

*A Light in the Darkness:
Modern U.S. Mine Lamps—
Carbide and Electric
Cap Lamps*

By
Paul J. Bartos

Miners have used six major lamp types in the two hundred years of U.S. underground mining. In approximate temporal sequence these are: covered oil lamps, safety lamps, spout oil wick lamps, candles and their holders, carbide lamps, and electric cap lamps. My article in the previous issue of this journal looked at oil lamps, safety lamps and candles; this article deals with carbide lamps and electric cap lamps.

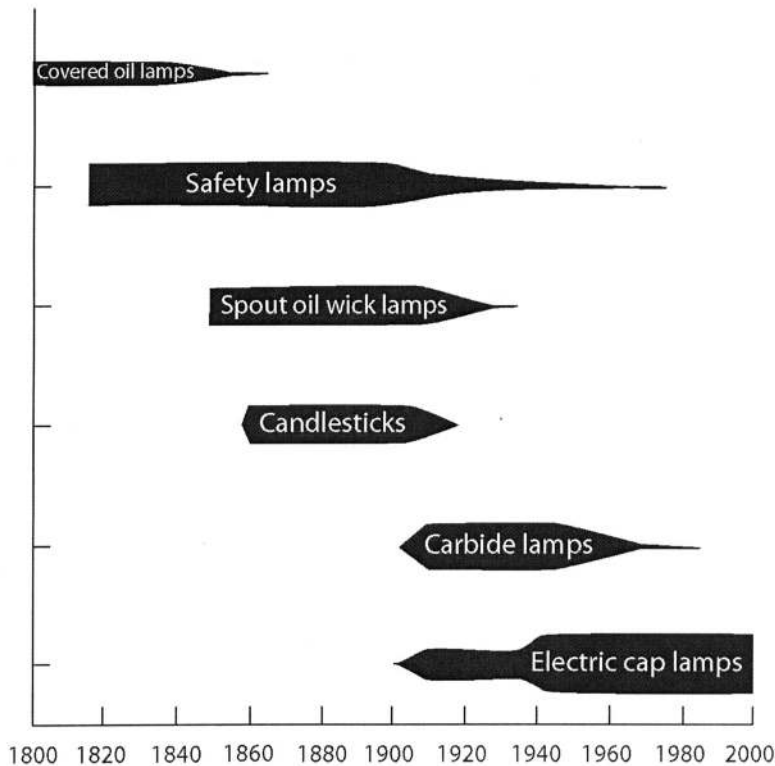
As discussed previously, a broad overlap in time exists in the use of many mine lighting inventions, much more than one would expect given the technological superiority of some of these lamp types. How, then, did the technologically inferior lamps manage to last as long as they did? To answer this question I will first look at the developmental history of the last two lamp types, then conduct a performance matrix analysis.

Carbide Lamps

Use of carbide lamps in mining in the United States began in the early 1900s and lasted into the 1950s, with their heyday being the period from 1910 to 1935. Carbide lamps represent a significant technological advance, producing a steady flame four to ten times brighter than candles or oil lamps. A carbide lamp operates on the principal that calcium carbide in contact with water gives off acetylene gas. This gas is easily and safely ignited, producing the bright, clean flame.

Calcium carbide was first chemically synthesized and described by Edmund Davy in 1836, but no commercial applications came out of his work. In 1862, Frederic Woehler resynthesized the compound and further described its properties, including its relationship with acetylene gas. However, with the preparation technique expensive and tedious,

U.S. Mine Lamp Time Sequence



Sequence Timeline for U.S. Mine Lamps. Shapes are approximately proportional to actual amount of a given mine lamp type in use at that particular time. Note the considerable overlap in time among the various lamp types. This is in spite of the fact that many of the lamps represented new, superior technologies that superseded earlier types.

commercial applications were not pursued.

In 1888, Thomas Willson, a Canadian electrical inventor living in Spray, North Carolina, began a series of experiments attempting to economically isolate metallic aluminum by reducing aluminum ores with carbon in an arc furnace. In the course of this work, he passed a strong electric current through a finely ground mixture of coal tar and lime, producing what proved to be calcium carbide. The carbide he reacted in turn with water to yield acetylene gas, which produced a bright flame when ignited. This calcium carbide process proved to be one of the great accidental discoveries of the chemical industry.

Willson acquired a patent for his process in 1892 and constructed the first commercial carbide plant in 1894. Willson's patents and plants evolved into the Union Carbide Company, which by 1908 controlled a large portion of the market, with large-scale production facilities at Sault Ste.

Marie, Michigan, and Niagara Falls, New York.¹ These produced calcium carbide using the cheap hydroelectricity just then becoming available.

Acetylene enjoyed a widespread series of applications. The first of these for illumination was in a bicycle lamp, with a patent granted to H. B. Clarke in 1896.² Frederick Baldwin produced the first truly popular bicycle lamp in his shop in 1900, and by 1905 miners were using Baldwin carbide lamps in both metal and coal mines. Baldwin's lamp appears to be the first carbide lamp used widely in mining.³

Baldwin's lamp was soon modified for use in underground conditions, and, all told, more than forty known manufacturers of carbide mine lamps eventually existed.⁴ The vast majority hailed from three locations: Illinois, principally the Chicago area; Pennsylvania, principally Pittsburgh; and New York City. Major manufacturing centers, albeit those near coal mining regions, produced

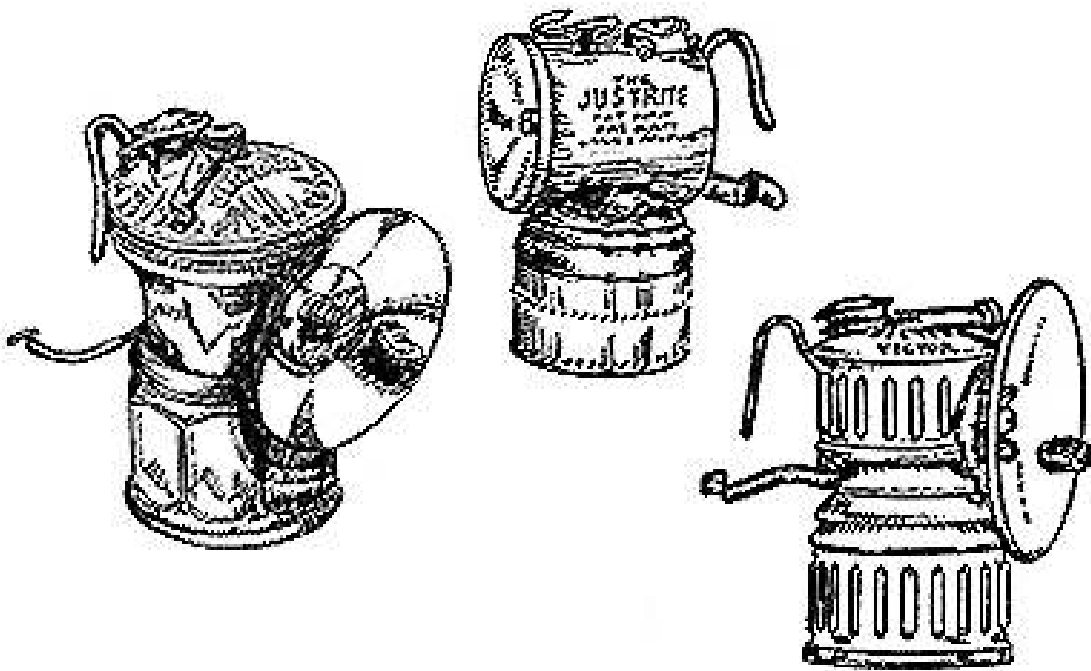
the relatively complicated carbide lamp, with the New York locale also allowing for easy export. In contrast, the simpler candlesticks and spout lamps were more locally produced.

A carbide lamp is a two-chambered device. When a valve is opened, water in the upper chamber drips upon chunks of calcium carbide housed in the lower chamber. The resulting chemical reaction yields acetylene gas and a calcium hydroxide residue. Pressure from accumulation of the acetylene gas forces the gas upward, through a felt filter that removes carbide and calcium hydroxide particles, into a small tube, where it is vented from the lamp at a burner tip. This is ignited with a flint, yielding a steady, brilliant flame amplified with a bright concave reflector. The flame itself is about an inch or so in length. The tip and the water's drip rate can both be adjusted to produce a longer and brighter flame at the cost of increased carbide consumption.

At least 316 patents respecting carbide lamps were issued over an interval of eighty-one years.⁵

In 1905, metal reflectors were introduced. These produced a spotlight four times brighter than that of non-reflector models. Reflectors represented a significant advance from the glass prism system used in early bicycle lamps but clearly impractical for underground conditions.

Aside from reflectors, most of the important innovations and improvements in the mining carbide lamp occurred in the years from 1913 to 1915. These included a flint striker in 1913, so that the lamp could be ignited anywhere without fumbling for matches; a breeze protector in 1914, since early lamps had the unfortunate tendency to extinguish in the slightest air movement; and, also in 1914, a water-feed valve "dropper" that solved the problem earlier models had with clogging with calcium hydroxide residue. This last invention led directly to a leading lamp model, the Guy's Dropper, and became the preferred mechanism for introducing water to carbide. The final major improvement, the lamp hooks and cap lamps that freed working hands, appeared in 1915.⁶



Some typical carbide lamps. CSM Geology Museum collection. (From H. A. Pobs, "Early Underground Mine Lamps." Museum Monograph No. 6; Tucson: Arizona Historical Society, (1974).)

Carbide lamps were clearly a major technological advance and their use skyrocketed. By 1915, an estimated 300,000 carbide mine lamps were in daily use.⁷ By 1919, one model alone, the Guy's Dropper, had an annual production of 720,000 lamps.⁸ All told, nearly eighty brands exist, many with multiple models—Justrite alone had over 154 models⁹—from at least forty-four manufacturers. Justrite, Autolite, and Guy's Dropper, the most popular brands, constituted 85 to 90 percent of all carbide mine lamps produced.

These lamps were cheap and easy to operate. Statistics in a 1914 advertisement by the Baldwin Lamp Company suggest that their lamp yielded ten to sixteen candlepower and consuming approximately eight ounces of carbide per man per ten-hour shift, at a cost per man-shift of approximately two cents. The typical brass carbide mine lamp cost a dollar. Nickel plating—a common feature, particularly for mine superintendents—cost a little more: \$1.25 to \$1.50, and occasionally \$2.00 per lamp.

Mining companies typically provided the calcium carbide. It came in various sizes of drums and cans and the key factor was that it had to be kept absolutely dry. Miners commonly owned a personal carrier, in which they carried a day's supply of carbide and water. Mines commonly provided a screen at the portal where miners sifted the spent carbide to recover the larger unused fragments.

Miners typically owned their lamps and had the responsibility to clean and maintain them.¹⁰ Some catalog ads for carbide lamps appear to be directed at the individual miner, however other ads strongly suggest that some companies purchased lamps as well as carbide for their miners.

The heyday of carbide lamps lasted approximately thirty years, into the 1940s, but significant carbide lamp use, particularly in smaller, remote operations, continued well into the 1950s.¹¹ Carbide lamps are even used today on a small scale at remote operations where electricity for recharging battery lamps is not available.¹² In addition,

a limited market developed for the lamps among outdoorsmen and spelunkers. However, by the late 1950s, only three carbide mine lamp manufacturers remained, reduced to one, Justrite, by 1960.¹³ In the mid 1970s, Justrite introduced a plastic carbide lamp that was not well received. By 1985, Justrite had ceased all production of carbide lamps.¹⁴

Electric Lamps

Electric mine lighting began as early as 1881, when collieries in Scotland and England experimented with glow lamps wired to a main cable. The light produced was relatively dim—approximately three candlepower—not portable, and met with strenuous objections from the miners. In the face of these problems the companies soon abandoned this first experiment in electric mine lighting.¹⁵

Researchers then directed their efforts toward inventing a portable electric lamp using either primary (direct charge) or secondary (rechargeable) batteries. By the late 1890s, several European models existed, principally using primary batteries. These lamps typically weighed between six and nine pounds, and generated one and a half to three candlepower with a lamp life of eight to twelve hours. By 1897, secondary battery lamps were available that could produce three candlepower over a ten- to twelve-hour charge.¹⁶

These models were all hand-held lamps and did not appear to be particularly popular. Reports show 2,135 electric lamps operating in Great Britain in 1909, decreasing to 2,035 in 1910.¹⁷ All told, these two thousand electric lamps represented only about 0.3 percent of the total of mine lamps being used in Great Britain.¹⁸

The first mention of the use of portable electric mine lamps in the United States came in relation to rescue work after a Pennsylvania coal mine disaster in 1901.¹⁹ The same article mentions the use in several mines in southeastern Pennsylvania of four-candlepower lamps manufactured by the

Portable Electric Power and Light Company of Jersey City, New Jersey. Two officials of the Bureau of Mines documented the use of a Hubbell electric hand lamp in Pennsylvania mines as early as 1907.²⁰ Another early lamp model, the Victor-American, appeared in Colorado at approximately the same time. Early American portable battery lamps were quite crude and inefficient. None could meet the Bureau of Mines' mine lamp specifications of 1914; nevertheless, they were actively used for several years.

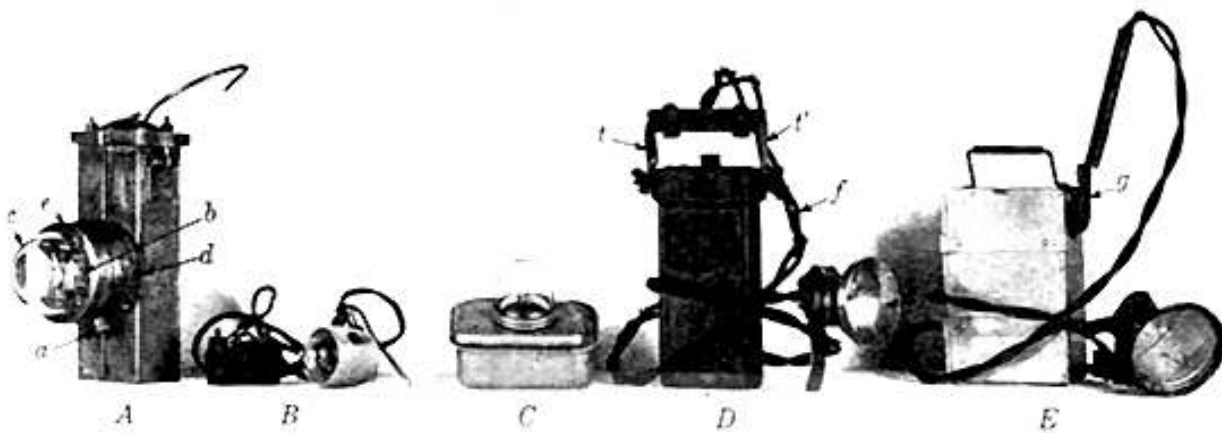
Early electric battery lamps were used especially as a safe illuminant in mines with methane gas present.²¹ Their design was considered significantly safer than other lamp types, as they typically featured an internal sealed system that minimized the sparking that could ignite either methane gas or coal dust. In particular, rescue operations in mines with dangerous quantities of residual methane usually featured electric battery lamps. From about 1910 to 1912 the Draeger Company specifically constructed these lamps for use in mine rescue operations, complete with locking flanges at any air access point.

A significant advance in electric mine lamps occurred in 1911, when tungsten wire replaced carbon as the bulb's filament.²² This solved two basic problems. In order for the lamp to operate

well, the filament had to be heated to a high temperature. That caused carbon to evaporate quickly, however, shortening the life of a carbon filament. Tungsten's other advantage was that it drew less current than carbon, so the battery could be lightened. Portable battery lamps became more popular thanks to these improvements, and additional models specifically designed for use in mines became available.

The invention of the alkaline battery provided another breakthrough in electric mine lamps. This battery was initially designed by Thomas Edison in 1903 to power electric cars. But by 1909, when the Type A-cell alkaline battery was sufficiently developed, the market for electric cars had collapsed, leaving Edison seeking other customers for his battery.²³ In 1911, Edison drafted a list of possible applications for the alkaline battery, one of the sixty-four possibilities being miners' lamps.²⁴

In 1915 the Edison electric cap lamp, containing a scaled-down alkaline battery designed to be carried on a miner's belt, entered general use and quickly became one of the leading electric lamp models. It contained a bulb with a tungsten filament, parabolic reflector, and heavy lens, connected by a stout rubber cord to a clasp-locked, aluminum-enclosed battery. The Edison lamp is



Early American electric mine lamps. A) Hubbell hand lamp; B) Pilley lamp; C) R. and B. lamp; D) Victor-American lamp; and E) Hirsch combination hand and cap lamp. These lamps were used from approximately 1907 to 1911. (From Ilsley and Hooker, "Permissible Electric Mine Lamps," 1930.

*Draeger battery rescue lamps, circa 1910.
(CSM Geology Museum collection.)*



very similar in its configuration to electric mine lamps used today. The initial Edison electric cap lamp put out about one candlepower. By 1931 improvements yielded a lamp that generated 70 candlepower.²⁵ By 1949, an Edison cap lamp produced 240 candlepower.

The federal government took a strong role in developing the basic design of the electric cap lamp in the United States. The U.S. Geological Survey began limited testing of mine lamps in 1909, with the newly created Bureau of Mines taking over these duties a little later. A 1913 congressional act formalized provisions for mine lamp safety investigations by the Bureau.²⁶

A year later the Bureau published a detailed list of specifications that miners' portable electric lamps would have to meet in order to be "permissible," in the language of the day. These included a minimum bulb life of 200 hours, a minimum light intensity of 0.4 candles, a minimum charge life of 12 hours, and a minimum life of 3,600 hours for conventional zinc-carbon batteries and 7,200

hours for alkaline batteries.²⁷

The first three lamps to meet the Bureau's approval were the CEAG hand-held lamp of the Mannesman Light Company of America, New York;²⁸ the Hirsch cap lamp of the Hirsch Electric Light Company, Philadelphia; and the Wico cap lamp of the Witherbee Igniter Company, Springfield, Massachusetts.²⁹ The first Edison electric cap lamp received approval the following year, 1915.

Colorado's lawmakers anticipated the Bureau's role in approving mine lamps and incorporated it into their own safety legislation. The state's Coal Mining Laws of 1913 specified that

After the 1st day of October, 1913, only electric lamps shall be used in coal mines, except in places generating explosive gas or noxious gases where an approved safety lamp shall be supplied for each working place for testing purposes and all lamps shall be the property of the [mine] owner.

... Provided that upon that date there shall have been produced and placed on sale a practical and efficient electric lamp which shall have been approved by the United States Bureau of Mines, as an electric light having such qualifications.³⁰

Lamp manufacturers participated voluntarily in the Bureau of Mines' specification program. Lamp manufacturers submitted their products to the Bureau, which then worked extensively with the companies to help their products meet the Bureau's safety and design criteria. Lamp manufacturers paid a testing fee of \$150,³¹ and each individual lamp model had to go through this process to be declared permissible.

Once the Bureau accepted a lamp, it published notice of the approval in a Bureau publication bearing some variation of the title "Permissible Electric Mine Lamps." The Bureau also provided a plate containing the Bureau's seal, a brief approval statement, and the approval number to the manufacturer. Copies of the approval plate were prominently displayed on each individual lamp. No lamp was considered approved unless it bore this plate, which soon became a key selling feature.

This sort of government activism in inventing and manufacturing processes differed considerably from how other types of mine lights were developed. It may help explain the essential constancy of electric cap lamp design down to the present. Workers at the time noted that this approach yielded a "startling similarity" among the various lamps offered to miners.³²

The Bureau appears to have had a very definite vision of what an effective electric cap lamp should be. On the whole, this approach appears to have been accepted as increasing the overall quality of the lamp, albeit at the cost of some individuality on the part of manufacturers. For their part, Bureau officials felt that their approach greatly expedited the safe commercial development of electric mine lights, and that "the mining

public has been saved expensive and dangerous experiments, which might have cost many lives," had they simply allowed the marketplace to determine mine lamp development.³³

Mines in the coalfields rapidly transitioned to electric lamps. In Pennsylvania an estimated 45,000 flame safety lamps and no electric lamps were in operation in 1911; 1917 found 17,000 flame safety lamps and 48,000 electric lamps in use. English coal mines showed similar results: 724,000 flame safety lamps and 4,300 electric lamps in 1911; 590,000 flame safety lamps and 157,000 electric lamps in 1917.³⁴

Approximately half of the coal lamps used in England were electric by 1928, three quarters by 1941.³⁵ However, as late as 1960, the last year of available data, flame safety lamps still constituted approximately 18 percent of all coal lamps used in England, this despite the overwhelming technological advantages then offered by electric lamps.³⁶

Metal mines, lacking the safety issues associated with methane, adopted electric lamps far more slowly. A 1935 estimate held that more than half of the miners in the United States still used open flame lamps, the vast majority being metal miners.³⁷ Given that early versions of carbide lamps generated about two to five candlepower, compared to one candlepower for contemporary electric lamps, it is clear that early electric lamps were not technologically superior to carbide lamps in light generation before the improvements in electric candlepower previously noted.

Several other obstacles hindered adoption of the electric cap lamp. The first obvious constraint was the availability of electricity for recharging its battery. The first mine electrification in the United States occurred at Telluride, Colorado, in 1891.³⁸ Other camps, such as Creede, Colorado, soon followed, but it took considerable time to electrify many of the remote, poorer camps in the country.³⁹

Even with a reliable supply of electricity, problems remained with using electric lamps. Electric

Early Edison electric cap lamp, approved by the Bureau of Mines in February 1915. Modern electric cap lamps are little different in appearance from this lamp. (From Clark and Ilsley, "Approved Electric Lamps for Miners," 1917.)



lamps and their charging system constitute an expensive, integrated system. One typically does not purchase an individual electric cap lamp, and lamps are typically returned to a central depository for recharging. In contrast, carbide and oil wick lamps were individual affairs, each miner being responsible for maintaining his lamp. Mine owners could and did require individual miners to procure their own oil and carbide lamps, thus saving mining companies money. That changed in United States in 1941, when a new decree required mine operators nationally to provide lamps for miners.⁴⁰

Cost was and remains perhaps the most significant obstacle to the electric lamp's acceptance. A new MSA electric cap lamp listed at \$246 in 2006, while an individual charger to accompany it cost another \$236.⁴¹ These prices are far beyond the means of the typical small-scale miner, particularly in the developing world.

At Cerro Rico de Potosi, Bolivia, a district quite familiar to the author,⁴² five to ten thousand artisan miners scratch out a marginal existence on the mountain. All of these miners belong to small-scale cooperatives, with little money available for capital expenses such as electric lamps.

Although electricity is readily available, many of Cerro Rico's miners use carbide lamps. The principal constraint on using electric lamps is the high cost of the lamps themselves.

Early prices for electric cap lamps are difficult to find, as mining supply catalogs of that era typically did not list electric cap lamps as an item to purchase. Rather, lamp companies rented the lamps to mining companies. Even much later, a 1942 study of electric cap lamps in a West Virginia coal district revealed that none of the twelve operating companies in the district had purchased lamps outright. Rather, mines rented 68 percent of the electric lamps, while the remaining 32 percent were acquired under rent-to-own contracts, ownership transferring to the mining company after a five-year period.⁴³ Rent-to-own and rental contracts, typical solutions for those selling high-priced goods to cash-poor buyers, suggest that electric cap lamps constituted a significant expense for mining companies.

However, electric lamps provided some cost advantages. Insurance companies preferred electric lamps and this was reflected in their premiums. Pennsylvania's Employers' Liability Act of 1907 made coal companies liable, meaning

that they either had to self-insure or take out liability insurance. Insurance companies made it clear that they preferred electric cap lamps, once those became available. Insurers charged mining companies using flame safety lamps an additional eleven cents per one hundred dollars of payroll, a premium waived for companies using electric lamps. Pennsylvania's rapid conversion from safety to electric lamps can be partly attributed to this insurance premium.⁴⁴

For many years the Bureau of Mines sponsored electric cap lamps and actively promoted their use. As late as 1935 Bureau publications express a certain dismay at the relatively slow rate of adoption of these lamps by the metal mining industry.⁴⁵ But the high initial cost of the lamp and recharging system discouraged their use, despite the system's significant advantages, until mandates from regulating and insurance agencies forced the issue.

A Performance Matrix

A performance matrix is a type of table that enables comparison of two or more competing technologies. The method is used by behavioral anthropologists as a way to compare all factors, quantitative and qualitative, with respect to competing technologies, in order to determine how adoption decisions are made.

Performance matrix analysis will help address two key questions associated with the U.S. adoption of mine lamps: Why did carbide lamps, a clearly superior technology, not immediately displace spout oil wick lamps? Why did carbide lamps last as long as they did against Edison electric cap lamps, also an apparently superior technology?

Both the coal and metal mining industries certainly appear to have strongly resisted change when faced with new lighting technologies. Only after the superiority of the carbide lamp was well established did many candle users convert, a process that took approximately ten years. It took

even longer, fifteen to twenty years, to abandon spout oil wick lamps, which lasted in mines into the 1920s, when they were replaced by electric lamps.

A performance matrix comparing carbide and spout oil wicks lamps, demonstrates the clear superiority of carbide lamps with respect to quality and quantity of light and operating costs. Other variables appear essentially equivalent, particularly when comparing Sunshine lamps to carbide lamps.

The key difference between the two appears to lie in the realm of safety. The flame from a spout oil wick lamp could be used to "read" air content, particularly for methane and carbon monoxide. The acetylene flame from a carbide lamp did not have that capability.⁴⁶ Thus, the oil spout lamp acted as a kind of early-warning system in coal mines, where pockets of bad air could be encountered at any turn. This fact alone probably justified the oil lamp's continued use despite what would be suggested by a comparison of cost and light values.

A similar story occurs when comparing electric cap lamps to carbide lamps, another case of significant resistance to the introduction of a superior technology. In every category but one, cost, electric cap lamps were superior to carbides. In the categories that would seem to matter most, light and safety—the latter particularly so in gassy coal mines—the electric cap lamp proved far superior to the carbide lamp. However, the one category where carbide lamps excelled, cost, was certainly not trivial.

Not only were electric lamps more expensive to purchase, but their upkeep was considerably greater. The electric lamp system required a special store room, recharging equipment, a lampman to service the lamps, and replacement bulbs and batteries. In earlier years the availability of electricity was another issue. Although the cost of electricity, once available, was probably on par with that of calcium carbide, those other factors produced a significant cost differential between

Performance Matrix Comparing Spout Oil Wick (Sunshine) Lamps to Carbide Lamps		
	Carbide	Oil Wick Lamps
Cost		
Initial Purchase	-	+
Operating Cost	+	-
Light		
Quantity (candlepower)	++	--
Quality (constancy of flame)	+	-
Ease of Operation	~	~
Ease of Fuel Transport	~	~
Safety	-	+
Ventilation (smoke generated)	~	~
Intangibles (tradition)	?	?
(+ decidedly better; ++ much, much better; - decidedly worse; -- much, much worse; ~ approximately the same; ? uncertain)		

Performance Matrix Comparing Electric Cap Lamps to Carbide Lamps		
	Carbide Lamps	Electric Cap Lamps
Cost		
Initial Purchase	++	--
Operating Cost	+	-
Light		
Quantity (candlepower)	--	++
Quality (constancy of flame)	-	+
Ease of Operation	-	+
Ease of Fuel Transport	--	++
Safety	--	++
Ventilation (smoke generated)	-	+
Intangibles (tradition)	?	?
(+ decidedly better; ++ much, much better; - decidedly worse; -- much, much worse; ~ approximately the same; ? uncertain)		

the two lamp types. That cost differential is probably what kept carbide lamps on the market for approximately sixty years after the introduction of electric cap lamps.

Conclusions

With respect to U.S. mine lamps, a few broad themes tend to reoccur again and again. First, adaptation to new lighting technologies happened slowly. Older lamp technologies often lingered considerably beyond the point when a new technology had established its superiority. This general reluctance to fully embrace new technologies in a relatively rapid manner often appeared to characterize the mining industry as a whole.⁴⁷

Second, the initial source of a typical breakthrough mine lamp innovation came from outside the mining industry, with the innovation itself being the modification of an existing invention to fit mining's circumstances. A series of industry-specific modifications often succeeded the breakthrough innovation. This pattern—a breakthrough innovation coming from outside a given industry, then incrementally modified once within—now appears to be the norm for many, if not most innovations.⁴⁸ It was certainly the case with carbide and electric mine lamps, though some exceptions to this generalization certainly occur. Safety lamps were invented specifically to address the problem of gas explosions in coal mines.

Third, a significant period of time lapsed between a discovery or invention and its commercial application. An interval of fifteen years passed from the introduction of cheap, mass-produced candles to the invention of the first candleholders that made them usable underground. In the case of carbide lamps, a minimal lag time of only one year passed between the commercialization of acetylene via calcium carbide and its application

to illumination. However, the jump from bicycle lamps to specially designed mine lamps took approximately eight years. Thus nine years passed between the creation of commercial acetylene and its application to mine lighting.

The passage from useable storage battery to electric cap light was somewhat shorter—about six years. Further, mine lamp data suggest a more rapid crossover from the source of the innovation to its underground application than is typically recognized.⁴⁹ Usually innovation tracer studies show a lengthier period, typically on the order of twenty years, between an invention in basic research and its commercial application. One researcher, examining a range of innovations from oral contraceptives to hybrid corn, discovered an average time of nineteen years from innovation to realization.⁵⁰ A similar gestation period has occurred in the computer and telecommunications industries.⁵¹

Innovations in mine lighting entered the mines relatively quickly, but it took far longer for miners to accept the new lamps and to completely discard older technologies. Thus mine lamps, besides being fascinating objects in their own right, also illuminate the nature of innovation and the adoption of technologies within a particular industry. ■

Dr. Paul Bartos has been associated with the mining industry for approximately thirty years, principally in ore deposit exploration and evaluation. Previously, he was director and curator of the Colorado School of Mines Geology Museum. Mr. Bartos is currently vice president and chief geologist of Esperanza Silver Corporation, a junior exploration company dedicated to exploring for precious metals in Mexico and Peru. He wishes to thank the Arizona Historical Society, especially Dr. Bruce Dinges, director of publications, for allowing the reproduction of Henry Pohs' mine lamp line drawings.

Notes:

1. G. G. Pond, "Calcium Carbide and Acetylene" (Pennsylvania State College, 1908); G. S. Clemmer, *American Miners' Carbide Lamps: A Collector's Guide to American Carbide Mine Lighting* (Tucson, AZ: Westernlore Press, 1987), 13-4. See also: "Discovery of the Commercial Process for Making Calcium Carbide and Acetylene," American Chemical Society website, www.acs.com.
2. U.S. Patent no. 566,660, 25 Aug. 1896.
3. Clemmer, *American Miners' Carbide Lamps*, 62-5; H. A. Pohs, *The Miner's Flame Light Book* (Denver: Flame Publishing Co., 1995), 394-409; D. Thorpe, *Carbide Light: The Last Flame in American Mines* (Washington, D.C.: Bergamot Books, 2006). There is evidence of some carbide manufacturers promoting their lamps for mine use as early as 1903, but it is unclear how extensive that use was.
4. Clemmer, *American Miners' Carbide Lamps*, 60-92.
5. H. Post, "Mine Lighting: A Hall of F(l)ame," *New Mexico Geology* 31, no. 4 (2009): 112.
6. These reflectors were sometimes modified in actual use. Coal miners often blackened a new reflector so as to reduce the high contrast that the light provided in its surroundings. Metal miners also sometimes blacked the reflector to avoid blinding their partners with a new lamp's relatively bright light. Ed Hunter, personal communication, 1 May 2010.
7. J. W. Paul, "Notes on Miners' Carbide Lamps," U.S. Bureau of Mines, *Miners Circular No. 18*, Washington, D.C.: USGPO, 1915, 3.
8. Clemmer, *American Miners' Carbide Lamps*, 48.
9. Pohs, *Miner's Flame Light Book*, 462.
10. D. A. Trotter, *The Lighting of Underground Mines* (Clausthal-Zellerfeld, Germany: Trans Tech Publications, 1982), 10.
11. The Colorado School of Mines Geology Museum displays photos of 1950s-era uranium miners using carbide lamps.
12. I have used these lamps in underground mine explorations throughout Latin America.
13. Clemmer, *American Miners' Carbide Lamps*, 57.
14. Pohs, *Miner's Flame Light Book*, 462.
15. G. E. Bayles, "The History of Mine Lighting, Part 2," *Mechanization* 21, no. 1 (1957): 73-6.
16. Bayles, "History of Mine Lighting," 76.
17. Anon., "Safety Lamps," *Coal Age* 1 (Dec. 1911): 316.
18. L. C. Ilsley, and A. B. Hooker, "Permissible Electric Mine Lamps," U.S. Bureau of Mines, *Bulletin* 332, 1930, 2.
19. Anon., "Portable Electric Mine Lamps," *Mines and Minerals* 22 (Dec. 1901): 195.
20. Ilsley and Hooker, "Permissible Electric Mine Lamps," 3.
21. H. H. Clark, "Ignition of Gas by Miniature Electric Lamps with Tungsten Filaments," U.S. Bureau of Mines, *Technical Paper* 23, 1912, 6.
22. Trotter, *Lighting of Underground Mines*, 12.
23. G. S. Bryan, *Edison: The Man and His Work* (Garden City, NY: Garden City Publishing Co., 1926); W. B. Carlson, "Thomas Edison as a Manager of R & D: The Case of the Alkaline Storage Battery, 1898-1915," *IEEE Technology and Society Magazine* 7, no. 4 (1988): 9.
24. Carlson, "Thomas Edison as a Manager of R & D," 10.
25. Bayles, "History of Mine Lighting," 76.
26. Bayles, "History of Mine Lighting," 74.
27. H. H. Clark, "Permissible Electric Lamps for Miners," U.S. Bureau of Mines, *Technical Paper* 75, 1914, 17.
28. CEAG refers to the Concordia Electricitäts Aktien Gesellschaft of Dortmund, Germany, a leading electric bulb manufacturer at the time.
29. Clark, "Permissible Electric Lamps for Miners," 9-12.
30. Colorado Coal Mining Laws of 1913, 5158*-30-2, sec. 133, p. 63.
31. H. H. Clark and L. C. Ilsley, "Approved Electric Lamps for Miners," U.S. Bureau of Mines, *Bulletin* 131, 1917, 8.
32. See: E. M. Chance, "Portable Mine Lamps," *Bulletin of the American Institute of Mining Engineers*, no. 122 (1917): 235-43.
33. Clark and Ilsley, "Approved Electric Lamps," 8.
34. Bayles, "History of Mine Lighting," 76.
35. A. G. Neill, "Features of the Modern Miners' Lamp in Great Britain," *Colliery Engineering* 87 (1967): 441-7.
36. Neill, "Features of Modern Miners' Lamp," 444.
37. D. H. Zellers and A. B. Hooker, "Maintaining the Permissibility of Electric Cap Lamps," U. S. Bureau of Mines, *Information Circular* 6832, 1935, 10.
38. M. J. Seifer, *Wizard: The Life and Times of Nikola Tesla* (New York: Citadel Press, 1996).
39. L. Olson (ed.), *Rocky Mountain Almanac for 1989* (Denver: Rocky Mountain States Publishing, 1988), 58. A famous poem about Creede, written in its heyday by Editor Cy Warman of the Creede Chronicle, contains the lines: "It's day all day in the daytime, and there is no night in Creede." This couplet has long been considered the epitome of a mining camp in full flush, with saloons and gambling halls open around the clock and miners on the night and day shifts exchanging the same cots. But as Olson points out, this poem was published in the same week in 1892 that electric lights were installed in the town. It may be that the author was referring simply to the electrification of the mining camp, rather than its wild and wooly nature. See also: A. Fay, *I Never Knew that about Colorado: A Quaint Volume of Forgotten Lore* (Ouray, CO: Western Reflections, Inc., 1997), 78.
40. Bayles, "History of Mine Lighting," 76.
41. Information courtesy of the Mine Safety Appliance Company, Feb. 2006.

42. P. J. Bartos, "The Pallacos of Cerro Rico de Potosi, Bolivia: A New Deposit Type," *Economic Geology* 95 (2000): 645-54; P. J. Bartos, "The Pallacos of Cerro Rico de Potosi: Geology, Discovery," in *Proceedings of Marcofest: A Special Symposium honoring Marco T. Einaudi*, Colorado School of Mines, 3-5 Apr. 2003.
43. A. B. Hooker, "Field Performance of Permissible Electric Cap Lamps," U.S. Bureau of Mines, *Circular 7188*, 1942, 3.
44. Chance, "Portable Mine Lamps." 235.
45. F. E. Cash, "Electric Cap Lamps in Alabama Mines, 1935," U.S. Bureau of Mines, *Information Circular 6865*, 1935, 5; Zellers and Hooker, "Maintaining the Permissibility of Electric Cap Lamps," 10, 12; Clark, "Permissible Electric Lamps for Miners," 5-6.
46. However, the length of a carbide flame could be used to indicate the overall amount of oxygen available. This was a concern in the Cripple Creek District, which had problems with carbon dioxide buildup. This concern, as well as the additional costs associated with electric cap lamps, led to a considerable delay in electric cap lamp adoption in this district. Ed Hunter, personal communication, 1 May 2010.
47. P. J. Bartos, "Innovation in the Mining Industry through Time" (Ph.D. diss., Colorado School of Mines, 2006); P. J. Bartos, "Is Mining a High Tech Industry?: Investigations into Innovation and Productivity Advance," *Resources Policy* 32 (2007): 149-58; R. Burt, "Innovation or Imitation?: Technological Dependency in the American Non-ferrous Mining Industry," *Technology and Culture* 41, no.2 (2000): 321-47; R. Burt, "Technological Backwardness in the Western American Mining Industry in the Nineteenth Century," *Mining History Journal* 14 (2007): 23-39.
48. P. Anderson and M. L. Tushman, "Managing through Cycles of Technological Change," *Research-Technology Management* 34, no. 3 (May-June 1991): 26-31; P. J. Bartos, M. A. Boland, and L.W. Freeman, "The Human Face of Economic Geology: Education, Careers, and Innovation," in M. D. Doggett and J. R. Parry (eds.), *Wealth Creation in the Minerals Industry: Integrating Science, Business, and Education*, Society of Economic Geologists Special Publication no. 12 (2006), 171-92.
49. See, for example: E. M. Rogers, *Diffusion of Innovations*, 4th ed. (New York: The Free Press, 1995) and references therein.
50. S. Globe, *The Interactions of Science and Technology in the Innovative Process: Some Case Studies* (Columbus, OH: Batelle-Columbus Laboratories, 1973). (Report to the National Science Foundation.)
51. B. Buxton, "Forward into the Past," *Time*, 11 Oct. 2004, 80.