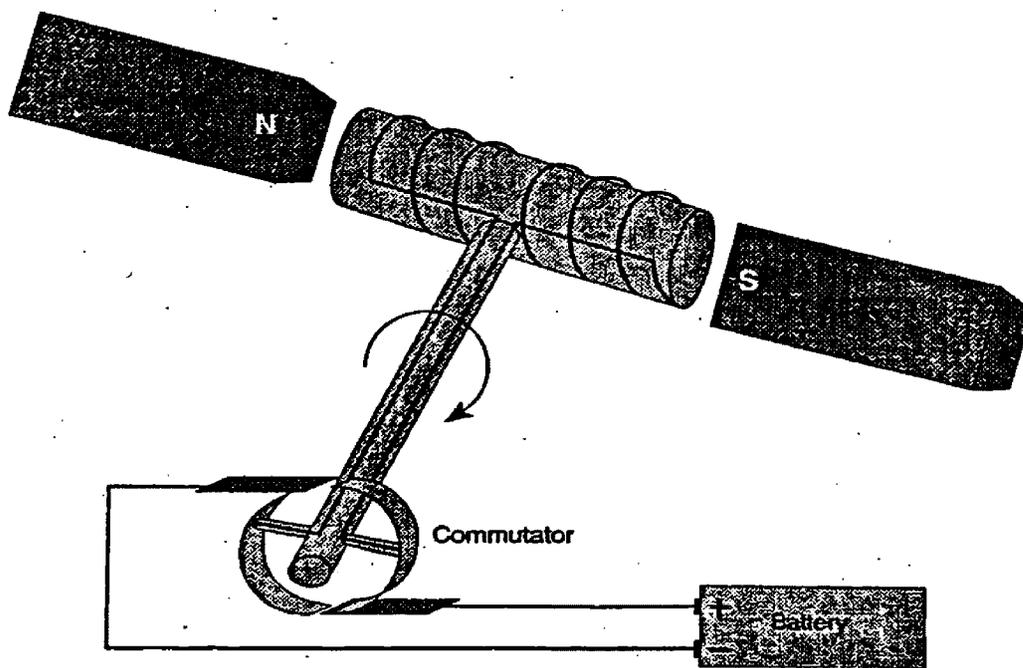


Plate XIV: A Simple Commutator. This arrangement reverses polarity in an armature, in this case the "T's" top, every half turn, ensuring that the repulsing ends of the stationary field magnets and the magnetized poles of the armature are always closest and the attracting ends most distant. From Laidler, *To Light such a Candle*, 134.

practice most motors have several stationary field magnets, not just two, and an arrangement of intermittently split copper rings and mica insulation was used in the early twentieth century.¹³⁸ As motor design evolved, commutators became much more intricate, a contrivance any watchmaker in 1850 would have admired for its impeccable mechanical timing. The commutator, in whatever form, is one of the most refined examples of ingenuity in electromagnetism.

However, commutators were meddlesome to put work in practice. Brushes arced constantly, and getting the timing to work properly required first class mechanical ingenuity. Direct current motors were undeniably simple in concept, but developing one reliable enough for heavy industry was another matter taking over 50 years. Fortunately for the Milwaukee, however, DC motors were an entirely workable proposition by 1910.

The AC motor proved more elusive to inventors, and not surprisingly, Nikola Tesla was largely responsible for developing an AC motor from an exotic classroom theory to a practical machine. AC and DC motors are fundamentally different, and an AC motor was not a practical solution to a company like the Milwaukee Road. However, since AC motors would become virtually ubiquitous in an industrial society, it would be instructive to further examine this device and to explain why it was not suitable for electrical traction applications in its earliest form.

Since an AC motor has a “whirling magnetic field” (See Plate XV, page 125) that acts upon the rotor, one of two conditions have to exist for its practical use: with the American standard frequency of an alternating current of 60 cycles per second, the rotor

¹³⁸International Textbook Company, *Types of Railway Motors* (London: Stationer’s Hall, 1909), 9.

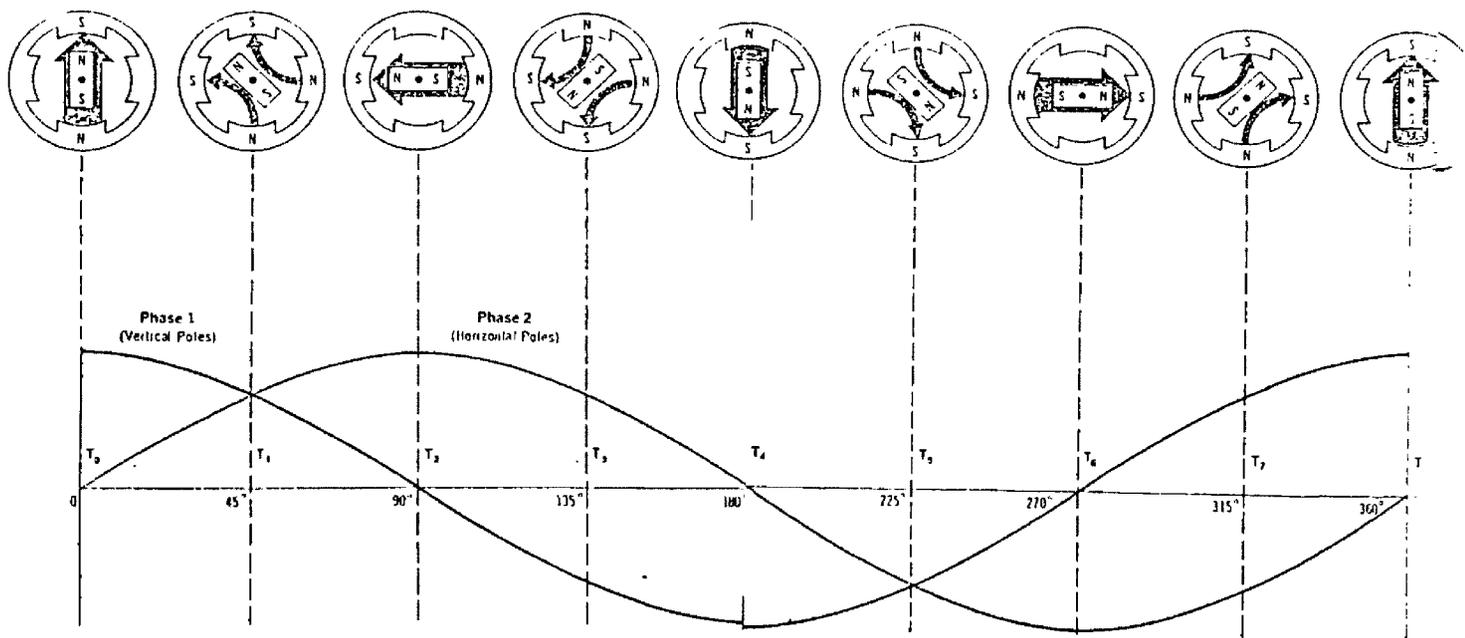


Plate XV: A simple two phase AC induction motor, and its rotating magnetic field.

When one current is at zero power, the other current is at maximum power. In the case of the AC motor, the movable armature (known as the *rotor*) is a simple bar magnet, with permanently fixed poles. The *stator* (in this case, four evenly-spaced stationary points surrounding the rotor) has a magnetic field that is in constant flux, causing the rotor to move. In the interests of clarity, a two phase motor is used as an example. Most modern AC induction motors are three phase rather than two phase, and therefore have three pairs of stators rather than two. Diagram from Mileaf, *Electricity 1-7*, 7-94-95.

had to be under a very light amount of physical load even to begin moving. For heavy applications such as a freight locomotive, the frequency had to be less than half of the standard 60 hertz frequency – either 25 or 12 ½ cycles per second.¹³⁹ Interestingly, the Westinghouse Company proposed a 14,000 volt, 15-cycle alternating current system for the Milwaukee’s use, but the motors would still have to be direct current, and the current transformation/conversion machinery required on board the locomotive was far too complicated (at that time) to be workable when compared to the GE system.¹⁴⁰ Since changing the frequency of an alternating current even today remains complicated and expensive practice, it has only seen large scale use in electrical traction fairly recently. The AC synchronous motors the Milwaukee used to convert AC to DC at their substations had to be “primed,” for want of a better word, by a secondary DC motor called an “exciter” before the rotating magnetic field could seize the rotor. (See Plate XVI, page 127). If the load was excessive, such as a 4000 ton train refusing to budge, the stator field cannot “grab” the rotor and move it. This is known as “slip.” Suiting an AC motor to its load can be done, but then the problem becomes constancy of speed. While

¹³⁹On the other end of the spectrum, frequencies as high as 133 and 1/3 cycles per second have been proposed. Generally speaking, low frequencies are poorly suited to lighting applications, and high frequencies are unsuited for electrical traction, as well as anything else requiring power and torque. An alternating current with a frequency of 8 and 1/3 hertz, while excellent for motoring a locomotive, would cause a very noticeable (and basically intolerable) flickering in a light bulb. The standard 60 hertz frequency used today in North America represents a compromise between the two philosophies. “The Day They Turned the Falls On: The Invention of the Universal Electrical Power System,” (Online at <http://ublib.buffalo.edu/libraries/projects/cases/niagara.htm>, downloaded 5/30/02), 17-18.

¹⁴⁰Author Unknown, “Electrification of Chicago, Milwaukee & St. Paul,” *Electrical World* 62:22 (November 29, 1913), 103.

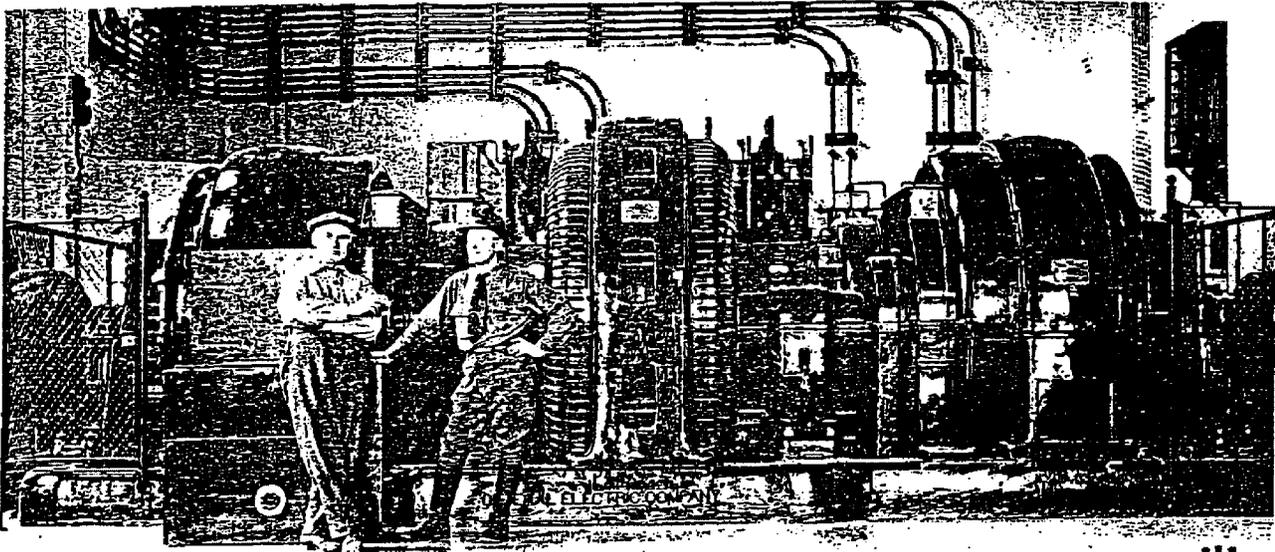


Plate XVI: The Milwaukee's motor-generator sets that converted AC to DC in the substations had an additional refinement, and differed slightly from induction motors. These machines were known as "synchronous" AC motors. In this case, the rotor was an unmagnetized bar of iron wound with a wire carrying direct current that magnetized the bar. The electrodynamics were somewhat complicated, but the basic difference between this type and an induction motor was that the rotor in an induction motor lagged slightly behind the rotating field. In a synchronous motor, the rotor spun at *exactly* the speed of the current's frequency. The practical implications of this for the Milwaukee was that this type of motor aided greatly in both the regulation of the frequency coming into the substation from the 100,000 volt AC transmission lines, as well as providing precise speeds for DC power generation. The photograph above shows a typical motor-generator set used in the Milwaukee substations. The AC synchronous motor is the large, heavily ventilated unit in the middle. It is flanked on either side by two 1,500 volt DC generators wired in series to provide 3,000 volts to the trolley wire. Such arrangements are now obsolete and current is now converted from AC to DC ("rectified") electrochemically rather than mechanically. However, the motor-generator set was an excellent example of AC/DC technology combined in a very efficient fashion – Thomas Edison's worst nightmare. Illustration from Holley, *The Milwaukee Electrics*, 164.

an admirable quality in most applications, such as fans, drills, generators, and friction cutting tools, to name only a few, attaching a truly constant speed motor to a locomotive was not only undesirable; it was tantamount to suicide.¹⁴¹ Theoretically, in 1914, an AC motor could be constructed that was large enough to move 4000 tons from a standstill on a perfectly flat grade. One might even be constructed to move that weight over some of North America's most formidable mountains. However, the daily usefulness of such a motor remained questionable. AC motors worked best at one constant speed; an early AC-motored locomotive was no match for a steam engine or direct current locomotive. Choosing this type of motor meant unwieldy designs and cost time and money in lost performance.¹⁴²

Early AC motors were also contrary when it came to voltage manipulation, which was somewhat ironic, considering this was its shining quality in transmission. While it is true that alternating current motors dominate today's industrial and household domains, and are much simpler and idiot-proof in terms of operation and maintenance, this was not always the case. It took a genius on the order of Nikola Tesla to conceive of such a motor, and the fabrication of a practical one took at least a decade of his toil.

¹⁴¹Tellingly, the first practical application of Tesla's famed induction motor was a small electric fan he invented in 1889. Literally billions of similar design would follow. The fan motor's output was 1/6 horsepower, and marketed by Westinghouse. Siegfried Giedion, *Mechanization Takes Command: A Contribution to Anonymous History* (New York: W. W. Norton & Company, Inc. , 1948), 558. However, most residential-sized motors run off of a single split- phase motor. Interview with Jon Roholt, July 30, 2004.

¹⁴²Single phase alternating current motors had been used for interurban trolleys the first two decades of the twentieth century, but they were heavy, inefficient, complicated, and twice as expensive to maintain when compared to contemporary direct current motors. George W. Hilton and John F. Due, *The Electric Interurban Railways in America*(Stanford: Stanford University Press, 1964), 59.

In comparison DC motors, simple conceptually and well understood by the turn of the century, offered a variety of speed and torque settings, and were an extremely sensible choice for the Milwaukee.¹⁴³ Additionally, the new motors were not only powerful and workable, and ran with a startling (to the point that this quality was almost universally commented upon) smoothness. This smoothness in starting and stopping, when compared the herky-jerky motion of a train pulled by a steam locomotive, was a distinct operational advantage for the Milwaukee. Sheered couplings and derailings, while not altogether eliminated, occurred much less often after the electrification.

Edison had dabbled with a direct current locomotive that could haul about three-quarters of a ton at a top speed of 40 mph, but for better or worse it was one of many neglected stepchildren in his myriad of projects, and Menlo Park would eventually obtain all of its DC motors from his former underling, Sprague.¹⁴⁴ Most scholars of technology

¹⁴³Generally, output torque in a DC motor is directly dependent on the amount of current going into the armature. Torque and speeds of modern DC motors are so easily controlled in this fashion that they are at a premium in delicate applications where finely controlled variable speeds are required, such as textile manufacture. DC motors can operate at as little as five to seven percent of the “base speed” (i.e., when the full current available is applied to the armature and it rotates at its maximum speed). This flexibility comes at a price, however. DC motors are more complicated mechanically, bigger, and more expensive than a comparably powered AC motor.

The constant base speed and torque of an AC motor is determined by the fixed number of windings on the poles that produce the rotating magnetic field. AC motors can (and do) “slip” when torque load on the motor increases. In terms of disadvantages for AC motors, speed control equipment is very complicated and expensive, and they tend to overheat at low speed when operating under a heavy torque load (two almost fatal flaws for this type of motor when it comes to electrical traction).

See www.instantweb.com/o/oddparts/acsi/motortut.htm.

¹⁴⁴At this point in his life and even much later, Edison was particularly enamored of the idea of electromagnetic separation of base and precious elements in metallic ores, especially gold and silver. He remained long convinced that the successful outcome of

cite Frank J. Sprague as the true father of the practical, mass produced, direct current traction motor that the Milwaukee would come to use (and that modern diesel electrics use as well).

Tellingly, some of the earliest electric motors were of the reciprocating type. The concept was so ingrained that the components of these motors resembled, piece for piece, those of a steam engine.¹⁴⁵ Old habits die hard the world over. There was also a corresponding atavistic phenomenon in locomotive design. While the motor in the illustration below is a rotary one, the motion of the motor is converted *back* to the reciprocating type via a jack shaft, which in turn drove conventionally coupled drivers.¹⁴⁶

Frank Sprague and most other inventors took a different tack. The long term trend was toward rotary designs. Electric motors in this era, in the case of GE's unusual Bipolar design, could even be altogether gearless, the purest form of rotary motion. The Bipolar's motors took this philosophy to its furthest extension. Most, however, employed reduction gearing on the inside of the wheel, very similar to Sprague's first hanging-nose design.¹⁴⁷ A form of Sprague motor is in fact used to this day on diesel electric locomotives, more than an century after the advent of Sprague's practical design.

this project would make his fortune accrued from the incandescent lamp look paltry in comparison. Neil Baldwin, *Edison: Inventing the Century* (New York: Hyperion Press, 1995), 119-20.

¹⁴⁵A. Sivard Strandh, *A History of the Machine* (Gothenberg, Sweden: Nordbok, 1979), 156.

¹⁴⁶William D. Middleton, *When the Steam Railroads Electrified* (Seattle: Kalmbach Publishing, 1974), 423.

¹⁴⁷ Middleton, *When the Steam Railroads Electrified*, 422-423.

Technically, a Sprague motor is classified as an axle hung, nose-suspended motor, with a single reduction gear. The Milwaukee's original General Electric freight and Little Joe locomotives both had this type of motor, and most modern diesels have it as well. In a Sprague layout, a high speed motor drove a pinion gear, which in turn drove a reduction gear arranged on the driving axle. Although the motor's housing was clamped to the axle to ensure proper gear tooth alignment, most of the motor's weight was suspended from the wheel-truck. This system had two advantages. Using "nose suspension," rather than having the motor directly over the axle, meant a locomotive's weight distribution tended to be better with Sprague motors, and this type demonstrated clear superiority with their lower center of gravity over rival electric and steam systems. Additionally, unlike the Bipolar "gearless" system, gear tooth ratios could be adjusted in motors if they required modification to either freight or higher speed (and therefore lower power) passenger service.¹⁴⁸

Sprague's various innovations were the death knell of cablecars, and cable traction and kinetic-type power transmission (such as the 200 odd-wheelpit scheme proposed at Niagra Falls) in general.¹⁴⁹ Any job that a cablecar did, in spite of its superb

¹⁴⁸ Holley, *The Milwaukee Electrics*, 282-83.

¹⁴⁹In the "Battle of the Currents," Westinghouse had not only won out over a rival electrical infrastructure. The company also vanquished sundry competing mechanical systems for transmitting energy. Most scholars peg the definitive triumph of alternating over direct current to Westinghouse's famed award of the Niagra Falls Project in 1895, which would ultimately power nearby Buffalo. The obvious efficiencies attained in transmitting "juice" over long distances with alternating, rather than direct, current made it an easy decision for the early American utility companies. In all likelihood, either electrical system would have been more efficient than proposed kinetic energy, mechanically based systems. In spite of electricity's early promise, a series of 238 hydromechanical turbine wheel-pits, 12 inlet tunnels, countless pulleys, and cable loops

ingenuity, a direct current trolley car could do better.¹⁵⁰ The key weaknesses of cablecars were very heavy installation expenses, more complicated machinery, and poorer overall performance compared to trolley cars, especially over distance. Even in the formative years of electrical traction, cablecar operation was not competitive, except in the most short distance, high traffic situations.¹⁵¹ The vast distances of the Dakotas and eastern Montana made cable traction an altogether all ill-suited solution to the Milwaukee's operational problems by 1915.

Regeneration and Shunting

Another extremely important facet of motors which would have practical, money-saving implications for the Milwaukee was the phenomenon of regeneration and shunting. Unlike other applications of motive force which use heat (coal, oil, gasoline), electrical designs can switch easily, and much more efficiently, between mechanical and electrical energy. The fuel that a coal fired train uses undergoes one way entropy. Fuel, in

stretching for two-and-a-half miles, was still a seriously considered option as late as 1886. Two pneumatic and hydraulic systems were proposed as well. Although complicated, a system running on compressed air could run existing steam plant in Buffalo with very little conversion. The excessive capitalization required by both hydromechanical and pneumatic systems encouraged the Niagra committee to pursue electrical options, and arguably made the most sensible choice at the time. "The Day They Turned the Falls On: The Invention of the Universal Power System" (Available online at <http://ublib.buffalo.edu/libraries/projects/cases/niagara.htm>, downloaded 5/30/02), 4-7.

¹⁵⁰George W. Hilton, *The Cablecar in America: A New Treatise upon Cable or Rope Traction as Applied to the Working of Street and Other Railways* (Berkeley: Howell-North Books, 1971), 147-151.

¹⁵¹George W. Hilton, *The Cablecar in America: A New Treatise upon Cable or Rope Traction as Applied to the Working of Street and Other Railways* (Berkeley, California: Howell-North Books, 1971), 153.

the form of coal is used to produce heat for the boiler of the locomotive, is irrevocably destroyed. Once the smoke billows from the stack, it cannot be efficiently converted back into useful energy.

Electricity is far more malleable and multifaceted as an energy source; both its intensity and type can be altered with exquisite control, and the energy can be recycled to a useful extent. Electrical energy can be converted into mechanical energy and once again be turned back into electrical variety. Such efficient arrangements are currently impossible with other types of energy. The Second Law of Thermodynamics states that such transfers are never perfect, since some energy is lost in the form of heat, but electricity is far more versatile in this sense than any other motive force currently used. Once a pound of coal or a pint of oil gives up its thermal energy, it produces water and a variety of gasses; in practice it cannot be turned back into a fuel.¹⁵² As early as 1863, it was possible to modify a direct current generator into a motor, and vice versa.¹⁵³ So similar, in fact, are these two types of direct current machinery, that an 1894 electricity textbook treats them as the same thing in virtually all cases.¹⁵⁴ The Milwaukee Road was

¹⁵²Richard Rhodes, *The Making of the Atomic Bomb* (New York: Simon & Schuster, 1991), 30.

¹⁵³Antonio Pacinotti announced the discovery of this phenomenon in that year. National Electrical Manufacturers Association, *A Chronological History of Electrical Development from 600 B. C.* (National Electrical Manufacturers Association, 1946), 35.

¹⁵⁴Francis B. Crocker and Schuyler S. Wheeler, *The Practical Management of Dynamos and Motors* (New York: D. Van Nostrand Company, 1894), 11-12. "Heretofore writers on the dynamo or motor have usually treated these machines entirely distinctly, and books or papers relating to the dynamo usually contain nothing about the motor or merely consider it briefly in a few special chapters, and books on the motor refer to the dynamo only incidentally. The authors have found that there is no necessity for this separation; in fact, nine out of ten statements which apply to the dynamo are equally

fully aware of this fact, and made it the basis of its regenerative braking system. The operator merely had to throw a switch and the train's motors became generators. No such parallel exists in either external or internal combustion power plants.

Regeneration is an important concept that bears some explaining, and it is also closely related conceptually to the practice of "shunting." The Milwaukee was in a unique position among American railroads because electrical traction's operational versatility made it possible for the company to use the kinetic energy of a descending train not only for braking itself, but even for powering ascending trains.

In motors, torque results from the interaction between the magnetic field force lines and the armature. Operating motors or generators, by their very nature, produce counterelectromotive force (CEMF), caused by the armature or rotor cutting through the surrounding field magnets line of electromagnetic force.¹⁵⁵ Conversely, motor action occurs in generators for the same reason. This is known as "countertorque." The lower the speed, the less the CEMF. Correspondingly, when speed increases, CEMF increases as well.¹⁵⁶ When current is applied to start the armature turning, it will flow in the direction determined by the applied DC power source. After rotation starts, the motor's conductor cuts electromagnetic lines of force.¹⁵⁷ Increasing field strength lowers the

applicable to the motor."

¹⁵⁵Mileaf, *Electricity 1-7*, 7-43, 7-45.

¹⁵⁶Mileaf, *Electricity One-Seven*, 7-48.

¹⁵⁷Mileaf, *Electricity One-Seven*, 7-49. While CEMF limits the motor's base speed, its role is quite important. For instance, if the motor armature is jammed, the low resistance of the armature's copper windings cannot handle any voltage applied, a huge short circuit ensues, and the motor immediately overheats and can eventually be destroyed unless the jam is cleared. With application of current the armature moves and

motor's speed while increasing its torque. When the current is lowered, or "shunted," the field's strength is lowered, resulting in a higher speed.

The practical implications for the Milwaukee of this phenomenon were many. At a certain point, if the field strengths surrounding the armature were consistent, a state of equilibrium is reached, the motor can rotate no faster, and is effectively half generator and half motor. Thus motors have a built in speed limiting device.¹⁵⁸ The only way to increase motor speed (which incidentally lessened power) was to weaken the overall electrical field surrounding the armature, which is known as shunting. The Westinghouse passenger locomotives, again possibly owing to the relative inexperience of the company in this field, were inadvertently designed to be particularly amenable to shunting. The first shunt lowered field strength to 86 percent of the normal field strength; the second shunt lowered it to 72 percent of normal field strength.¹⁵⁹ The field could be weakened even further as well. Retired Milwaukee fireman Bill Merrill succinctly explained Westinghouse's unwitting contribution to speeds higher than considered advisable:

There was one thing you could do on a Westinghouse and make it beat anything on wheels, you see, the Westinghouse had two shunts per speed where a GE only had one. A shunt would weaken your traction motor field and give you more speed but less pull. You could run a Westinghouse wide open in the second shunt and then put it into regeneration to weaken the field even more. It was almost like another shunt. Now the motor was set to regenerate and slow down as you closed the throttle (author's note-cut the amount of current). Instead though, you would leave the throttle

cuts lines of force (flux) and cuts down the short circuit current that line voltage caused in a low resistance (jammed) armature. CEMF also acts as a current limiter, allowing enough current through to be useful without overheating the motor. Power supply operates in an armature as a true electrical load rather than a short circuit. Natural or base speed occurs when the sum of the voltage drop across the armature as a result of its built in resistance plus CEMF just equals applied line voltage.

¹⁵⁸Lou Bloomfield, www.physicscentral.com/loe/lou-02-02.html, 1-2

¹⁵⁹Westinghouse, Rules and Regulations Governing the Operation of the Westinghouse and Electric Passenger Locomotives Class EP-3 (East Pittsburgh: Westinghouse Electric & Manufacturing Co. , 1926)

wide open and keep motoring. Then you would get going faster instead of slower. You could get your train up to 90 miles per hour on level track like that. It was strictly against the rules though. It was hard on the traction motors and might create a flashover.¹⁶⁰

The “flashover” that Merrill referred to occurred when the commutator’s brushes touched each other because of bumping, such as at a grade crossing, or in certain instances going 90 miles per hour in a 283-ton vehicle, itself towing roughly 1,500 tons. Performance was hindered and carbon deposits on the brushes had to be immediately tended to. Merrill’s anecdote also exemplifies the close relationship between shunting and regeneration.

Regeneration basically took shunting one step further. Regeneration takes place when the generator action in the motor is so high (and the field’s strength so weak) that the motor effectively becomes a generator, consequently turning them into self-regulating brakes. Braking begins when the voltage produced by the descending train exceeds that of the trolley. For example, a descending Little Joe class locomotive typically put out 3400 volts to the trolley wire’s 3200 volts when braking regeneratively.¹⁶¹ If there was radio contact between the engineer and the substation operator the trolley’s voltage could be dropped even further, and hence enhanced braking power even further.

A modern diesel in fact goes into regeneration as well. Rather than going back onto the grid to power other trains (as the Milwaukee’s system allowed), the diesel driver motors’s current generated by downhill momentum is fed through into cast iron grids and dissipated as thermal rather than electrical energy, in effect similar to the heating elements in a kitchen range translating electrical energy into heat. In both cases the current’s relatively high voltage (220 for a range, roughly twice that for a downhill train

¹⁶⁰Holley, *The Milwaukee Electrics*, 112-13.

¹⁶¹Holley, *The Milwaukee Electrics*, 287.

acting as a generator) is reduced to virtually nil by the high resistance of the iron. To convert this heat back into work, rather than possibly powering a nearby ascending locomotive as the Milwaukee was able to do, would require some sort of Stirling (caloric) engine attached to the resistor grid. While possible, the results would not be practical.

The practical results for the Milwaukee's use of regenerative braking were many. If an descending grade was longer and steeper than an ascending grade (for example, an eastbound train sumitting Pipestone Pass out of Butte), a train actually produced more energy than it had expended in crossing a summit. This energy could then be used to power a train ascending elsewhere. The advantages over airbraking were obvious. Airbraking typically slowed a train to about 40 miles per hour, while regeneration could slow a train to 17 miles per hour or even less. The savings in hydraulic line, rail and wheel flange wear, brakeshoe pads, and the like has never been documented, but knowledgeable observers universally concur that savings had to be substantial.

Putting It All Together: The Milwaukee's Electrical Fleet

The Milwaukee employed four types of electrical locomotives over the years – three from General Electric, and one from Westinghouse. All designs varied widely, owing to the relatively primitive state of heavy industrial traction in the first half of the twentieth century.¹⁶² General Electric introduced the "E-1" series in 1915, as part of a

¹⁶²Ironically, primitive designs resulted in almost ridiculously overbuilt motors which in turn resulted in stupendous power and endurance figures (a windfall for the ad department). A GE freight motor could go at 132% of its normal power rating for an hour (at overload rating, where the motor does heat up substantially, but not to the point of danger), and last 70 years in the process. By way of contrast, diesel-electric engines cannot be overloaded for any practical length of time because the DC motors have been designed with much finer tolerances, owing to advances in electrical engineering in the past century. Also, a portable diesel engine can only put out so much power - a self propelled prime mover (such as a steam or diesel engine) cannot exceed its power rating. An electric locomotive, drawing power off of a very large hydroelectric grid, can. The

package deal with the Milwaukee, wherein GE and subcontractor American Locomotive Company (ALCO) would supply 30 locomotives and a 3,000 volt trolley system, complete with substations, over territory in Montana, Idaho, and Washington. These locomotives became the early mainstay of the electrical fleet, and many were in service for an astonishing 58 years.¹⁶³ (See Plate XVII, page 139).

The second type of locomotive resulted in something quite different. The Bipolar was General Electric's answer to Westinghouse for passenger motors. The rather unusual name referred to the two poles that provided the electric field for the armature. Unlike other design in which the motor drove a small pinion gear, the armature on this locomotive was the wheel's axle itself. The Bipolars were state of the art in 1915: a gearless motor with only two poles (see below for a more technical description), an admirable example of simplicity, public relations glamor, and durability. Barring some untoward event, they were almost completely silent in operation. Although other electrical designs were relatively quiet when compared to steam or diesel locomotives, the Bipolar's lack of sound (other than a low hum) consistently impressed observers. The Bipolars were also much more aesthetically pleasing than the other designs, and most closely resembled the comfortable proportions of a steam engine. (See Plate XVIII, page 140).

The Bipolar's other defining characteristic was its ruggedness. They were in service from 1918 to 1962 and had an unparalleled ability to accelerate quickly and negotiate tighter turns than any of the Milwaukee's other electrical locomotives.

power put out by the dams at Black Eagle and Thompson Falls, and potentially available for the Milwaukee's locomotives, remains several orders of magnitude higher than the power of any diesel engine, portable or not, in this or any age. Even though motors in diesels cannot handle overload relative to the older GE designs, this obviously was not a decisive factor in the overall competition between motors and engines, and the subsequent dominance of the diesel-electric. Holley, *The Milwaukee Electrics*, 294.

¹⁶³ Holley, *The Milwaukee Electrics*, 33.

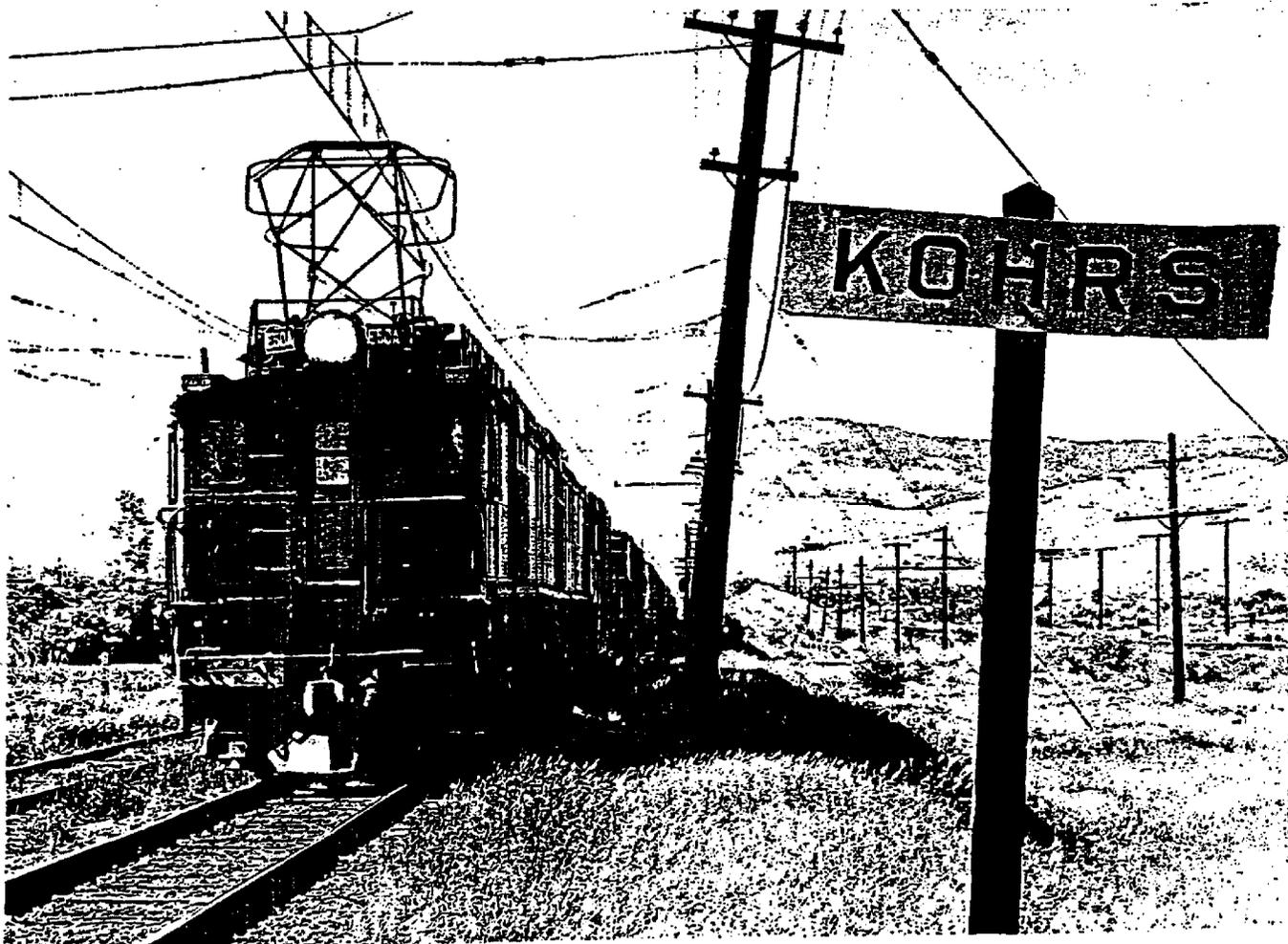


Plate XVII: A GE EF-1 operating near Deerlodge in 1972, almost 60 years after it was introduced. Holley, *The Milwaukee Electrics*, 56.

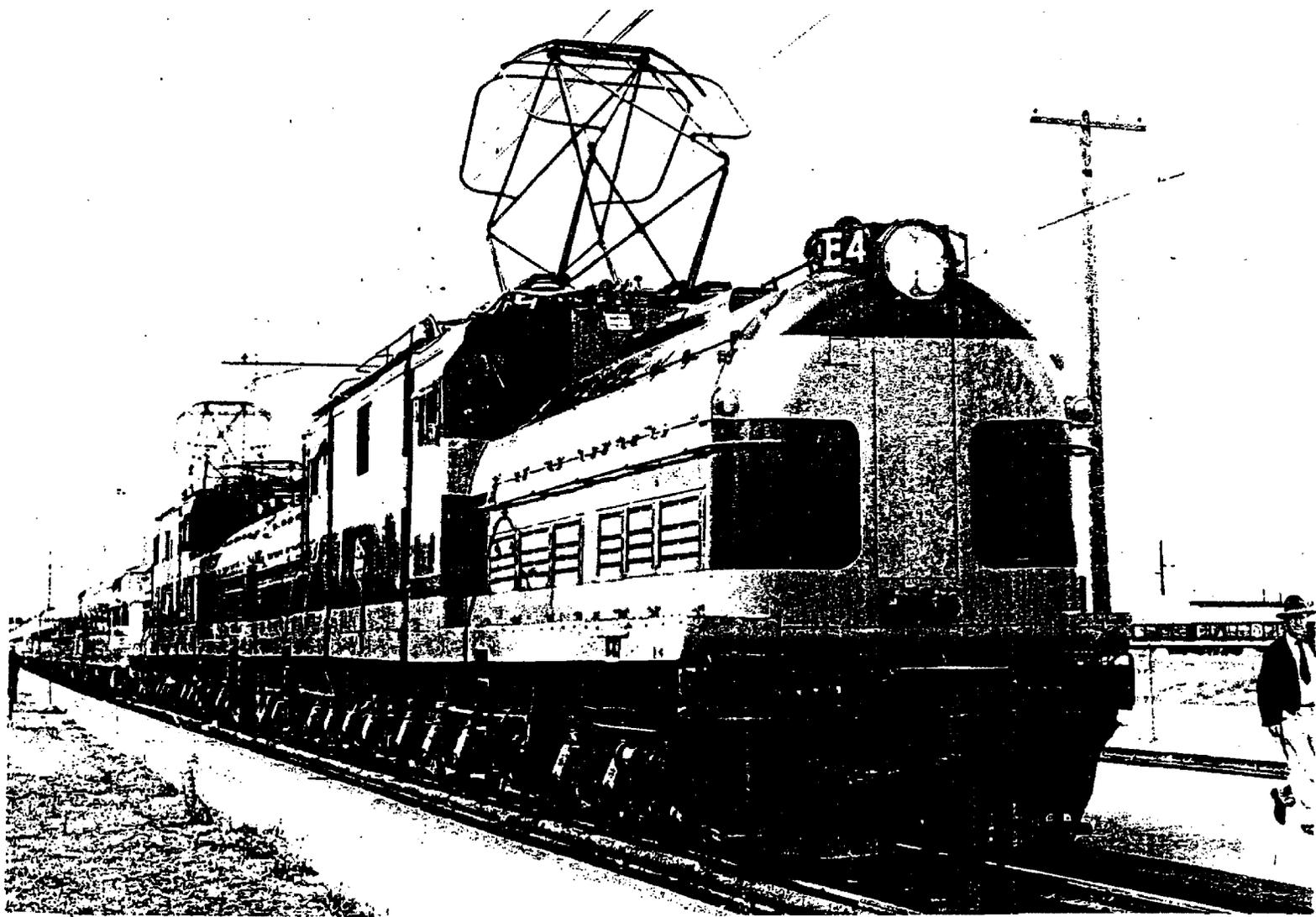


Plate XVIII: Two Bipolars, date unknown. Note the unique rounded design, superficially similar to a steam locomotive's profile. Holley, *The Milwaukee Electrics*, 96.

According to Cascade Division engineer King Clover, who was rounding a blind curve in western Washington on one occasion: “A tree had come down at Hyak and knocked the track twelve inches out of line in the shape of a ‘U.’ I knew we couldn’t stop before we got there and I thought we were going over in the ditch. Instead we went over that track just fine and the Bipolar stayed on the rails. By the time we got stopped, the out of line track was under the baggage car.”¹⁶⁴

For its time, the Bipolar epitomized modern design. While these locomotives were fairly popular with the public, management, and the Milwaukee’s roundhouse maintenance crews, they were much less well-liked by the men who had to operate them in the field, especially engineers working in the Rocky Mountain Division. Simply put, aforementioned flexibility of this locomotive gave an extremely rough ride at speeds higher than sixty miles an hour, particularly on poorly maintained track, which was a universal problem for railroads during and after the Second World War.¹⁶⁵ Retired fireman Bill Merrill compared the ride to that of a “lumber wagon.”¹⁶⁶ This problem led to more than disgruntled crewmen. All of the high speed jostling made Bipolars notoriously susceptible to flashover as well.

The perennial competition between GE and Westinghouse had important implications for the Milwaukee Road in 1917. The railroad was looking to expand its passenger operations with 15 additional locomotives and desired to purchase the appropriate equipment from General Electric, with whom the Milwaukee had, up to that point, enjoyed an exclusive relationship. America’s entry into the First World War,

¹⁶⁴Holley, *The Milwaukee Electrics*, 92.

¹⁶⁵Holley, *The Milwaukee Electrics*, 117.

¹⁶⁶Holley, *The Milwaukee Electrics*, 100.

however, complicated matters. All major purchases of physical plant had to go through the United States Railroad Administration, and in the case of the Milwaukee's proposed purchase, the Administration insisted that 10 Westinghouse motors had to be part of the package, theoretically in the interests of more efficient production.¹⁶⁷

However, Westinghouse had nowhere near the track record that General Electric had when it came to direct current traction. Not surprisingly, both Westinghouse and GE took the Milwaukee's proposed performance specifications and took two completely divergent approaches to design. GE's answer to these specifications was the Bipolar; Westinghouse responded with the EP-3. (See Plate XIX, page 143).

The EP-3 was the most massive locomotive that the Milwaukee owned in its seven decades and for many Milwaukee personnel, it represented the biggest headache of any locomotive in the electrical fleet. The locomotive had some fundamental design flaws that centered on the wheels and suspension, chief among them the unnecessarily large diameter of the drivers, which measured five feet, compared to roughly three feet for the GE locomotives. Because of relative inexperience in the field, Westinghouse designers took their cue from steam locomotive design, which achieved additional torque and speed by enlarging the drivers. As previously mentioned, torque was desirable; however, Westinghouse took the concept in the wrong direction in the case of the EP-3. Since electrics usually had the motor's energy going through a reduction gear, smaller wheels could be used. Smaller drivers had the distinct advantage of putting far less stress on the entire locomotive frame. The high torque of the five foot drivers, combined with a

¹⁶⁷Holley, *The Milwaukee Electrics*, 102.

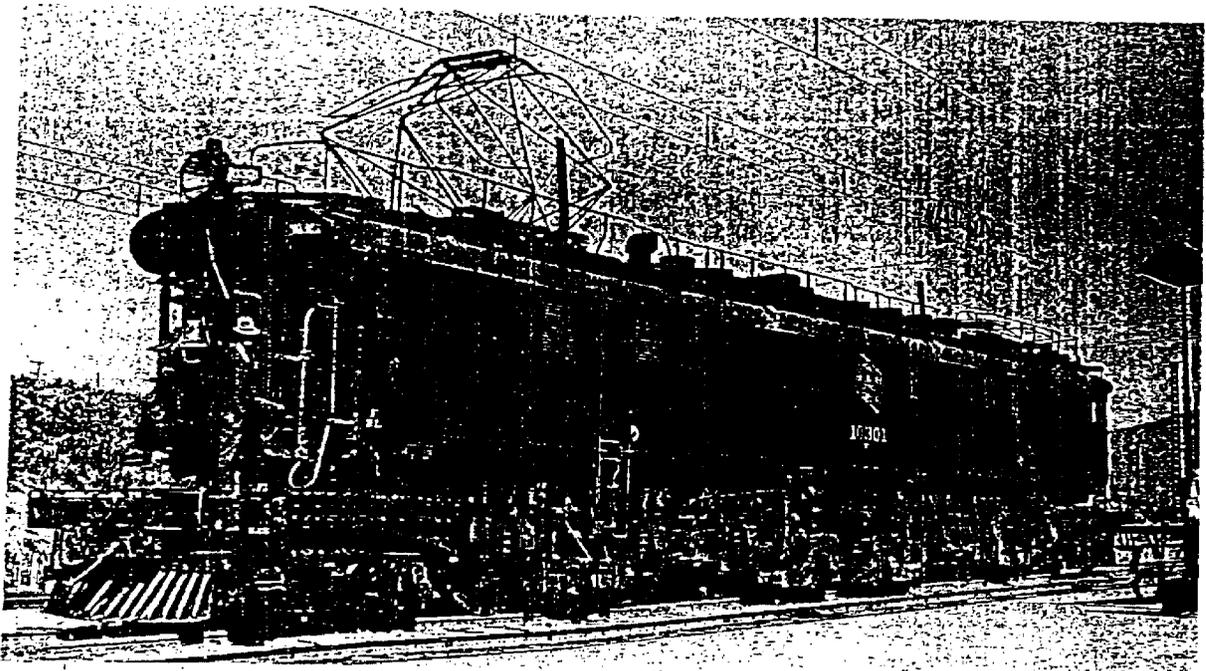


Plate XIX: A Westinghouse EP-3, 1931. Note the relatively large driving wheels. Holley, *The Milwaukee Electrics*, 106.

poorly designed, inflexible (for any transcontinental's tight-radius mountain turns) carriage, resulted in the constant re-welding of cracked EP-3 frames.

The EP3's other problem was a novel system of shock absorbers incorporated into the wheels. Called a quill, the system consisted of a hollow steel tube surrounding the axle. (See Plate XX, page 145). These two components were connected by a series of springs, which were supposed to absorb the jolt of two very powerful motors starting a train from a standstill. The Westinghouse locomotives did provide a very smooth and fast ride, which endeared them to engineers, but the system of quills and springs was too delicate and overrefined to provide consistently reliable service. Management, and more particularly maintenance men, detested these ten locomotives.¹⁶⁸

At the pinnacle in terms of design and performance were the EF and EP-4, or Little Joe class locomotives, purchased by the Milwaukee in the late 1940s. There are three possibilities for the origin of the unusual name. Technically this class of locomotive was slightly less physically imposing than the even larger AC trolley trains purchased by the Great Northern for tunnel use. There was also the distinct possibility that some irony was involved in the choice of the name, much like the *nom de guerre* of Robin Hood's huge and powerful right-hand-man, Little John. For a Joe was no small thing; each weighed in at a hefty 289 tons. Finally, these locomotives had originally been intended for sale to the Soviet Union, then squarely under the thumb of a "Little Joe" of its own. Whatever the origin of the name, with the beginning of the Cold War, a sale of such an advanced product to an increasingly hostile nation was unthinkable. Consequently, GE

¹⁶⁸Holley, *The Milwaukee Electrics*, 117.

1. JOURNAL (AXLE)
2. DRIVING WHEEL
3. SPIRER ARMS
4. COIL SPRING
5. BULL GEAR
6. PINION GEAR
7. TRACTION MOTOR
8. AIR BOX
9. ARMATURE BEARING-OIL
10. QUILL
11. QUILL BEARING
12. GEAR COVER
13. QUILL DRIVE OP
14. DRIVING WHEEL SPRING CAP
15. BRUSH DOOR

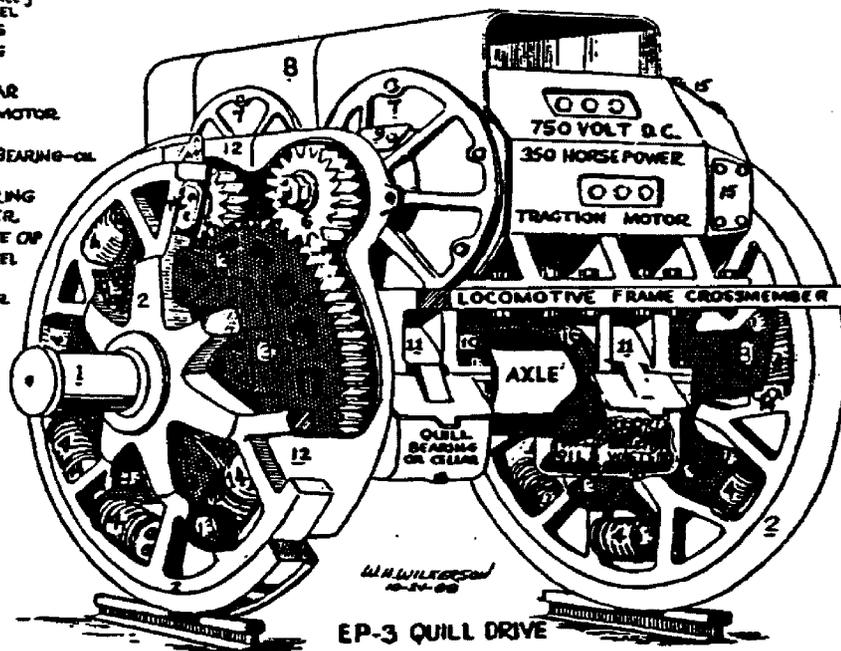


Plate XX: Quill drive, used on the Westinghouse EP-3 Motors. Not surprisingly, Westinghouse designed something completely at variance with what General Electric had developed at the same time. While it had undoubtedly pioneered long-distance AC transmission, the Westinghouse Company was a lesser force in the field of electrical traction. While quill-drive motors gave the EP-3's a smooth and fast ride, the motor's design was overrefined and ill-suited to the rough terrain of the Northern Rockies. Additionally, always hard-pressed Milwaukee Road maintenance men favored the simpler GE motors over the quills. The gearing arrangement is similar to that of Baldwin's unsuccessful 1944 turbine design. Illustration from Bill Wilkerson, *The Milwaukee Road Electric Passenger Locomotives*, (Harlowtown, Montana: Times Clarion Press, 1998), 51.

changed the gauge on the locomotives and the Milwaukee purchased them at a very reasonable price.¹⁶⁹

Like the first General Electric locomotives purchased in the 1910s, the Joes were remarkably durable and efficient; they actually helped to stave off the Milwaukee Road's final bankruptcy. This "staving" again came in the form of greater reliability and corresponding lowered maintenance costs than could be achieved with either late steam or early diesel technology. The Little Joe was an almost perfect combination of power, a simple but reliable design, and a surprising ability to work with more modern diesel/electric units. (See Plate XXI, page 148). Much more was known about motor design and performance by the time the Little Joes were manufactured, and although an engineer could not run a Joe's motors in excess of "recommended" ratings as he could with the older designs, the superior performance of the newer design was patently obvious.

Crews loved these 12 locomotives, and they were in constant service for 24 years, right up until the end of the electrification in 1974. Essentially, they were purchased because of the dire need to haul more tonnage in the electrified divisions after the Second World War. A Joe's thirst for current was prodigious, and Laurence Wylie was obliged to reconfigure components in the trolley system in order to get voltages up from 3,000 volts in the pre-1950 period to 3,400 volts subsequently. The Joes were hailed for their day-in, day-out reliability, but it was their power that made them almost legendary in engineering circles. The following anecdote speaks to both reliability and power:

¹⁶⁹Holley, *The Milwaukee Electrics*, 118.

The Little Joes could really put out some power...One time I was riding over the Butte Hill on a train with two Little Joes and some diesels. *The diesels broke down* [my emphasis] while we were on the grade so the engineer stopped the train. We didn't want to double the hill, so I gave the engineer approval to see if the Joes could make it by themselves. It was a good day with dry rail and no wind to blow the sand off the track. Also we were right beside the Janney substation when we started, so I knew we could get full voltage. Running at 475 amps per traction motor, the Joes pulled the train over the hill with no problem at all. After the trip, I did some calculations and they showed that the Joes had to produce 6,700 to 7,000 horsepower each at 30% adhesion to pull that train.¹⁷⁰

This combination of these four machines, then, was the Milwaukee's electrical fleet *in toto*. A look into what was involved in running one of these machines would be instructive, as well as illustrative of the fact that both types of current were utilized with considerable ingenuity by the railroad. After the 100,000 volt AC hydroelectric current was converted via a motor-generator set in one of the substations to direct current and then sent onto the 3000 volt trolley line, it was ready for use by the Bipolar, which had twelve motors. These motors could be arranged in four different ways, depending on the combination of speed or power an engineer desired. The full 3000 volts was not used to start the train from a standstill – the force the motors would put out if the engineer allowed full voltage had the potential to shear fasteners or couplings at any point on the train. “Peeling out” would be the closest analogy in the automotive world, and trains, having both steel wheels, rails as a road, and loads several orders of magnitude higher, do not peel out – they either derail or decouple, occasionally with catastrophic results. The

¹⁷⁰Holley, *The Milwaukee Electrics*, 137-39. The above quote was by Barry Kirk, head of the electrical division from 1963 to 1971. A contemporary diesel, by way of comparison, was typically rated at 1500 horsepower per unit.

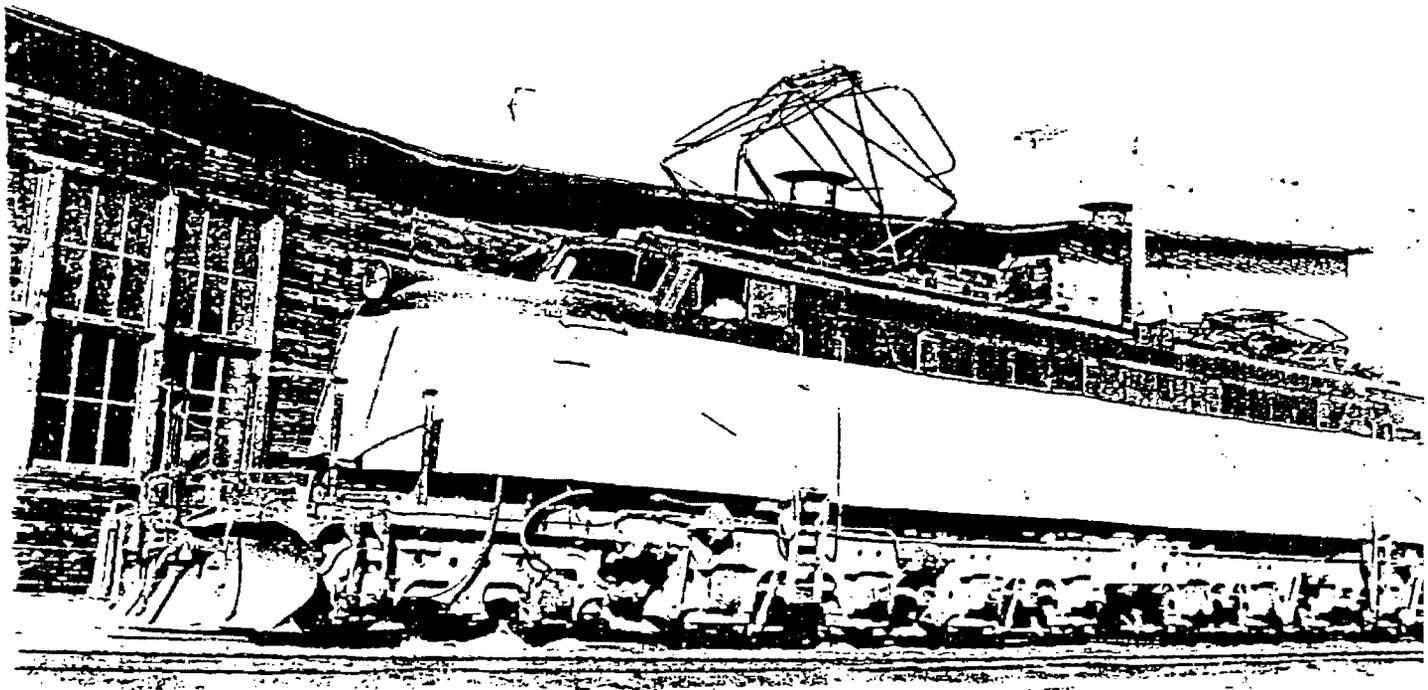


Plate XXI: A GE EF-4, better known as a Little Joe, Deerlodge, 1973. Holley, *The Milwaukee Electrics*, 149.

problem was not a lack of power. The problem was that power itself had to be applied slowly and smoothly. Through a series of cast iron resistor banks, the voltage was cut to a desirable level. Regardless of the voltage being used or the way the engineer arranged the motors, maximum current (amps) could be drawn, although current strength dropped as the train picked up speed. The engineer would then move the throttle to the next setting, which eliminated a set amount of resistance from the grids and restored current strength.

The number one resistor setting cut voltage to 1200 volts, which meant that 100 volts went to each motor in the series. The number 10 setting had all resistors “cut out” which meant that the maximum possible voltage of 250 volts went to each motor in the series for a total of 3000 volts. What current remained returned through the rail to the substation motor-generator sets.¹⁷¹ Even if a healthy amount of voltage remained after going through the motors, there was little danger of “third rail” type electrocution, because the distance through which the current had to travel back to the substation –usually several miles– cut the strength of the voltage (since it was direct rather than alternating, as well as the fact that steel rail does not conduct electrical current nearly as well as copper trolley wire).¹⁷²

Changing settings depended on how much current went through the circuit. The engineer was supposed to keep a particular setting cut in until current strength dropped to 225 amps, and then he “shifted” the throttle to the next setting, so he could draw the

¹⁷¹Bill Wilkerson, *The Milwaukee’s Electric Passenger Locomotives* (Harlowtown, Montana: Times Clarion Press, 1998), 23-4.

¹⁷²Interview with Jon Roholt, Electrical Engineer for Idaho Power, August 20, 2003.

maximum of 250 amps that the manufacturer, General Electric, recommended for acceleration. The Bipolar had ten settings for a series arrangement. By the time the throttle had been moved to position “10” all the grid resistors were removed (“cut out”), and the 3000 trolley line volts gave 250 volts to each of the 12 motors.

The engineer also had the option of arranging the motor circuits in “series-parallel,” since this arrangement did not precipitate such large voltage drops across a circuit. At the maximum throttle setting of “10” (for a total of 3000 volts) the motors could be situated in two parallel series of six (500 volts per motor set), three of four (750 volts) or four of three (1000 volts). In parallel arrangements current strength varied, again according to Ohm’s law.

To complicate things further, engineers avoided excessive use of resistor grids whenever possible. Resistors in the form of motors presented useful work, but other resistors, in the form of cast iron grids, meant incidental, useless heat (very similar, conceptually, to the useless and costly friction in a steam engine layout) which had to be cooled by blowers to prevent the grids from overheating dangerously while the train ran. The motors themselves were always potentially in danger of overheating, a fact which worked to the railroad’s advantage when operating in a climate that was cold six months of the year.¹⁷³ Indeed, in colder weather, the electrics proved themselves more efficient,

¹⁷³Holley, *The Milwaukee Electrics*, 63, shows a GE advertisement with one of its products silhouetted against a massive crag, a cascade of “white coal” nearby, modestly titled “World’s Mightiest Locomotives.” Among other purported benefits of GE’s locomotives was the claim: “Operate best in cold weather when steam locomotives have their greatest trouble.” Compared to the Milwaukee’s steam fleet, this was true. Although DC batteries still die in frigid conditions, trolley wire systems do well in very cold weather – possibly one of the reasons for The Soviet Union’s ultimate (and mystifying, to

cost effective, and reliable from the outset. In the words of one of the railroad's board members:

Our electrification has been tested by the worst winter weather in the memory of modern railroaders. There were times when every steam locomotive in the Rocky Mountain Division was frozen, but the electric locomotives went right along. Electrification has in every way exceeded our expectations. This is so, not only as respects tonnage handled and mileage made, but also the regularity of operation.¹⁷⁴

If anything, the electrics worked too well in colder conditions, to the detriment of operations in warmer weather. In summer, for example, constant vigilance had to be exercised by the engineer to ensure against overheating. Skillful use of the series and parallel arrangement according to circumstances often obviated the need for excessive use of the resistor grids.

Although the electrics were easier to operate than steam engines, getting the right combination for a particular set of circumstances could be difficult for an engineer. Even with earlier, more simply designed locomotives in the Milwaukee's electric fleet, such as the Bipolar, had a bewildering variety of settings and grid resistance amounts available. The Little Joe class locomotives, purchased by the Milwaukee in late 1948, had 37 resistance settings for each motor arrangement, plus the capability to "tie-in" electrically with any diesel electric units that might be in tandem with the electrics, a common

American eyes) preference for electric rather than diesel traction in polar conditions when covering long distances.

¹⁷⁴Charles R. and Dorothy M. Wood, *Milwaukee Road West*, 73.

situation in the railroad's final years.¹⁷⁵ The Joe's control throttle, however, changed the motor arrangement at the appropriate time automatically – a tidy parallel to the introduction and eventual dominance of automatic transmissions in the American auto industry. The operation of the throttle from standstill to full speed on a Joe roughly paralleled shifting gears in a car; there were just more gears to handle (and it took at least two miles to stop a fully loaded train).

In spite of such a seemingly complicated series of processes to learn over the years, the electrics were in an entirely different league from steam as a whole, as can clearly be seen by a good number of eyewitness accounts of experts as well as contemporary literature. The engineers would eventually grow very fond of the system and trains that the Milwaukee had in place, and the system was doubtless cheaper and more reliable than steam. However, were there any drawbacks to the new system, and if so, what were they?

Some Problems Exclusive to the Electrics

¹⁷⁵Bill Wilkerson, *The Milwaukee Road EF-4 Locomotives* (Harlowtown, Montana: Times Clarion Press; 1991), 13-14. This tie-in device was an excellent example of the ingenious mind of Laurence Wylie, The Milwaukee's Chief Electrical Engineer from the late 1940s to the late 1960s, and was responsible for keeping the Milwaukee's increasingly aged electrical fleet going in the face of ever stiffer competition from diesels. Wylie constantly struggled with the company's upper echelon, which favored the "Mechanical" (steam, and later diesel) Division over the electrics, and Wylie resorted to some austere (but brilliant) *ad hoc* solutions. Holley, *The Milwaukee Electrics*, 210-213. Wylie also struggled within the Electrical Division itself. His superior, Rainier Beeuwkes, who was responsible for the field implementation of GE engineer A. H. Armstrong's original designs of the Milwaukee's infrastructure, ruled the Electrical Division with an iron (almost Edisonian) hand for 34 years (1914-1948). Believing everything perfect "as is," Beeuwkes refused to modify virtually anything in the Electrical Division during his tenure, according to Wylie. Holley, *The Milwaukee Electrics*, 160.

While a marked improvement over steam in terms of lower operating costs and overall reliability, the system the Milwaukee had in place was hardly perfect (and it grew less “perfect” with each passing decade, owing to the Milwaukee’s studious neglect of its electrical division). Electrical traction was not without its drawbacks, especially in states with climates hostile to all rail locomotives, whether steam, electrical, or diesel. Although the Milwaukee’s electrics were less complex mechanically than its steam engines, a number of anxieties existed for a given electric locomotive’s engineers, as well as rail maintenance crews and substation operators.

One potential weakness of electrification in the face of diesels is in the arena of distance. Longer distances cost much more in terms of infrastructure for straight electrics than for diesels. Indeed, the partial electrification Trans-Siberian Railway becomes more explicable only when one realizes that there was absolutely no equivalent of an interstate highway system in the Soviet Union, or (to this day) in the Russian Federation. One would assume the other factor in this partial electrification is the superior performance of straight electric motors in one of the world’s coldest inhabited regions.¹⁷⁶

Lightning poses a constant danger in any outdoor electrical system, in particular, a “system” consisting of 432 miles of electrically-dependent infrastructure in the Rocky Mountain Division. While the Northern Plains is not Tornado Alley, danger from electrical storms on remained a constant concern for both utility companies and large

¹⁷⁶For a critique of the old Soviet rail system’s transition from steam to electrics and diesels, see Ernest W. Williams, Jr. , *Freight Transportation in the Soviet Union: Including Comparisons with the United States* (Princeton: Princeton University Press, 1962), 134-35.

consumers of electricity, such as the Milwaukee. Even today, lightning is a seemingly random, but ubiquitous, source of concern for electrical utilities running high voltage lines. The dangers were more than theoretical for the Milwaukee. A thunderbolt hit the trolley line near the Two Dot substation in the 1930s, caused some transformers within the substation to explode, and blew out the roof of the structure. The building burned for several hours, with considerable damage.¹⁷⁷ In spite of this mishap, accidents of this nature were rare, because lightning arresters had been standard fare for all electrical lines from beginning of the twentieth century.¹⁷⁸

The trolley was also vulnerable to other vagaries of nature, particularly excessive snow. A typical trolley set up consisted of a top, “messenger” wire, usually made of 7/16 inch steel cable, connected by a series of intermediate clips to the copper wire through which the current ran.¹⁷⁹ While damage from the weather or the occasional rock slide could wipe out sections of trolley line, the damage could be compartmentalized. If damage occurred between Gold Creek and Ravena, for example, operations slackened only between those two substations, not the entire line. Nevertheless, given conditions in

¹⁷⁷Noel T. Holley, *The Milwaukee Electrics*, 241.

¹⁷⁸International Textbook Company, *Types of Collectors for Heavy Traction* (London: International Textbook Company, Stationer’s Hall, 1909), 51. When lightning hit unprotected electrical plant, it ruined both motors and substation equipment (and in the cold logic of a railroad’s insurers, also killed valuable trained operators). Lighting arresters were designed to shunt very high voltage loads, such as lightning, directly to ground as quickly as possible.

¹⁷⁹International Textbook Company, *Transmission Systems for Heavy Traction* (London: International Textbook Company, Stationer’s Hall, 1909), 41.

the northern Rockies, trolley repair crews were seldom idle.¹⁸⁰

Electrolysis was another constant aggravation. This phenomenon dissolves chemical compounds electrically. The most widely known example of this (and a mainstay of many a local science fair) is dissolving water into its constituent parts, hydrogen and oxygen, by means of a dry cell battery and two metal electrodes inserted into the water (the converse of this process is used to power fuel cells). Electrolysis is not exclusive to water. It also occurs in iron, copper, and lead compounds, among many others. Since rails are made of steel, and steel is nothing more than a special type of iron with the right amount of carbon in it, electrolysis consequently had practical implications for those running direct current lines, such as the Milwaukee. Instead of returning the current to the substation as planned, some of the current would go to ground in the inevitable gaps between the rails, eating steel off of the “positive” end of the rail section.¹⁸¹ While the Milwaukee made fairly successful efforts to ameliorate this problem, the rails required constant inspection for pitting and gaps on the positive ends of the return rails, which if not maintained, could cause a derailment.¹⁸² It was all of these above mentioned aggravations that gave diesel-electric proponents within the Milwaukee’s mechanical division some of the ammunition they required when decrying the electrics. The irony, however, is that the diesels being lauded as a solution borrowed extensively from the straight electric traction technology the Milwaukee first employed in

¹⁸⁰Noel T. Holley, *The Milwaukee Electrics*, 156.

¹⁸¹International Textbook Company, *Transmission Systems for Heavy Traction* (London: International Textbook Company, Stationer’s Hall, 1909), 59.

¹⁸²Interview with Milt Clark, April 10, 2002.

Montana in 1914.

Diesels, the “Technological Children” of the Milwaukee Electrics

The heir to the struggle between steam engines and electric motor drive is the diesel-electric unit, a hybrid design that combines a number of desirable features from both systems of motive power: Diesels inherited from steam the ability to carry fuel along for the ride, rather than depending on an outside source, such as a trolley wire. A diesel's direct current motors provide both power and speed, as are required. The maintenance requirements for a modern diesel unit are a relatively simple affair compared to tending to a steamer, although the projected savings promised in diesel's early years were excessively rosy, at least in practical terms.¹⁸³ A diesel locomotive at regular operating speed will consume 180 gallons of fuel per hour, no small amount, to be sure. The act of fueling is accomplished in a very similar fashion to that of a typical motorist putting ten dollars worth of gasoline into his car at the corner gas station. True, the backbreaking toil of the fireman had been eliminated altogether. The burden lies solely now with the

¹⁸³The thermal efficiency of a diesel electric unit is roughly 30%, compared to 7% for a steamer. Tuplin, *The Steam Locomotive*, 82-84. However, early diesels amortized much faster than the older electrical plant. Engineer Swede Hansen: “There ain't a diesel made that can compare with a Joe (GE Models #E-F4 and EP-4). A damn diesel is just like an automobile, there are too many things that can go wrong with them. They just can't take it. The diesels were nice when they were new, but they went to pot after a few years.” Noel T. Holley, *The Milwaukee Electrics: An Inside Look at Locomotives and Engineering* (Edmonds, Washington: Hudman Publishing, 1999), 144. In spite of generally admirable qualities, electric locomotive E-21 (a Little Joe) went runaway on Hansen in 1951. He put himself in the hospital for a month stopping the train with emergency friction brakes. With a typical sense of occasion and largess toward its employees, the Milwaukee presented Mr. Hansen with a “gold pass” (free rides on the line's passenger trains) for his trouble. Holley, *The Milwaukee Electrics*, 238.

mechanics. In the case of the Milwaukee Road, however, straight electric operation still made economic sense after World War II, a mark of its tenacious superiority even after forty-plus years of hard operation in the Rocky Mountain Division. Diesel fuel cost the Milwaukee 9 cents per gallon in the mid 1950s; compared to 6.8 cents for the same amount of power provided by electricity.¹⁸⁴ The twenty four million dollar investment of 1914 was still not only markedly superior to steam as of 1955, but also still more economic than the system that was supposedly state-of-the-art, the diesel-electric.

Amazingly enough to anyone who has ever been stuck behind a city bus, diesel engines, when properly maintained, burn cleaner than gasoline variety. The qualifier is “properly maintained.” Even in gasoline engines, fuel injection has now all but completely replaced the traditional carbureted fuel-air system. Again, there is more than one correct approach to a mechanical problem, especially when all of the systems involved are in their relative infancies (or like late steam, which at this time was in its dotage). Fuel injectors are far easier to deal with than fiddling with a carburetor’s many parts, and with the aid of modern electronics, can reach astounding levels of performance.¹⁸⁵ Gasoline and diesel fuel injection lost out to the carburetor in the early

¹⁸⁴Noel T. Holley, *The Milwaukee Electrics: An Inside Look at Locomotives and Railroading* (Edmonds, Washington: Hudman Publishing, 1999), 213.

¹⁸⁵Recently, a technician well-versed in EFI (Electronic Fuel Injection) altered a GM Corvette’s engine to produce approximately 1200 horsepower. By way of comparison, the author’s Honda Accord is rated at about 145 horsepower, which can attain speed of 100 miles per hour in about 20 seconds. A 2005 six-liter Corvette stock engine (no slouch in terms of acceleration capability) redlines at just over 400 horsepower. The altered Corvette can literally go from zero to 180 miles per hour in well under ten seconds– and it continues to accelerate even at 180 miles per hour. No-one has been able to find out when this vehicle stops accelerating under actual road conditions

twentieth century because consistently machining efficient injectors on a mass basis was not possible at the time. Like other early prototypes of a given technology, engineers realized that a better solution was theoretically feasible, but material technology was up to the challenge at the time. Neither the absolutely consistent, piece-to-piece machining precision required for proper fuel injection, nor the metallurgy then existed. Additionally, diesels, because they necessarily operate under much higher compression ratios, had to be constructed much more robustly than gasoline engines, and were therefore much heavier and suited only for large scale applications, such as stationary, marine, and locomotive engines.

It should be noted here that both the nascent postwar diesel systems and the straight electric system utilized the still ubiquitous Sprague motor – proof that the diesels that came later owed a good deal of their design characteristics to the Milwaukee electrics pioneered by the Milwaukee. The simple, elegant, and mechanically advantageous virtues of the Sprague-type motor were recognized early on by GE electrical engineers, and was exemplified by its use in both the early and late mainstays of the Milwaukee’s electrical fleet (the GE EF-1 and the Little Joe, respectively). More importantly, for the wider railroad world, this type of motor was also used in the vast majority of diesel-electric locomotives that would eventually dominate the American rail system after the Second World War. The important thing to bear in mind is that the diesels were not as “revolutionary” as they were made out to be, and that they owed a good deal of their

because it would be an exercise in suicide. While impressive, it is not particularly safe nor fuel efficient (even by NASCAR standards) for a ground vehicle. The Learning Channel, *Rides*, documentary aired February 13, 2004.

superior performance to the pioneering work of Frank Sprague.

Tellingly, steam fared less well compared to even the earliest, most primitive, diesel electrics (direct descendants of the Milwaukee straight-electrics). For example, in the twelve year transition period for the Baltimore and Ohio Railroad from steam to diesels (1945-1957) fuel costs for the railroad dropped from \$23.6 million annually in 1945 to \$21.2 million in 1957. More dramatically, fuel costs comprised 18.5 percent of the B & O's operating costs at the end of World War II. By 1960 this figure had dropped to 8.5 percent, an impressive number in the light of general postwar inflation.¹⁸⁶ The B & O enjoyed even greater cuts in water expenses as well. Unlike the old steamers, the locomotives now only required water as a coolant for the diesel engine block, which circulated in a sealed system, rather than as a prime mover escaping to the open atmosphere. Accordingly, water costs for the B & O dropped from \$945,000 a year in 1945 to \$147,000 a year in 1960.¹⁸⁷

The Baltimore and Ohio was not the only company to avail itself of the new technology. A Pennsylvania Railroad study noted the cost of operation for a freight steamer was \$2.37 per mile, while a comparatively powerful diesel operated at a cost of \$1.94 per mile. The Penn had a good deal of track mileage and an 18 percentage reduction in per mile costs was not a difficult decision for the railroad to make.

There were other, more general advantages to diesels as well. Diesels, like the Milwaukee's electrical fleet before them, were much more standardized than steamers.

¹⁸⁶<http://www.exotic.railfan.net/dieselfaq.htm>, 2

¹⁸⁷<http://www.exotic.railfan.net/dieselfaq.htm>, 2, 3.

One unforeseen financial consequence of modularization (discussed earlier) is that banks were much more willing to loan to an applicant holding a finished product with standardized, rather than individually machined (essentially unique), parts.

Diesels, like the Milwaukee electrics before them, had much wider ranges of operational maximum efficiency. A diesel was available 90 percent of the time (comparable with the Milwaukee's electrical fleet in its early, well-tended prime) compared to 40 percent for a steamer. Finally, it was becoming an ever more difficult proposition for a yard master to find readily available spare parts for an aging national steam fleet. More and more, if one wanted a spare part, one had to contact Baldwin or ALCO for a custom job.¹⁸⁸

Economically, it is much easier (if a corporation can bring the finances to bear) to produce millions of Model T's, than it is to produce 300 GE Diesels, which in their own turn are cheaper to produce twelve Little Joes, which in turn are cheaper to produce than one basically unique steam engine. No matter how powerful and efficient each individual locomotive may be, economics can sometimes outweigh actual performance.¹⁸⁹ Train transport is doomed by this concept in a larger sense, unless it can accomplish some sort of hybrid system with road transport combining the best from each competing system (such as piggybacking) or capitalize on its real strengths towing true bulk goods long distances (such as coal) over straight and relatively level roads.

¹⁸⁸<http://exotic.railfan.net/dieselfaq.htm>, 2-3.

¹⁸⁹James F. Dunnigan, *How to Make War: A Comprehensive Guide to Modern Warfare in the 21st Century* (New York: HarperCollins Publishers, Inc. , 2003), 556.

We see this phenomenon in the rise of interstate trucking (tellingly, diesels are also used in today's semi truck trailers). Trucks and interstates have replaced railroads for all but the heaviest freight, and the rail industry is subsidized to a large degree. Trucks will never replace trains for huge loads of raw materials, such as coal, destined for steam turbine electrical plants. For everything else, which is the unquestioned majority of the American freight market, trucks work quite well.¹⁹⁰ The miles and miles of immobile copper cable that the BAP and the Milwaukee strung, the thousands of trolley poles, the substations every 30 miles, the Milwaukee's dependence on Montana Power, and the reliance on skilled and independent workers, all underscored the huge cost in infrastructure, and ultimate inflexibility, of the electrified rail system. Even with reliable, efficient diesel-electrics, building railheads to thousands of towns off of the trunk lines was, and remains, an inefficient option. Semis hauling loads of 80,000 pounds can go almost anywhere roads are paved, and only the most remote locales in the United States or Canada do not have a paved road and delivery point. Railroads by their very nature are

¹⁹⁰ In spite of today's dominance of the diesel truck, for over the road hauling, direct current motors are used extensively in another part of the American freight system: forklifts. Retail customers seldom buy a commodity by the boxcar or semi-load. Something has to break loads down into smaller parts, and get them to their intended customers. This can be done by hand to a degree, but at a certain point machinery has to take over in the interests of efficiency. Forklifts are yet another type of vehicle where various engine technologies compete, even today. The author has used both electrical (direct current motor off of a 5000 pound series of batteries, where the batteries provide needed ballast) as well as two and four-stroke internal combustion (propane, and gasoline) type forklifts extensively, with varying degrees of success. From personal experience, the usefulness of a machine has to do more with its age and upkeep rather than the type of motive power it utilizes. Either type can be very effective and safe, or more trouble than it is worth and a menace to any worker in the vicinity. In terms of sheer physical weight, coal hauling completely dominates contemporary western American rail traffic. Interview with Milt Clark, former employee of the Milwaukee Road and Soo Line, currently with Montana Rail Link, April 10, 2002.

more inflexible than highways. This was particularly true of electrical traction when compared to moving it on the American highway system, which became increasingly widespread after 1920, and was the best on the planet after the Second World War. Perennially benighted Montana, usually near the end of the line when it came to Federal Highway appropriations, did not have a contiguous Interstate until the early 1980's .

In spite of the above-mentioned “inflexibilities” of all railroads – steam, electric, or diesel-electric – for certain tasks, how efficient and powerful are the modern diesel-electrics? Darryl Munson, a former brakeman and switcher for the Union Pacific and then an engineer for the Kaiser Steel Railway companies, noted that at Kaiser Steel’s (now defunct) “Eagle Mountain” ore railway (which connected with the Southern California Railroad) ore train, weights of 10,000 tons over a staggering four percent grade were an everyday occurrence. In terms of operational problems, full-blown runaways were a very rare occurrence, at least during Munson’s time at the Kaiser line. Three occurred during Munson’s fifteen years at Kaiser, and there were no major derailments or loss of life. More common, according to Munson, were “break-in-two’s,” in which the drawbars would sheer because of the high tensile forces involved in pulling a train of such size. Break-in-two’s usually occurred when the locomotives were attempting to get a train rolling from a dead stop. Interestingly, Kaiser largely eschewed the process of middle helpers, and put all of the GE U-33-C diesels either on the front or tail ends of the train (usually three in front, and one helper in back). Alternatively, Kaiser would place three units in the front, and three in the middle. Even with such a set of powerful locomotives, the trains typically only moved along at the rate of eight miles per hour and the track had

to be heavily sanded¹⁹¹ (10,000 tons is still 10,000 tons and needs to be handled gingerly). Tellingly, Munson also stated that Kaiser had looked at something similar to what the Butte, Anaconda and Pacific had installed, but since it was not in immediate proximity to a copper mine/smelter facility like the BAP, it was more economical to use diesels.¹⁹²

In spite of such impressive examples of performance, even in the Space Age, and with all of the hard-won advances in railroad technology that took much of their “technological DNA” from the first Milwaukee electric locomotives, running trains can still be a hazardous business. For example, in early February 1989, a Montana Rail Link train attempted to cross through the Mullan Tunnel on the Continental Divide twenty miles west of Helena. Forty-eight cars on the train decoupled and turned into a 20 mile runaway, owing to a lack of middle helpers and miserable operating conditions – the daytime high was 30 below Fahrenheit. A colossal wreck in the Helena freight yards ensued, several hundred people had to evacuate the area, and large portions of Helena had to do without basic utilities for the span of a day.¹⁹³ Even with all that the engineers and scientists know today, a locomotive having all the modern failsafes under adverse, or even ideal, conditions can fail, and great care and skill must be exercised to avoid these situations. A typical train’s load requirements are in the neighborhood of 4000 tons (it

¹⁹¹Sanding the rails is an age old railroad practice with the goal of getting more traction from the driving wheels. Many old steamers actually had “sand domes.”

¹⁹²Interview with Darryl Munson, former brakeman and master engineer for the Union Pacific and Kaiser Steel Eagle Mountain Railways, February 10, 2004.

¹⁹³Martin J. Kidson, “Crossing the Divide by Rail,” *Helena Independent Record*, 2 June 2002, 1,6(C). Modern American freight trains still have to climb or descend a 1.5 to 2% grade between ten and fifteen miles per hour – anything outside of this range is either difficult to climb or hazardous to descend.

should be noted that weights as high as 10,000 tons are hardly representative)¹⁹⁴ and speeds range anywhere from one to 60 miles an hour. The forces involved in moving something this massive so quickly are great enough that forged steel couplings can fail. In spite of such hazards and limitations diesels have completely usurped both steam and straight electric technology. Diesels combine the versatility of steam with the low maintenance and variable power availability of electrics. Indeed, diesel-electric technology is no longer limited to rail transport.¹⁹⁵

With all of the advantages of the diesel-electric locomotives combination of motor and engine technology, why did the Milwaukee instead opt for straight electrification, an infrastructure requiring a large expenditure of time and money? The short answer was that a practical diesel-electric design did not exist in 1915 when the Milwaukee made its unusual choice to electrify. Admittedly, the electrification cost over twenty million dollars, but this investment paid for itself within fifteen to twenty years, according to the figures available. Additionally, it can be argued that the diesel-electrics owe their very existence to the pioneering work done by GE and the Milwaukee.

¹⁹⁴Interview with Darryl Munson, former brakeman and master engineer for the Union Pacific and Kaiser Steel Eagle Mountain Railways, February 10, 2004. These high-end weights are for short haul applications, and typically for mine-to-smelter ore hauling operations, such as what the BAP had installed between Butte and Anaconda, or later the Kaiser operation in southern California.

¹⁹⁵ Volkswagen recently produced a prototype hybrid diesel electric car that gets 282 miles to the gallon. "Energy Forever," by Amory B. and L. Hunter Lovins, *The American Prospect*, February 11, 2002, 32.

Conclusion

Was, then, electrification to blame for the Milwaukee's ultimate demise? It is the author's hope that by illustrating through a number of specific examples in the above pages that the answer is a resounding no. In spite of a number of design modifications such as altering fuel or streamlining, late steam technology was not even close to the efficiency and power offered by the relatively primitive designs of the GE EF-1 and Bipolar locomotives. The superiority of the Little Joe class locomotive to late steam and even early diesel-electric designs is even more apparent. The mechanical advantages of rotary design of the motors versus the reciprocating design of steamers was yet another factor. So too we must consider the incalculable advantages of regenerative braking. In virtually every category of mechanical performance these new designs of motors completely eclipsed what had been the benchmark of performance for over a century, the high pressure Stephenson-type reciprocating locomotive. Of equal significance: many design features still used on modern diesel-electrics, such as the Sprague-type motor mentioned above, can trace their ancestry back to the first of the Milwaukee's GE locomotives, the EF and EP 1's.

All well and good on the performance front, but what about the bottom line? As was mentioned in the first chapter of this thesis, the railroad clearly had other financial problems, some self-inflicted, others the result of simply being in the wrong place at the wrong time. The ill timing of its expansion, the arguable deviousness and or incompetence of its management over a period of decades, the high bond-to-stock ratio resulting from transcontinental expansion, all of these factors were the real culprits, not

electrification. The author firmly believes that if a rival railroad with sounder finances (such as the Great Northern or Northern Pacific) had undergone similar electrification, the heavy freight system in the American west would appear a great deal different than it does today.

As we have seen, the locomotives represent more than just the rather freakish choice of a upstart granger railroad. The story of electrical traction is also representative of a number of complex phenomena apparent in technological history. We see resistance to change on the part of both the engineers and the public. We see non-technological factors, such as Thomas Edison's pridefulness and intense personalization of the "Battle of the Currents," heavily outweighing purely technical considerations. We see rival systems clash, sometimes over a period of many years, when it is not readily apparent which system is superior. Paradoxically, we also see the successful integration of rival systems, such as the Milwaukee's tandem use of the electrics and more modern diesel-electrics, as well as their use of both alternating and direct electrical currents. We see de-skilling of a skilled trade, such as an engineer, and attendant modularization of a given manufacturing process. We see many other things as well. The story of these locomotives and their role in saving the Milwaukee time and money is also in large part the story of invention and technology for American technology as a whole prior to the Second World War.

Epilogue

The substation at what was once Loweth, Montana, high in the Castle Mountains,

is one of the most forlorn images in Eastern Montana and that is saying something. The bleak hills that surround the building certainly do not help – brown, treeless, and scoured by winds on all but the mildest of summer days. The substation itself would be a pitiful sight in any setting. Gutted of its vintage motor-generator sets, transformers, and anything else of value that could be removed and sold in 1977, the building is a virtual hulk. Local vandals helped complete the transformation, by applying graffiti liberally and shooting out every last window, defacing a structure that was once the pride of both General Electric and one of the larger players in the American rail system. Other than a few pieces of rigging and some rusted, shot-out five gallon cans, nothing of worth in this substations remains, other than the brick structure itself.¹⁹⁶ The building still stands, but not out of sentimentality on anyone's part. Only the failure of the railroad to find a local market for scrap brick spared the Loweth building the fate of most of the other substations, which the company's creditors razed. A few other substations in the Rocky Mountain District still stand. One at Goldcreek, which is remarkably well preserved, the other, at Ravenna, is in identical condition to the Loweth substation. A fairly well-preserved substation about halfway between Missoula and Frenchtown also remains.

Most of the locomotives suffered fates similar to those of the substations. They were cut into scrap and sold to a junkyard or foundry. There is a GE Locomotive still proudly on display in Harlowtown, itself now just another slowly dying hamlet on the Great Plains. In addition, a Little Joe stands near the Old Territorial Prison in Deer

¹⁹⁶ One Milwaukee buff warned the author off of tarrying long around the old substations because of PCB's. Interview with Rich Misplon, December 12, 2002.

Lodge, the sole economic mainstays of which, at the dawn of the twenty-first century, are the Montana State Prison and nearby State Mental Hospital.

In a way, the wretched image of the Loweth Substation symbolizes the failed promise of the Milwaukee Road's fitful 70-year tenure in Montana and the passing of heavy industry's primacy in the American economy. For whatever combination of reasons – the rise of interstate trucking, more efficient rail competitors in the region, Montana's tenuous economic situation through much of the twentieth century – all that remains to serve as monuments to the Milwaukee Road's operations in the state are two locomotives and one caboose decorating town squares, a few ruggedly handsome passenger depots (some boarded up in sorry disrepair; others well maintained, such as the Boone and Crockett Club under the Higgins Street Bridge in Missoula), numberless creosoted trolley poles, scores of tunnels, and a few gutted brick substations.

Maybe the most important legacy of the Milwaukee Road's electrification was not its ultimately anemic contribution to the economies of the Great Plains, the Rockies, and the Northwest, but rather the groundbreaking work in electrical traction that the railroad undertook in tandem with General Electric, the implications of which still exist today. The wedding of the most advantageous aspects of the "motor" and "engine" philosophies for making a vehicle (in this case, very large vehicles) move in an efficient fashion. The motor system, initially less promising than the engine system, was in ascendancy by the second decade of the twentieth century. Motors, paradoxically, made the evolution from external combustion engines to the greater power and modularized efficiencies of the V-16 internal combustion engines (the prime movers on a modern diesel-electric unit).

Modern American rail systems owe their existence to a successful wedding of motor and engine technology. Without the admittedly primitive and overbuilt direct current motors that the railroad utilized in the mid-'teens, none of what followed, including today's diesel electric units, would have been possible. The process of steady improvement in components of the straight electrics resulted in viable technology for diesel electrics by the 1950s.

Although railroads have surrendered a great deal of their dominance to over-the-road trucks since the Second World War, they still remain an indisputably pivotal component of the American transportation system, and modern diesel-electric technology owes much to the early electric designs. What made the Milwaukee Road unique was its choice of electrical motive power on a unprecedentedly vast scale and its ingenious use of both types of currents. The Milwaukee's achievement of installing such a unique system, however overall financially unstable the company, were resounding mechanical and economic triumphs over steam. Though the Milwaukee Road is now gone, another casualty of changing economic trends, the story of its electrical locomotive fleet remains a fascinating example of human ingenuity.

Bibliography

An “*” next to a bibliographic entry indicates a primary source.

Abdill, George B. *This Was Railroading*. Seattle: Superior Publishing Company, 1958.

Adams, Henry. *The Education of Henry Adams*. New York: Random House, 1931.

Baker, Don. *The Montana Railroad: Alias, The Jawbone, also Known as The Chicago, Milwaukee, St. Paul and Puget Sound, and The Chicago, Milwaukee, St. Paul and Pacific, and Finally as The Milwaukee Road*. Boulder, Colorado: Published by Fred Pruett, date unknown.

Baldwin, Neil. *Edison: Inventing the Century*. New York: Hyperion Press, 1995.

Basalla, George. *The Evolution of Technology*. Cambridge: Cambridge University Press, 1988.

Benton, James E. *4-10-2 -Three Barrels of Steam: A Complete Collector's File of the*

Only Three Cylinder 4-10-2 Locomotive Built for Service in the U. S. A. Felton, California: Greenwood Publishers, 1973.

* Booz-Allen and Hamilton Inc. for Transamerica Interway Inc. *Piggyback: the Efficient Alternative for the 80's.* New York: Transamerica Interway Inc. , 1980.

Boyer, Dennis. *Prairie Whistles: Tales of Midwest Railroading.* Black Earth, Wisconsin: Trails Books, 2001.

Bruno, Leonard C. *The Tradition of Technology: Landmarks of Western Technology in the Collections of the Library of Congress.* Washington, D. C. : Government Printing Office, 1995.

Cheney, Margaret. *Tesla: Man Out of Time.* New York: Barnes and Noble, 1993.

Conot, Robert. *A Streak of Luck: The Life and Legend of Thomas Alva Edison.* New York: Seaview Books, 1979.

* Crocker, Francis B. , and Wheeler, Schuyler S. *The Practical Management of Dynamos and Motors.* New York: D. Van Nostrand Company, 1894.

Crump, Thomas. *A Brief History of Science, As Seen through the Development of Scientific Instruments*. New York: Carr and Graff Publishers, 2001.

Daumas, Maurice. *A History of Technology: Progress and Invention. Progress through the Ages. Volume III: The Expansion of Mechanization: 1725-1860*. New York: Crown Publishers, 1968.

Day, John. *Engines: The Search for Power*. New York: St. Martin's Press, 1980.

Derleth, August. *The Milwaukee Road: Its First Hundred Years*. New York: Creative Age Press, 1948.

Dunnigan, James F. *How to Make War: A Comprehensive Guide to Modern Warfare in the 21st Century*. New York: Harper Collins Publishers, Inc. , 2003

* Fitz, William C. (Editor). *Steam and Stirling: Engines You Can Build*. Traverse City, Michigan: Wildwood Publications, 1980.

Frey, Robert L. , and Schrenk, Lorenz P. *Northern Pacific Supersteam Era: 1925-1945*.

San Marino, California: Golden West Publishing, 2000.

Giedion, Siegfried. *Mechanization Takes Command: A Contribution to Anonymous History*. New York: W. W. Norton & Company, Inc. , 1948.

Halberstadt, Hans, *Modern Diesel Locomotives*. Saint Paul: MBI Publishing, 2000.

Hilton, George. *The Cable Car in America.: A New Treatise on Rope Traction as Applied to the Working of Street and Other Railways*. Berkeley, California: Howell-North Books, 1971.

Hilton, George W., and Due, John F. *The Electric Interurban Railways in America*. Stanford: Stanford University Press, 1964.

Holley, Noel T. *The Milwaukee Electrics: An Inside Look at Locomotives and Railroading*. Edmonds, Washington: Hudman Publishing, 1999.

Hughes, Thomas P. *Networks of Power: Electrification in Western Society, 1870-1920*. Baltimore: Johns Hopkins Press, 1983.

_____. *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970*. New York: Penguin, 1989.

* International Textbook Company. *Brakes, Part 1*. London: International Textbook Company, Stationer's Hall, 1910.

* _____. *Brakes, Parts 2 and 3*. London: International Textbook Company, Stationer's Hall, 1910.

* _____. *Electric Locomotives*. London: International Textbook Company, Stationer's Hall, 1909.

* _____. *Operating Instructions*. London: International textbook Company, Stationer's Hall, 1910.

* _____. *Single Phase Speed Control*. London: International Textbook Company, Stationer's Hall, 1909.

* _____. *Speed Control*. London: International Textbook Company, Stationer's Hall, 1909.

* _____ . *Transmission Systems for Heavy Traction*. London: International Textbook Company, Stationer's Hall, 1909.

* _____ . *Types of Collectors for Heavy Traction*. London: International Textbook Company, Stationer's Hall, 1909.

* _____ . *Types of Railway Motors*. London: International Textbook Company, Stationer's Hall, 1909.

Jonnes, Jill. *Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World*. New York: Random House, 2003.

Laidler, Keith J. *To Light Such a Candle: Chapters in the History of Science and Technology*. Oxford: Oxford University Press, 1998.

Launius, Roger D. (Ed.), *Innovation and the Development of Flight*. College Station: Texas A & M Press, 1999.

Marcusson, Isaac F. *Anaconda*. New York: Dodd, Mead, & Company, 1957.

Martin, Albro. *Enterprise Denied: Origins of the Decline of the American Railroad, 1897-1817*. New York: Columbia University Press, 1971.

McCarter, Steve. *Guide to the Milwaukee Road in Montana*. Helena, Montana: Montana Historical Society Press, 1992.

Meyer, Jerome S. *The World Book of Great Inventions*. Cleveland: World Publishing Company, 1956.

Middleton, William D. *When the Steam Railroads Electrified*. Seattle: Kalmbach Publishing, 1974.

* Mileaf, Harry (Ed.). *Electricity One-Seven*. Rochelle Park, New Jersey: Hayden Book Company, Inc., 1977.

Moran, Richard. *Executioner's Current: Thomas Edison, George Westinghouse, and the Invention of the Electric Chair*. New York: Alfred A. Knopf, 2002.

Morgan, David Page. *Diesels West!: Evolution of Power on the Burlington*. Milwaukee: Kalmbach Publishing, 1963.

Mutschler, Charles V. *Wired for Success: The Butte, Anaconda & Pacific Railway, 1892-1985*. Pullman, Washington: Washington State University Press, 2002.

* National Electrical Manufacturers Association. *A Chronological History of Electrical Development from 600 B. C.* New York: National Electrical Manufacturers Association, 1946.

Nevins, Allan and Hill, Frank Ernest. *Ford: The Times, the Man, the Company*. New York: Charles Scribner's Sons, 1954.

* Nordbye, Jan p. *The Wankel Engine: Design, Development, Applications*. Philadelphia: Chilton Book Company, 1971.

Norman, Donald A. *Turn Signals Are the Facial Expressions of Automobiles*. New York: Addison-Wesley Publishing Company, 1992.

Petroski, Henry. *The Evolution of Useful Things*. New York: Alfred A. Knopf, 1993.

_____. *The Pencil: A History of Design and Circumstances*. New York: Alfred A. Knopf, 1989.

Pisanni, Donald J. *Water and American Government: The Reclamation Bureau's National Water Policy and the West, 1902-1905*. Berkeley: University of California Press, 2002.

* Ploss, Thomas. *The Nation Pays Again: The Demise of the Milwaukee Road: 1928 - 1986*. San Marino, California: Self Published, 1991.

Pool, Robert. *Beyond Engineering: How Society Shapes Technology*. New York: Oxford University Press, 1997.

Rhodes, Richard. *The Making of the Atomic Bomb*. New York: Simon & Schuster, 1991.

*Ripley, William Zebina. *Railroads: Finance and Organization*. (London: Long, Green and Company, 1915.

Saulsy, Richard.. *I. G. Farben*. New York: Boni and Gauer, 1947.

Schiffer, Michael Brian. *Taking Charge: The Electric Automobile in America*. Washington, D. C.: Smithsonian Institution Press, 1994.

Schrenk, Lorenz P., and Frey, Robert L. *Northern Pacific Diesel Era, 1945-1970*. San Marino, California: Golden West Publishing, 2000.

* Simon & Schuster, *The Way Things Work: An Illustrated Encyclopedia of Technology*. New York: Simon & Schuster, 1967.

Solomon, Brian. *American Steam Locomotive*. Osceola, Wisconsin: MBI Publishing, 1998.

Swartout, Robert R. , and Fritz, Harry W.(Editors). *Montana Heritage: An Anthology of Historical Essays*. Helena, Montana: Montana Historical Society Press, 1992.

Strandh, Sigvard. *A History of the Machine*. Gothenberg, Sweden: Nordbok, 1979.

Tedlow, Richard. *Giants of Enterprise: Seven Business Innovators and the Empires They Built*. New York: Harper Collins, 2001.

Tuplin, W. A. *The Steam Locomotive*. New York: Charles Scribner's Sons, 1974.

Vesey, Laurence R. *The Emergence of the American University*. Chicago: University of Chicago Press, 1965.

Vogel, Steven. *Prime Mover: A Natural History of Muscle*. New York: W. W. Norton & Company, 2001.

*Westinghouse Electric and Manufacturing Company. *Special Publication #1575: A Brief Outline of the Development and Progress of the Electric Railway Industry*. East Pittsburgh: The Eddy Press Corporation, 1923.

Wheeler, Keith. *The Railroaders*. New York: Time-Life Books, 1973.

White, John H. ,Ed.) *American Locomotives, an Engineering History, 1850-1880*. Baltimore: Johns Hopkins Press, Baltimore, 1997.

White, Michael. *Acid Tongues and Tranquil Dreams*. New York: William Morrow, 2001.

* Wilkerson, Bill .*The Milwaukee Diesels*. Harlowtown, Montana: Times Clarion Press, 1993.

* _____ . *The Milwaukee Road EF-4 Locomotives*. Harlowtown, Montana: Times Clarion Press, 1991.

* _____ . *The Milwaukee Road Electric Passenger Locomotives*. Harlowtown, Montana: Times Clarion Press, 1998.

Williams, Ernest W. ,Jr. , *Freight Transportation in the Soviet Union: Including Comparisons with the United States*. Princeton: Princeton University Press, 1962.

Withuhn, William L. (ed.). *Rails Across America*. New York: Smithmark Publishers, 1993.

Wood, Charles R. and Dorothy M. *Milwaukee Road West*. Seattle: Superior Publishing Company, 1972.

PERIODICALS

Chandler, Alfred D. Jr. "Patterns of American Railroad Finance 1830-1850." 28 *Business History Review* (1954): 261.

* Kendall, Carpenter. "The Handwriting on the Wall." *Milwaukee Railway System Employee's Magazine* (February, 1916): 1.

* Kidson, Martin. "Crossing the Divide by Rail." *Helena Independent Record*. 2 June 2002, 1,6. (C).

Lovins, Amory, and Lovins, L. Hunter. "Energy Forever." *The American Prospect*. (February 11, 2002): 32.

* Ryan, John D. "Montana Power Company Bulletin Number 6 - The Montana Power Company: Is It a Monopoly?" (Butte, Montana: Montana Power) : 1.

Swett, Ira L. "Montana Trolleys II, Butte, Anaconda, and Pacific," *Interurbans Magazine*. South Gate, California. Volume 26 Number 4, (Winter 1969).

* Unknown Author. *The Butte Miner* (December 9, 1915) :1.

Unknown Author. "St. Paul's Electrification System," *Literary Digest* (April 12, 1916): 1120-21.

* Unknown Author, "Electrification of Chicago, Milwaukee & St. Paul," *Electrical World* 62:22 (November 29, 1913): 103.

* Westinghouse. *Rules and Regulations Governing the Operation of the Westinghouse and Electric Passenger Locomotives Class EP-3*. East Pittsburgh: Westinghouse Electric and Manufacturing Co. , 1926.

GOVERNMENT PUBLICATIONS

* Bureau of Naval Personnel. *Basic Electricity*. New York: Dover Publications, 1970.

* Interstate Commerce Commission. Publication No. 17021: *Investigation of Chicago, Milwaukee & St. Paul Railway Company*. Washington, D.C. : Government Printing Office, 1928.

INTERVIEWS

* Milt Clark, former dispatcher, Milwaukee Road, Soo Line, currently with Montana Rail Link. April 10, 2002.

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