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MARK R. WILSON

On May 29, 1945, Charles F. Calhoun, a vice president of the Permanente Metals Corporation (PMC), composed a telegram to his fellow company officers that celebrated a long-awaited triumph. "This is to confirm delivery to Tokyo, May 26th, during high wind, of large Permanente shipment by way Marion, Ohio, and B-29 express," Calhoun began. "It is reported there was no loss of goods in transit but that considerable damage resulted from cargo being jettisoned within Tokyo city limits." He could not resist adding, tongue firmly in cheek, "All . . . claims of property damage will be forwarded to Permanente claims adjustment department."[1]

If PMC had actually taken on the task of settling "claims of property damage" in this case, its job would have been overwhelming. The "Permanente shipment" dropped over Tokyo consisted of 348 tons worth of large M76 incendiary bombs, filled with a sticky and extraordinarily flammable magnesium–asphalt mixture known as "goop." The bombs filled with Permanente "goop" were part of a total of 3,251 tons of incendiaries dropped over Tokyo by a giant fleet of 464 B-29 bombers on the night of May 25–26. Although it was far less deadly than the March 9–10 raid that had killed more than eighty thousand Tokyo residents, the late May operation actually involved many more planes and double the bomb tonnage. It destroyed roughly

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1. Calhoun to Eugene E. Trefethen, Jr., May 29, 1945, folder Magnesium Bombs Misc. 1945, Carton 135, HJK Papers.

17 square miles of the city, including the homes of over half a million people.[2]

Calhoun was giddy about the reports of the use of the M76 "goop" bombs because they seemed to validate PMC's more than four years of work on magnesium production, a period that had been full of setbacks and losses. In contrast to the company's successes in the mass production of merchant ships—which had made Calhoun's boss, Henry J. Kaiser, into one of the most celebrated leaders of the country's war effort—the magnesium operations had been heavily criticized and unprofitable. Since 1944, sales of "goop" to the U.S. Army's Chemical Weapons Service (CWS) had already begun to alleviate those earlier problems. And now, the PMC product was actually being used to defeat Japan, as the company's officers had long hoped it would. Equally important, the news meant that credit for the firebombs used in Japan should no longer be monopolized by Standard Oil of New Jersey, which claimed responsibility for the industrial development of napalm, the leading rival technology to "goop."

To the dismay of Calhoun and other PMC officers, "goop" never did get much attention—in 1945 or after.[3] Overshadowed by napalm and the atomic bomb, it could be relegated to the status of one of the many minor weapons of World War II. Over 17,000 tons of "goop"-filled M76 and M74 incendiary bombs were dropped by the Allies on Japan and Germany during World War II, but this amounted to only about 8 percent of the total tonnage of incendiaries that were dropped.[4] Although "goop" was regarded by many in the American military establishment as the new standard in incendiary bomb technology in 1945, it did not come close to displacing its rivals before the war's end. Nor was it widely used in subsequent conflicts. This helps to explain why historians of World War II firebombing have ignored "goop," concentrating almost exclusively instead on the development of napalm by the National Defense Research Committee (NDRC), university chemists including Louis F. Fieser of Harvard and J. Enrique Zanetti of Columbia, and research labs at Standard Oil.[5]

Given that the "goop" bomb was just one among many weapons used during World War II, it is not surprising that it has not received

2. U.S. Strategic Bombing Survey, *Effects of Incendiary Bomb Attacks on Japan*, 117; Schaffer, *Wings of Judgment*, 137; Werrell, *Blankets of Fire*, 188.

3. It is not even mentioned in the most comprehensive history of American incendiary weapons during this era: Mountcastle, *Flame On!*

4. Chemical Corps Association, *Chemical Warfare Service in World War II*, 74.

5. Mountcastle, *Flame On!*, 30–53; Schaffer, *Wings of Judgment*, 108; Russell, *War and Nature*, 101.

much attention. For good reasons, historians have concentrated on the strategic and ethical dimensions of the use of incendiaries, rather than the record of their production.[6] Nonetheless, the story of PMC's efforts to make magnesium and "goop" has important things to suggest about the history of American military–industrial relations.

The story of PMC "goop" and the magnesium industry in World War II is valuable because it provides considerable insight into the changing relationships between the wartime state and an individual firm, as well as those that developed across a whole industry. This microlevel perspective is often absent in studies of the "military–industrial complex" (MIC) and its history. One reason for this absence has been scholars' legitimate interest in describing a large system that encompasses many firms, industries, and governmental institutions. Much of the scholarship on World War II itself, for example, concentrates on the question of how fully the largest American industrial corporations were able to use the conflict to extend their influence over the state.[7] The relatively small literature that does provide a microlevel view, which evidently has been limited by a paucity of available business records, has tended to concentrate on firm size, production technology methods, and industrial learning curves.[8] This work has made important contributions to the field of the history of technology but has said less about other important issues that have long interested critics and historians of the MIC. Among these are concerns about excessive profit-taking, at low risk, in the defense sector.

These long-standing questions about defense production and profits can never be answered fully by any one case, even a relatively well-documented one such as the story of PMC, magnesium, and incendiaries in World War II. However, this case may serve to challenge some common assumptions about competition, risk, and profitability in the modern arms industries. Like their counterparts elsewhere around the world, Americans have always been concerned about alleged profiteering by military suppliers.[9] More recently,

6. Schaffer, *Wings of Judgment*; Sherry, *Rise of American Air Power;* Crane, *Bombs, Cities, and Civilians*; Biddle, *Rhetoric and Reality in Air Warfare*; Searle, "'It Made a Lot of Sense to Kill Skilled Workers'"; Ralph, "Improvised Destruction."

7. Hooks, *Forging the Military-Industrial Complex*; Sparrow, *From the Outside In*; Waddell, *War Against the New Deal*; Koistinen, *Arsenal of World War II.*

8. Holley, Jr. "A Detroit Dream of Mass-Produced Fighter Aircraft"; Gemery and Hogendorn, "Microeconomic Bases of Short-Run Learning Curves"; Zeitlin, "Flexibility and Mass Production at War"; Mishina, "Learning by New Experiences: Revisiting the Flying Fortress Learning Curve," in N. Lamoreaux, D. Raff and P. Temin, eds., Thompson, "How Much Did the Liberty Shipbuilders Learn?"; Ferguson, "One Thousand Planes a Day"; Heinrich, "Jack of All Trades."

9. Brandes, *Warhogs.*

critics of the MIC have identified a particularly modern pattern of excess profit-taking in the defense sector, which appears to have been prevalent since at least 1940. This view understands the military economy since (and during) World War II as being dominated by a small number of favored contractors, who have long enjoyed a variety of state subsidies—including cost-plus or otherwise noncompetitive contracts, follow-on orders, bailouts, and other advantages that allow them to take high profits with very little risk.[10]

This common understanding of risk and profitability in the defense sector, the story of PMC suggests, needs to be substantially qualified and enriched. First of all, the company's history demonstrates that the American economy during World War II allowed for risk-taking, failure, and substantial dollar losses, even in highly subsidized industries such as magnesium. Indeed, the story of PMC and "goop" begins with a firm's scramble to limit large dollar losses on a failed manufacturing venture. This failure was what led the company's officers to give up on magnesium ingot production and focus on incendiaries. Although PMC reduced its losses and turned its fortunes around by war's end, its wartime experience was nonetheless one in which risk-taking and contingency played major roles. Perhaps some critics of the MIC have exaggerated the ease of high profit-taking because they have failed to pay enough attention to times of war. While peacetime demand for military goods may be relatively stable, any adequate understanding of military industries needs to take account of war and its sometimes unpredictable effects. As War Production Board (WPB) chief Donald Nelson noted in June 1944, "war demand is a very fluid thing."[11] Its fluidity helps to explain the rapid rise and fall of a giant magnesium industry in the United States during the 1940s, as well as the roller-coaster of failures and triumphs that PMC experienced over the same period.

If PMC's record of troubles with magnesium helps us to better appreciate the complexity of the World War II economy, so too does its record of success in limiting the losses it took on a magnesium production venture that proved to be quite costly and inefficient. To a certain extent, of course, this success simply confirms traditional views of the MIC. Like other military contractors before and since,

10. For a concise statement of this view, see Higgs, "Private Profit, Public Risk." For a case study that seeks to challenge the standard view, see Gholz, "Curtiss-Wright Corporation and Cold War-Era Defense Procurement."

11. U.S. Senate, *Investigation of the National Defense Program: Hearings. . . Part 24*, 10627. Cited hereafter as "Truman Committee Magnesium Hearings."

PMC limited its risk by taking advantage of government loans, favorable tax laws, direct subsidies, and its deliberately cultivated relationships with government administrators and military procurement officials. However, for PMC, most of these benefits failed to do enough to limit losses, in part because some government officials drove relatively hard bargains. In response, PMC officials—who had been extraordinarily aggressive from the beginning in soliciting defense work—continued to search for more profitable outlets for their magnesium. Here they found considerable success, thanks in part to the fact that the wartime state was a multidimensional entity, whose organizational complexity limited its monopsony power. When PMC's relationship with one part of this multi departmental customer soured, the company's officials succeeded in finding more profitable relationships with another part. Here, then, is a case in which the opportunities for profit in the MIC seem to have been boosted by a firm's ability to engage in a sort of venue shopping.[12] Again, perhaps this is a phenomenon that occurs more frequently during major wars, when military demand becomes more volatile and the state itself often undergoes chaotic transformations. In the case of PMC during World War II, in any event, it turned out that dollar losses could be limited not simply because the state absorbed all risks, but because an entrepreneurial attitude toward the wartime state helped the firm to develop new relationships that would help to erase the costs of its past failures.

Permanente Metals Corp. and the U.S. Magnesium Expansion Program, 1940–1944

Before it became the supplier of "goop" for a new generation of incendiary bombs, PMC was an important player in one of the most extraordinary industrial expansion programs of World War II. Magnesium metal, a third lighter than aluminum, seemed an obvious candidate for more widespread use in a variety of twentieth-century industries, including aircraft. But until World War II, very little of it was made in the United States. Until 1941, the sole U.S. producer was the Dow Chemical Corp., which made fewer than five million pounds of the metal in 1938, and about twelve million pounds in 1940.

12. This term has been used frequently by scholars of bankruptcy law, to describe a party's efforts to locate the most generous court; it is also part of the conceptual toolkit of political scientists. See, for example, Karch, "Venue Shopping, Policy Feedback, and American Preschool Education."

Starting in 1941, however, the U.S. government coordinated a massive expansion of the industry, which involved a private PMC plant and several government-owned contractor-operated (GOCO) operations, which ended the Dow monopoly. National output in 1943 was about 368 million pounds—nearly one hundred times the 1938 production level. By early 1944, when mobilization officials realized that the program was far too large and cut it back sharply, U.S. production capacity had grown to nearly six-hundred million pounds a year, about a third of which was handled by Dow.[13] In the case of magnesium, like that of synthetic rubber, the war had transformed, in a matter of months, a tiny industry into a substantial one.

Although Dow had a money-losing monopoly in the manufacture of domestic magnesium during most of the interwar period, it started World War II with a substantial production capacity. In 1937, the company started to invest in a 50 per cent expansion of its plant at Midland, Michigan, which produced magnesium from local brines using a proprietary electrolytic process. In early 1940, after the outbreak of war in Europe but before the big U.S. industrial mobilization push that would begin that summer, Dow officials went ahead with the construction of a giant new plant at Freeport, Texas. The Freeport plant, which was designed to process thirty million gallons of seawater a day, started production in January 1941. During the calendar year 1941, Dow produced over thirty-two million pounds of magnesium—nearly triple its 1940 output. In 1942, when it produced just over sixty million pounds, Dow still accounted for 84 percent of domestic output. Throughout the war, it would remain the industry leader and low-cost producer. Dow's wartime profits on magnesium metal production would be steady but modest: while the magnesium business accounted for a quarter or more of the company's total wartime sales, it contributed only about 10 percent of Dow's net income, which averaged a little over $8 million a year in 1941-45.[14]

It was during the 1940–41 "defense period" of U.S. war mobilization, when Dow was expanding its magnesium operations, that Henry Kaiser and his lieutenants entered the business. The magnesium plant they built at Permanente, California was unique, in

13. "Magnesium by the Ton," *Fortune* 29 (March 1944): 157, 181; "[War Production Board] Curtails Magnesium Production," *New York Times* (March 18, 1944): 19; Dow, *Annual Report,* 1944; Roberts, *Light Metals,* 191, 321.

14. Truman Committee Magnesium Hearings, 10297–2, 10710-1; Dow, *Annual Report[s],* 1941–46; Roberts, *Light Metals,* 191.

more ways than one. First, PMC was the only company in the mid-twentieth century, other than Dow, that ran a private, for-profit magnesium plant. Second, PMC was the only American adopter of the "Hansgirg process," a production technology that used high-temperature furnaces to separate magnesium oxide garnered from common ores. Both of these factors would contribute to PMC's decision in late 1943 to abandon the production of primary metal in favor of "goop." Even before it became clear that the United States had overinvested in magnesium production capacity, PMC's early adoption of high-cost production technology encouraged it to take the path that led to the "goop" bomb.

During the winter of 1940–41, when the Kaiser men succeeded in becoming the first to break the Dow magnesium monopoly, they seemed well positioned to profit from an early entrance into a swelling war industry. One of the most important reasons for the Allies' scramble during these months to achieve a massive expansion of magnesium production capacity, it appears, was anxiety about having fallen behind Germany. In 1940, during the Battle of Britain, analysis of downed German planes found large quantities of magnesium in engine mounts, gun mounts, wing surfaces, and other parts. In addition, some of the bombs dropped by German planes in 1940 used magnesium casings, which were designed to cause high-temperature fires that would be difficult to extinguish.[15] As the next section will explain, the British and Americans quickly imitated this magnesium bomb technology, which would eventually absorb a large fraction of the industry's output. But in the United States, most of the magnesium expansion effort was intended initially to give the aircraft industry the materials it needed for critical parts. Studies of German aircraft in 1940 had suggested that new American planes might each require at least a thousand pounds of the light metal. If the United States was going to make fifty thousand planes a year, as President Roosevelt had suggested in May 1940, this might mean that aircraft parts alone would require at least 50 million pounds of magnesium a year, or close to five times Dow's existing capacity. [16]

While growing estimates of military requirements for aircraft and bombs were the most important cause of a new push in Washington

15. "Flame Bombs," *Newsweek* (July 12, 1943): 22.

16. "Magnesium by the Ton," *Fortune* 29 (March 1944): 157. Later in the war, Dow officials indicated that later that reports of the early "magnesium gap" were exaggerated. By 1941, they reported, American and German planes used about the same amount of magnesium: about 800 pounds in a medium bomber. Truman Committee Magnesium Hearings, 10357.

in early 1941 to build more magnesium plants, a secondary factor was a widely shared interest in ending Dow's monopoly. Especially in the early months of World War II, many New Dealers enthusiastically promoted the expansion of military–industrial capacity, putting them at odds with many business leaders, who resisted it. Henry Kaiser, as the historian Stephen Adams has shown by describing his efforts in the construction business and the steel industry, was an important player in this struggle. In men such as Kaiser, New Dealers found new ways to challenge what they saw as monopolistic industries, including magnesium, while supporting President Roosevelt's efforts in 1939–41 to turn the country away from neutrality and into an "arsenal of democracy."[17]

Just as they did with merchant shipbuilding and steel, Kaiser and his lieutenants moved early and aggressively to enter the field of magnesium production. Encouraged by New Dealers interested in breaking monopolies and increasing production, Kaiser moved in 1940 to position himself as the leading candidate for U.S. government assistance to break the Dow monopoly. In the summer and fall of 1940, Kaiser and Calhoun, his energetic point man in Washington, approached a variety of U.S. government officials to sound them out about the possibility of going into the magnesium business. Some were discouraging. Calhoun was particularly frustrated by Marion Folsom, the prominent Eastman Kodak executive who was then working as a mobilization planner at the National Defense Advisory Council. In September, Folsom told him that Dow could handle whatever expansion would be required.[18] Calhoun and Kaiser had better luck, however, with other Washington officials, including Interior Department undersecretary Alvin J. Wirtz and Leon Henderson, the influential New Deal economist and price-control czar, who both encouraged Kaiser to challenge Dow by building a magnesium plant in the West.[19] Many politicians in the Western states, naturally, were allied with the New Dealers in this cause. And by the early part of 1941, Kaiser's efforts were being championed by more top officials in Washington, including Secretary of Interior

17. Adams, *Mr. Kaiser*, 99–100; Heiner, *Henry J. Kaiser*, 114; Lauderbaugh, *American Steelmakers*; Bernstein, "Automobile Industry."

18. Calhoun memo on "Magnetic Magnesium," September 19, 1940, folder Chad Calhoun—Misc. 1940, Carton 5, HJK Papers.

19. Calhoun memos to HJK, September 19 and October 1, 1940, folder Misc. Correspondence 1940, Carton 316, HJK Papers; "Chronological Record," in "Magnesium—Confidential: Mr. Kaiser's Copy" (binder), July 1941, Carton 318, HJK Papers; "The Earth Movers, III," *Fortune* 28 (October 1943): 139–40; Adams, *Mr. Kaiser*, 99–100; Heiner, *Henry J. Kaiser*, 114.

Harold Ickes and Sidney Hillman, co-chairman of the Office of Production Management (OPM).[20]

As he positioned himself in Washington as the leading candidate to run a new magnesium plant, Kaiser also worked to gain control over the U.S. rights to the production process invented by Dr. Fritz Hansgirg. After discovering the method in his Vienna laboratory in 1928, Hansgirg had worked during the 1930s to build small magnesium plants in Austria, Britain, and Korea.[21] Although none of these met with much early success, the Hansgirg process was of great interest to Kaiser, who envisioned a variety of future uses for magnesium and liked the idea of being able to make it out of common ores abundant in the West. Kaiser had his first face-to-face meeting with Hansgirg in August 1940. In December, he paid $750,000 for the U.S. rights to the Hansgirg process.[22]

Kaiser succeeded in gaining government approval and financing for a magnesium plant during the first months of 1941, at the beginning of a period that saw a rather chaotic effort to expand the industry. By January 1941, only a few months after mobilization officials had promised that they would be able to meet future demand with little trouble, there was a growing panic about impending shortages of several critical materials, including rubber, aluminum, and magnesium. Some critics attributed this problem to monopoly and oligopoly in these industries, and to interwar licensing agreements between German and American corporations such as IG Farben, Standard Oil, and Alcoa.[23] (Like several of its counterparts in other industries, Dow was prosecuted by the Justice Department during the early months of the war for alleged antitrust violations; like its peers, it would end up pleading *nolo contendere* to criminal charges and signing a consent decree in early 1942.)[24] As the prospect of future shortages rose in early 1941, OPM officials started to worry that Dow's output would not be enough. These growing concerns helped Kaiser to arrange, in early February, for a loan from the Reconstruction Finance Corporation (RFC) of $9.25 million at 4 percent interest.[25]

20. Nash, *World War II and the West*, 124, 249.

21. "Magnesium by the Ton," 191.

22. "Chronological Record," in "Magnesium—Confidential: Mr. Kaiser's Copy" (binder), July 1941, Carton 318, HJK Papers; "The Earth Movers, III," 139–40.

23. "Folklore of Magnesium," *Time* (February 10, 1941): 64–66; Koistinen, *Arsenal of World War II*, 136–7, 150–2.

24. Truman Committee Magnesium Hearings, 10301–2; Wells, *Antitrust*, 43-89; Freyer, *Antitrust and Global Capitalism*, 8–59.

25. Emil Schram to HJK, February 15, 1941, folder Magnesium—Negotiations for Financing Plant, 1940–41, Carton 128, HJK Papers.

Kaiser would use this loan to build the first magnesium plant to challenge the Dow monopoly. He was soon celebrated in the press as a heroic entrepreneur who had managed to overcome one of many trust-created bottlenecks in the war program.[26]

While the Kaiser men had reason to celebrate the finalization of their RFC loan in February 1941, in the weeks that followed, the situation became much more complicated. Kaiser wanted permission, and more loans, to build a bigger operation. The initial RFC loan would allow him to build one production unit with an annual capacity of 8 million pounds of magnesium. He wanted to create two more such units, so that total capacity would be 24 million pounds—making Kaiser a significant rival to Dow. But these efforts found little support from RFC chief Jesse Jones, who was concerned about Kaiser's lack of experience in making the metal.[27] Other doubters included the Army Air Corps officers, based at Wright Field, Ohio, who had become the military establishment's coordinators of magnesium expansion. Like Jones, the Air Corps was dubious about the prospects for the Hansgirg process.[28] In May 1941, they were dismayed to hear that Kaiser had already ordered, without approval, equipment for three units; they wanted the technology to be shown successful in the first plant before approving more.[29]

Kaiser would get the expansion he wanted, but not under the circumstances he preferred. In early June 1941, OPM announced that the country should expand its annual magnesium production capacity to 400 million pounds, a figure that was eight times as large as what the Air Corps had projected just two months before.[30] Most of the expansion would be financed by public funds administered via the Defense Plant Corporation (DPC), which would serve to build large GOCO facilities. The DPC now started negotiations to finance two giant new government-owned plants: a Dow-operated facility at Velasco, Texas, and an operation outside Las Vegas, Nevada to be managed by Basic Magnesium, Inc., a joint effort of a small Cleveland company and a British firm. By the end of 1941, these two GOCO plants alone, in which the United States would invest close to $200 million, were being built with a combined approved annual capacity

26. "Magnesium—Lesson in Speed," *Time* (March 3, 1941): 67–8.

27. Jones, *Fifty Billion Dollars*, 332.

28. Roberts, *Light Metals*, 166.

29. HJK to Patterson, May 19, 1941, folder US Govt—War Dept—Scheeberger and Lewis, Carton 11, HJK Papers; Lt. Col. P. Schneeberger notes, May 22, 1941, in "Case History of Permanente Project."

30. Roberts, *Light Metals*, 156, 157, 169.

of close to 190 million pounds—about eight times the capacity that Kaiser was aiming for in early 1941.[31] The immense Basic Magnesium plant, which became the second biggest user of structural steel and electricity in the world to date, would alone produce 39 percent of national output in 1943.[32] Basic and the slightly smaller Dow-Velasco operation were the two largest plants in a network of what would become a dozen brand new government-owned magnesium metal production facilities, which would use four distinct production processes (table 1). For Kaiser, needless to say, this development was bad news. In May 1941, when the big government-financed expansion program was still more rumor than reality, Kaiser understood its implications. "We feel that the economics of our situation have been seriously jeopardized by the government's action," Kaiser complained to Wright Field, adding that he was now having second thoughts about trying to expand his own efforts.[33]

As part of the expansion program, Kaiser received his 24 million pounds a year of approved capacity, which was financed by increasing his RFC loan to a total of $22.75 million.[34] In addition, starting in October 1941, Kaiser was brought into the GOCO side of the magnesium program, as one of several companies that received fixed fees in return for managing plants.[35] This action was one piece of a broader push by mobilization authorities in October to finish signing the contracts for all the additional plant needed for the 400 million pound a year magnesium program.[36] Located at Manteca, California, the Kaiser-managed GOCO plant, built with $6 million from the DPC, was one of several new plants that used a ferrosilicon process to

31. *Minutes of the Supply Priorities and Allocations Board,* 46–7.

32. The Basic operation included a huge chlorine plant, because magnesite from ore was mixed with peat and other ingredients to make pellets that were chlorinated and then electrolyzed. Nash, *World War II and the West,* 123–8; Fagerberg, Jr., "A World War II Cost Accounting Assignment," 81–88; Nickel, "Dollars, Defense, and the Desert," 308.

33. HJK to Lt. Col. P. Schneeberger, May 19, 1941, folder Magnesium—Negotiations for Financing Plant, 1940–41, Carton 128, HJK Papers.

34. AAF Facilities Section, Washington, DC to Industrial Plant Section, Wright Field, June 17, 1941; Calhoun to Schneeberger, June 21, 1941, in "Case History of Permanente Project"; Edgar Lewis to HJK, June 11, 1941 and Army Air Corps Materiel Division to Permanente Corp., June 12, 1941, in folder US Govt—War Dept—Scheeberger and Lewis, Carton 11, HJK Papers; Roberts, *Light Metals,* 156, 157, 169.

35. Calhoun to HKJ, October 23, 1941, folder Magnesium—Negotiations for Financing Plant, 1940–41, Carton 128, HJK Papers.

36. *Minutes of the Supply Priorities and Allocations Board,* 15, 26.

Table 1 Estimated production costs at U.S. magnesium plants, winter 1943–44

Plant	Owner	Operator	Authorized Production Capacity	Process	Cost/lb
Velasco, TX	USA	Dow	72 million lbs	Dow	$0.13
Painesville, OH	USA	Diamond Magnesium Co.	36 million lbs	Dow	$0.17
Freeport, TX	Dow	Dow	36 million lbs	Dow	$0.18
Austin, TX	USA	International Minerals & Chemical	24 million lbs	Dow	$0.18
Marysville, MI	USA	Dow	72 million lbs	Dow	$0.20
Midland, MI	Dow	Dow	18 million lbs	Dow	$0.20
Luckey, OH	USA	Magnesium Reduction Co.	10 million lbs	Ferrosilicon	$0.20
Henderson, NV	USA	Basic Magnesium/Anaconda Copper	112 million lbs	Ore→electrolytic	$0.22
Canaan, CT	USA	New England Lime Co.	10 million lbs	Ferrosilicon	$0.26
Manteca, CA	USA	PMC	20 million lbs	Ferrosilicon	$0.29
Permanente, CA	PMC	PMC	28 million lbs	Hansgirg	$0.30
Spokane, WA	USA	Electro-Metallurgical	48 million lbs	Ferrosilicon	$0.44
Wingdale, NY	USA	Amco Magnesium Corp.	10 million lbs	Ferrosilicon	$0.44
Lk. Charles, LA	USA	Mathieson Alkali Works	54 million lbs.	Electrolytic	$0.71
Detroit, MI	USA	Ford	40 million lbs.	Ferrosilicon	$0.74

Sources: January 1944 cost data for government-owned plants appear in *Centralization of Heavy Industry in the United States: Hearing,* 22-23. Discussions of plants and their capacities appear in *Investigation of the National Defense Program, Additional Report. . . Magnesium*. Estimated costs for the Austin, TX GOCO plant and the privately owned plants, which were not listed in government documents, are taken from Chad Calhoun to Henry J. Kaiser, November 17, 1943, folder Administration, Carton 132, HJK Papers. For similar estimates of Dow and Kaiser costs, see "Magnesium by the Ton," *Fortune* 29 (March 1944): 182; Nash, *World War II and the West*, 126–27.

produce magnesium metal.[37] The Manteca plant started making metal on June 30, 1942; by October, it was turning out 10 tons of magnesium a day.[38]

Although Kaiser did become a GOCO plant operator, his privately owned for-profit magnesium operation remained more significant because it was larger, more widely publicized, and more important to the company's bottom line. In November 1941, the Todd-California Shipbuilding Corp., the company that had formerly controlled Kaiser's shipbuilding and magnesium operations, changed its name to the Permanente Metals Corp. Two months before, the first of Kaiser's three units had begun to cast magnesium ingot. In October and November, the new plant made a total of 20,000 pounds of metal. During the first eleven days of December, it turned out nearly 43,000 pounds more; output was projected to increase dramatically in early 1942.[39] Thus by the time of the Pearl Harbor attacks, PMC already had one working magnesium unit using the Hansgirg process, and two more under construction. Led by Eugene E. Trefethen, Jr.,[40] PMC's magnesium division occupied a unique position in the industry. A monopoly only a few months before, that industry was being transformed quickly by the construction of GOCO plants, which by early 1944 would represent 90 percent of U.S. magnesium capacity.[41] By the time of Pearl Harbor, PMC, as the only private magnesium producer other than the much better established Dow, still seemed to be in a position to take advantage of special opportunities. But it was also encountering serious difficulties and risks.

In May 1941, as he was seeking approval for additional units, Kaiser had boasted to mobilization authorities that the Hansgirg process was cheaper and more efficient than the well-established

37. Lindbergh to Hugh Fulton, May 11, 1943, folder Truman Committee 1942–43, Carton 318, HJK Papers. Credited to Dr. Lloyd M. Pidgeon of Canada's National Research Council, this process combined dolomite ore, a source of magnesium oxide, with ferrosilicon, a combination of iron and quartz. Heating briquettes of this mix at high temperatures released magnesium. Like the Hansgirg process, the ferrosilicon method failed during the war to produce magnesium at low costs. "Magnesium by the Ton," 194.

38. Trefethen to Arthur Bunker (WPB), July 8, 1942, folder Operations Progress Reports DPC; Trefethen to Samuel H. Husbands, DPC, October 9, 1942, folder Magnesium Operations Forecasts, DPC 1942, both in Carton 130, HJK Papers.

39. Harry P. Davis to Knudsen, December 12, 1941, folder W.S. Knudsen, OPM, Carton 128, HJK Papers; Schneeberger to AAF Facilities Section, Washington, D.C., 20 Dec. 1941, in "Case History of Permanente Project."

40. HJK to Trefethen, December 12, 1941, in folder HJK to E.E. Trefethen, Carton 8, HJK Papers.

41. "Magnesium by the Ton," 157.

electrolytic method used by Dow.[42] In July, when OPM director general William Knudsen visited the unfinished Permanente plant as part of national tour of sixty war plants, hopes for the Kaiser operation were high.[43] But less than a year later, as one journalist recalled, "Permanente was denounced as the worst flop of the war effort."[44] The project seemed to be cursed. In September 1941, as the first unit was being finished, three men died in an accidental explosion. Just after Pearl Harbor, Hansgirg himself was arrested by the FBI, which suspected him of being an enemy alien. (He was soon released and found refuge at Black Mountain College in North Carolina.). In March, Harry Davis, the plant's chief production manager, died in a car accident.[45] By then, it was becoming clear that PMC would not reach its planned production schedule for 1942.[46] This was especially disappointing to mobilization authorities, who had been hoping that PMC would alleviate the period of peak shortages in that year, before the large new GOCO plants came on line. Permanente's second and third production units did not begin making metal until June and October 1942, respectively. For the entire war, Permanente would make only 10,000 tons of magnesium ingot, which was less than its approved annual capacity of 12,000 tons.[47]

Although PMC certainly had some bad luck, its production problems came mostly from the difficulty of using the Hansgirg process. The first step, which involved baking readily available brucite and magnesite ores to yield magnesium oxide, was relatively simple. Converting the magnesium oxide into pure magnesium metal, however, was much trickier. Using the Hansgirg process to do this required mixing the magnesium oxide with carbon and heating the combination to a temperature of 3,800 degrees Farenheit, and then, using natural gas, shock-cooling it in a thousandth of a second down to 380 degrees. This generated magnesium in the highly volatile form of a fine powder, as well as carbon dioxide. Directed into retorts (distilling pipes), where it formed larger crystals, the magnesium could then be collected and cast into ingots or pigs.[48] However clever

42. HJK to S.R. Fuller, Jr., May 12, 1941, folder Magnesium--Negotiations for Financing Plant, 1940–41, Carton 128, HJK Papers.

43. *Minutes of the Office of Production Management,* 44.

44. "Magnesium by the Ton," 188, 191.

45. "The Earth Movers, III," 139–42.

46. "Hansgirg Disappointment," *Newsweek* (April 6, 1942).

47. Undated "Permanente Magnesium" typescript with chronology, folder Advertising—Permanente, Carton 132, HJK Papers; "The Earth Movers, III," 141; Heiner, *Henry J. Kaiser*, 111.

48. Undated "Permanente Magnesium" typescript with chronology, folder Advertising—Permanente, Carton 132, HJK Papers; "Revolution in Magnesium," *Time* (November 17, 1941): 89.

and efficient the Hansgirg process might have seemed in theory, employing it in practice meant trying to run a plant with an under tested technology, and one that was hot, dirty, and dangerous. In early months, PMC had trouble with parts that could not withstand the furnace temperatures, as well as at least two major explosions. The company became concerned about an "extensive dust hazard" in the Permanente plant, which not only meant risk of more explosions, but also potential problems of silicosis or other lung diseases among workers.[49]

PMC's production difficulties in 1941–42 not only meant disappointing output for the war program, but also significant dollar losses for the company. This set PMC apart from the many other companies that had trouble early on with their magnesium operations, including Basic Magnesium, the operator of the immense GOCO plant outside Las Vegas. (In the fall of 1942, continuing production problems at Basic led the DPC to bring in the Anaconda Copper Co. as the new manager of that plant.) During the first part of the war, the price of magnesium metal was capped by the Office of Price Administration (OPA) at 22.5 cents a pound. This cap suited Dow, whose costs were estimated at 18 cents or less; for GOCO plant operators, who worked for a negotiated fee, it was insignificant. But for PMC, which owned its own high-cost plant, the OPA price ceiling guaranteed large losses. As late as March 1943, the company estimated that production costs at the Permanente facility were still as high as 44 cents a pound. By the autumn of 1942, according to one estimate, the plant was losing $12,000 a day.[50] From the beginning of the war through July 1943, PMC's metals division had losses of nearly $4.3 million, or over $10.9 million counting depreciation. This contrasted sharply with the $27.5 million in pretax profits earned over the same period in its shipbuilding division. While the losses on magnesium did serve to lower Kaiser's effective tax rate on its ship profits to just under 50% (relatively low for World War II contractors), PMC officials were still troubled by their failures.[51]

49. George L. Dealey to Trefethen, March 16, 1943, folder Magnesium—Dust Hazards, Carton 132, HJK Papers; "Permanente Squeaks Through," *Time* (February 8, 1943): 76–8.

50. Data in Lindbergh to Fulton, May 11, 1943 and June 25, 1943, folder Truman Committee, 1942–43, Carton 318, HJK Papers; "The Earth Movers, III," 141.

51. "Permanente Metals Corp. Combined Profit and Loss Estimate to July 31, 1943," folder Carbothermic Magnesium Operating Funds, Carton 131, HJK Papers.

In late 1942, after a year of struggle, PMC managed to get some relief on prices. In October, Kaiser reported to the WPB that he was taking such "large losses" at the Permanente plant that he might soon be forced to shut it down. Although Knudsen called the plant a "lemon" and other mobilization authorities scolded PMC for its failures, the company succeeded in getting a subsidy.[52] The relief was provided via a wartime government corporation, the Metals Reserve Company (MRC), which started to buy PMC's magnesium at cost, up to a maximum of 50 cents a pound. Starting in May 1943, the maximum price paid by the MRC was lowered to 40 cents; later in the year, this was lowered to 30 cents.[53] This aid helped PMC's bottom line. From December 1942 to November 1943, a year during which the MRC bought 13.5 million pounds of PMC magnesium, the subsidy amounted to $2.75 million.[54] For at least a few weeks in the summer of 1943, when the MRC maximum was 40 cents and PMC direct production costs were down to 36 cents, the company was actually close to turning a profit on magnesium metal[55] (table 2).

But the relief did not last. In November 1943, when national magnesium output was finally meeting military requirements, U.S. officials moved to cancel PMC's subsidy. Jones, the war loan czar, complained to Kaiser that his company's prices remained well above those of most other producers. "Either your method of producing the metal is inferior to other processes," said Jones, "or your operation is bad."[56] This criticism was well-founded: PMC never brought its costs down much below $0.30 a pound, which left it among the middle ranks of all plants, and far worse than all those using the Dow process. Immediately after Jones's complaint to Kaiser, the government proceeded to end the MRC purchases. For PMC, this meant that it would have to sell magnesium at 20.5 cents, the current OPA maximum price, instead of 30 cents, the most recent MRC maximum. As he had in the past, Kaiser complained that being forced to sell at OPA prices might cause him to close the plant. But such protests had

52. Kaiser to Bunker, October 26, 1942, folder Magnesium Prices Washington; H.V. Lindbergh to Trefethen, November 23, 1942, folder Magnesium Prices Washington, both in Carton 131, HJK Papers.

53. Lindbergh to Fulton, June 25, 1943, folder Truman Committee 1942–43, Carton 318, HJK Papers.

54. Lindbergh to Trefethen, November 20, 1943, folder Administration, Carton 132, HJK Papers.

55. Data in Lindberg to Fulton, May 11, 1943 and June 25, 1943, folder Truman Committee, Carton 318, HJK Papers.

56. Jones to HJK, November 11, 1943 and Calhoun to HJK, November 17, 1943, both in folder Administration, Carton 132, HJK Papers.

Table 2 PMC's Permanente plant magnesium metal output, "field costs" (not counting overhead), and U.S. government price ceilings, 1943

Month	Magnesium ingot production (lbs)	Field costs/lb	MRC price/lb	OPA ceiling/lb
January 1943	519,541	$0.81	$0.50	$0.225
February 1943	944,907	$0.44	$0.50	$0.205
March 1943	1,048,826	$0.44	$0.50	$0.205
April 1943	1,162,945	$0.44	$0.50	$0.205
May 1943	1,332,451	$0.40	$0.40	$0.205
June 1943	1,644,000	$0.36	$0.40	$0.205
July 1943	1,434,000	n.a.	$0.40	$0.205
August 1943 (est.)	1,700,000	$0.39	$0.40	$0.205

Source: H.V. Lindbergh to Hugh Fulton, May 11, 1943 and June 25, 1943; Henry J. Kaiser to Arthur H. Bunker, August 7, 1943, all in folder Truman Committee, Carton 318, HJK Papers.

little effect in Washington because the government no longer needed PMC's output.

By the beginning of 1944, it was clear that the United States had significantly overinvested in magnesium production capacity. In March, the WPB, as it announced the first major cuts in the magnesium program, admitted that current production capacity exceeded demand by nearly 100 million pounds a year—an amount equal to about ten times the level of prewar U.S. output.[57] According to Congressional investigators, there was suddenly so much surplus magnesium that "Government agencies are experiencing difficulties in locating storage space for the metal."[58] The magnesium glut in early 1944 seemed at first glance to be yet another blow to PMC, which over the previous months had solved many of its production problems, reduced costs, and raised output to nearly 85 per cent of planned capacity. Contrasting this recent record with the company's troubles of two years before, one journalist now proclaimed, "Permanente has pulled itself out of a hell of a hole."[59] However, it now faced the challenge of an early demobilization of the national magnesium industry. This did not come as much of a surprise to PMC officials, who discussed indications of a national magnesium surplus as early as April 1943.[60]

57. WPB press release, March 16, 1944, copy in folder War Production Board 1944-45, Carton 153, HJK Papers; "[War Production Board] Curtails Magnesium Production," *New York Times* (March 18, 1944): 19.

58. *Investigation of the National Defense Program, Additional Report. . . Magnesium* (Washington, DC: GPO, 1944), 53. Cited hereafter as Truman Committee Magnesium Report.

59. "Magnesium by the Ton," 181, 188, 191.

60. Rawn to Lindbergh, April 2, 1943, folder Sales—Permanente 1943, Carton 134, HJK Papers.

Nearly a year later, in March 1944, the WPB, noting that national production was outpacing demand by nearly 10 million pounds a month, announced major cuts at five GOCO plants, including the one operated by PMC at Manteca. In April, the huge Basic Magnesium plant was ordered to go to 60 per cent of capacity. These were just the first in a series of orders in 1944, which by the end of that year had completely shut down nine of the GOCO plants, including Manteca and the two giants: Basic and the Dow-operated facility at Velasco, Texas.[61]

Despite the downsizing of the national magnesium program, PMC would enjoy a relatively successful year in 1944. Because Washington officials, prodded by Dow and Kaiser, [62] had decided on a policy of closing the GOCO plants first, PMC's privately owned operation escaped forced cuts or closures. Equally important, the company by this time had begun to concentrate on the production of incendiary bombs. Early in 1944, it effectively abandoned its efforts to make metal ingot or pigs and turned its attention to "goop." This new product took advantage of the peculiarities of the Hansgirg process. It could also bypass OPA price caps and be sold to the CWS at a profit. Rather suddenly, several of PMC's problems had been turned into possibilities.

The Incendiary Weapons Program, Magnesium, and PMC "Goop," 1941–45

The shift at PMC from metal to incendiary weapons material was representative of broader developments in the U.S. magnesium program during World War II. Although American mobilization officials were interested from the beginning in the uses of magnesium in bombs, they gave higher priority during the early months of the war to making metal alloys for aircraft parts. But as output increased, more magnesium could be allocated to weapons. This was certainly the experience of PMC. From the beginning, the company sought orders from the CWS, which oversaw the incendiary bomb program. But it was not until 1944 that PMC was able to focus on production

61. WPB press release, March 16, 1944, copy in folder War Production Board 1944–45, Carton 153, HJK Papers; "[War Production Board] Curtails Magnesium Production," *New York Times* (March 18, 1944): 19; "Government Cuts Magnesium Output," *New York Times* (July 30, 1944): S9; "U.S. Soon to Quit Magnesium Field," *New York Times* (November 25, 1944): 22; Nash, *World War II and the West*, 127.

62. Rawn to Lindbergh, April 2, 1943, folder Sales—Permanente 1943, Carton 134, HJK Papers.

for the CWS. By then, the company had developed "goop," which both it and the CWS regarded as their best opportunity to make a major contribution to the war effort. For PMC, it had the added benefit of promising to turn significant financial losses into profits.

In early 1941, as they were seeking approval and financing for their first magnesium plant, Kaiser and his lieutenants were already exploring the possibility of making bombs for the army.[63] They continued to push this effort over the next few months. In October 1941, after another visit to the War Department, Calhoun sent his fellow PMC officers an enthusiastic report. "There is an immediate possibility for us to get into the incendiary bomb business," Calhoun wrote. By this time, PMC had just started to make magnesium; authority over incendiary weapons had shifted only days before from the Army's Ordnance Department to the much smaller CWS. The CWS's ambitious new incendiary bomb program called for the manufacture of six million incendiary bombs a month. This would require 4,000 tons of magnesium per month, far more than PMC's planned maximum output.[64] Calhoun now asked the OPM for permission to have the Permanente plant direct half its future production to incendiary bomb program.[65] The main weapon in this proposed program was the M50 bomb, a four-pound metallic incendiary weapon (delivered in clusters) that used a magnesium casing and a filling of thermite (a mixture of aluminum powder and iron oxide). Based on the British magnesium bomb known as the Mark III, the M50 technology had been introduced to the American public in a May 1941 photoessay in *Life* magazine.[66] For Calhoun and his fellow PMC officers, the M50 program promised to be a giant consumer of their plant's magnesium, which would go into the flammable bomb casings.

The early efforts of PMC to become leading firebomb suppliers foundered, along with the CWS's first bomb program, when mobilization authorities decided to direct most American-made magnesium to the aircraft program. This hardly represented a lack of interest in magnesium weapons. In the short run, the United States

63. "Chronological Record," in "Magnesium—Confidential: Mr. Kaiser's Copy" (binder), July 1941, Carton 318, HJK Papers; Calhoun to HJK, March 6, 1941, folder Magnesium-Incendiaries 1941, Carton 128, HJK Papers.

64. Calhoun to Harry P. Davis and Trefethen, October 4, 1941, folder Magnesium-Incendiaries 1941, Carton 128, HJK Papers.

65. Calhoun to HJK, October 24, 1941, folder Magnesium—Negotiations for Financing Plant, 1940–41, Carton 128, HJK Papers.

66. "Incendiary Bombs," *Life* (May 19, 1941): 55–62.

would continue to send magnesium to Britain for its bomb program; in the longer run, mobilizers expected to use huge quantities of magnesium in American-made bombs. On December 16, 1941, when U.S. industrial mobilization authorities decided to increase planned magnesium capacity from 400 million to 550 pounds a year, the projected demand for incendiaries clearly informed their decision.[67] For the moment, however, most magnesium was used (in combination with aluminum) in alloys for a variety of aircraft parts, including wheels, brake assemblies, engine casings, gasoline tanks, and doors. In 1941 and 1942, nearly all of U.S. magnesium production went to alloys and aircraft parts; only about 5 per cent of output went into bombs.[68] Because magnesium was so scarce, the CWS developed a substitute for the M50 that used a casing made of steel instead of magnesium. Known as the M54, this substitute metallic incendiary was used in the celebrated April 1942 "Doolittle raid" on Tokyo, a small firebombing effort by B-25 bombers that prefigured the devastating B-29 raids that would occur three years later.[69]

Although its hopes to become a major bomb supplier were delayed by the nation's early magnesium allocation policies, PMC found a welcome ally in the CWS, for which the firebomb program was becoming its central concern. Despite the promise of jellied gasoline (napalm) weapons, which were already under development, CWS officers worked hard in 1941 and 1942 to acquire more magnesium for its M50 program. In the short run, they were disappointed. When the CWS asked for approval to proceed with its efforts to manufacture hundred million of the M50 weapons, military planners balked. Pointing out that few American bombers would actually be operating in theater in 1942, U.S. Army Air Forces (USAAF) officials concluded in February 1942 that they would need only eight million incendiary bombs in 1942 and fifty-one million in 1943. Protesting this finding, the CWS complained that the M50/54 program, which already involved over three-hundred prime and subcontractors, "will be completely ruined." Meanwhile, after the office of Assistant Secretary of War Robert Patterson questioned the need for so much magnesium, CWS fought for the survival of the huge expansion program. Here

67. *Minutes of the Office of Production Management*, 80; *Minutes of the Supply Priorities and Allocations Board*, 46–47.

68. Lt. Col. P.X. English to Chief of Air Corps, April 19, 1941, folder 471, box 161, e.2A, RG 175; Roberts, *Light Metals*, 151, 285, appendix; "Revolution in Magnesium," *Time* (November 17, 1941): 91; "Dow Goes Down to the Sea," *Fortune* 26 (December 1942): 192.

69. "Goop and Roe," *New Yorker* (May 19, 1945): 20–1; Chemical Corps Association, *Chemical Warfare Service in World War II,* 65–7.

they were remarkably successful, although in the short run they had to settle for Patterson's decision to cut the M50/54 program down to twenty million bombs.[70] Over time, however, as magnesium output rose and the Allied air forces increased their demands for incendiaries, the CWS had more success. After the first part of 1943, the bomb program was no longer constrained by concerns about a scarcity of the metal.[71] By the end of the war, it had procured 222 million of the metallic incendiary bombs, 200 million of which were the M50 model that used the magnesium casing.[72]

By the middle of 1942, PMC had succeeded in gaining a foothold in the M50 program, which allowed it to develop a stronger relationship with the CWS. Although it is difficult to discern from extant records how Permanente's early magnesium output was distributed, we do know that its first ingot was sent to Alcoa, Tennessee, where it was incorporated into aluminum alloys for use in aircraft parts.[73] In June 1942, however, PMC received a CWS order for 70,000 pounds of magnesium alloy (containing about 5 per cent aluminum), which was to be delivered to four California metal fabricators who would fashion it into M50 bomb casings. This order not only gave PMC the role in the firebomb program that the company always desired, but also helped them to limit their mounting losses. Because the alloy was not subject to an OPA ceiling, PMC could sell it at 28 cents a pound—far above the current cap of 22.5 cents on magnesium metal.[74] Over the coming months, PMC continued to pursue work on bomb casings. As late as March 1944, it was hoping to be able to supply alloy for the casings of large 500-pound bombs. By that time, however, the Allies' territorial gains and the emergence of the B-29 made the Army less interested in lightweight casings.[75]

70. Lt. Col. P.X. English to Edgar Lewis, January 17, 1942, folder 471.6, box 161; Col. J. E. Zanetti memo to Chief, CWS, February 24, 1942, folder 400.17, box 151; Col. John Y. York, Jr. to Chief of Staff, February 25, 1942; Lt. Col. P.X. English to A.H. Browning, March 26, 1942, folder 471.6, box 161; "Conference, Manufacturing and Procurement Program of the Chemical Warfare Service," May 27, 1942, folder 337, box 143, all in e.4A, RG 175.

71. Gen. R.C. Ditto to Julius H. Amberg, June 19, 1944, folder 334.8, box 142, e.4A, RG 175.

72. *Chemical Warfare Service in World War II*, 83.

73. Calhoun to HJK, December 11, 1941, folder Magnesium—Allocations and Prices 1941, Carton 128, HJK Papers.

74. Trefethen to Calhoun, June 8, 1942 and George C. Davis, Jr. to Trefethen, October 22, 1942, folder Magnesium—Sales; Lindbergh to Trefethen, June 13, 1942, folder Magnesium-Sales-Chemical Warfare Procurement, Bomb Alloy, all in Carton 131, HJK Papers.

75. W.L. Rawn to Trefethen, March 29, 1944, folder Bombs—Magnesium Alloy Casings Research 1944, Carton 135, HJK Papers.

Equally important, incendiary bomb technology was changing. Increasingly, thermite-filled metallic magnesium bombs were being displaced by weapons designed to spew sticky flammable fillings.

Well before PMC developed "goop," the U.S. military had begun to acquire stockpiles of bombs filled with jellied gasoline, known as napalm. Some of the most important development work on this substance, sponsored by the NDRC, was done by Fieser, the Harvard chemist, as well as the Standard Oil Development Co.[76] In early 1942, when it was first tested, part of the appeal of the napalm bomb was that it, unlike the M50, did not use precious magnesium. But it was also impressive for its ability to produce hard-to-extinguish fires. In May 1942, USAAF officials decided to phase out the M54 bomb and make more napalm weapons.[77] These were being used in Europe by early 1943, when allied air commands were just beginning to shift away from their previous strong preference for high-explosive bombs.[78] At first, napalm was used to fill M47 bombs, which had been designed originally to carry chemical weapons. Later, the preferred delivery system was the M69, a six-pound bomb that was dropped in clusters of about 500 pounds. In elaborate tests conducted in the summer of 1943, the M69 succeeded in burning reproductions of German and Japanese dwellings. By the end of the war, the CWS had procured over thirty million of these small napalm bombs.[79]

In mid-1943, just as the napalm bomb program was beginning to flourish, PMC began to work on the rival technology that would soon be known as "goop." This work was evidently encouraged by the CWS. Although some of its officers favored napalm, others were interested in exploring different technologies, or at least hedging their bets. As usual, PMC was highly attentive to the prospect of new military work. By July 1943, Calhoun was listening carefully at meetings at the Edgewood Arsenal, the Maryland facility that served as the CWS's headquarters.[80] In early August, Kaiser informed the

76. "Chemical Warfare Service Research and Development Program Report for April 1942," folder 400.12, box 149, e.4A, RG 175; Russell, *War and Nature*, 104–5.

77. Capt. A. Leggin memo to Army-Navy Munitions Board Priorities Committee, May 14, 1942, folder 334.8, box 137, e.4A, RG 175.

78. "Flame Bombs," *Newsweek* (July 12, 1943): 22-23; Russell, *War and Nature*, 108; Biddle, *Rhetoric and Reality in Air Warfare,* 229. In 1942, the British were more interested than the Americans in using incendiaries. Mountcastle, *Flame On!*, 69.

79. "Report of NDRC Observers on Incendiary Bomb Tests at Jefferson Proving Grounds, July 9–22, 1942," folder 334.8, box 137, "Chemical Warfare Technical Trends No. 6," September 1, 1943, folder 461, box 153, both in e.4A, RG 175; Goop and Roe," *New Yorker* (May 19, 1945): 21; Standard Oil Co. of N.J., *M-69*; Chemical Corps Association, *Chemical Warfare Service in World War II*, 69

80. Calhoun to Trefethen, July 12, 1943, folder Bombs—Misc., Carton 131, HJK Papers.

WPB that his company was engaged in new confidential research work for the CWS, using materials unique to the Hansgirg process.[81] By September 1943, Trefethen, the PMC magnesium division chief, was proposing to have 90 per cent of the company's magnesium efforts go into the incendiary bomb program. According to Trefethen, this shift not only "would solve our immediate financial problems," but also "will be a tremendous contribution to the war effort." Kaiser agreed. "This is our real opportunity," he announced a few days later, "to be of service to the war effort."[82]

The material on which PMC now pinned its hopes made use of the fine magnesium dust that resulted from the Hansgirg process. A dangerous form of the metal, inconvenient for making ingot, the dust was more promising as a firebomb fuel. As the Truman Committee noted in a March 1944 report, the Permanente plant's output in the coming months "will be very valuable," because the powdery form of the metal, unlike the larger chunks created by other processes, could be "used directly in incendiary bombs and pyrotechnics."[83] Although the details of the genesis of "goop" remain obscure, it is reasonable to conclude that PMC's experience with the hazards of the material helped to inspire its engineers to think of it as a promising incendiary. In October 1943, PMC had created a formula for what the CWS would call "PT Mix." By weight, this early formula consisted of 39 percent "microscopic magnesium dust," 10 percent asphalt, 5 percent distillate, 27 percent gasoline, 10 percent magnesium crystals, 5 percent sodium nitrate, 3 percent isobutyl methacrylate gel, and 1 percent ammonium perchlorate. It was the first three of these ingredients—the dust, asphalt, and distillate—that comprised "goop"; the rest of the mix was essentially napalm plus even more magnesium. By early 1944, the formula remained similar, albeit with a slightly higher concentration of gasoline.[84] According to PMC, this material was superior to napalm. It displayed "better burning characteristics than anything developed to date by anyone," the company boasted in October 1943.[85]

81. HJK to Arthur H. Bunker, August 7, 1943, folder Truman Committee 1942–43, Carton 318, HJK Papers.

82. Trefethen to Calhoun, September 2, 1943; HJK to Calhoun et. al., September 25, 1943, folder Bombs—Misc., Carton 131, HJK Papers.

83. Truman Committee Magnesium Report, 16–9.

84. Unsigned description of "Permanente Incendiary Material," October 25, 1943, folder Bombs 14,000,000 lb. Order, Carton 131; Lindbergh to file, April 20, 1944, folder Bombs—Bomb Loading, Carton 134, HJK Papers.

85. Lindbergh to Trefethen, October 4, 1943, folder Bombs—Misc., Carton 131, HJK Papers.

After preliminary tests of "goop" in actual bombs in September 1943 proved disappointing, the USAAF demanded that the development of the bomb be overseen by the CWS at its Edgewood Arsenal, where PMC could still participate in the loading and testing of bombs. [86] In November, CWS negotiated a contract with PMC that called for the delivery of 3 million pounds of "goop," at the price of 36 cents a pound.[87] PMC, which by the time of the signing of the formal contract had already decided to focus on "goop," started deliveries immediately. Well before the end of 1943, the CWS arsenals at Edgewood and Huntsville, Alabama were producing PT Mix by using commercial dough mixers to combine the PMC "goop" with other ingredients. At the Edgewood Arsenal, roughly 170 pounds of the mixture was then loaded into big 500-pound bomb casings.[88]

For PMC officials, the prospect of profits, as well as patriotism, guided their decision to abandon magnesium metal production in favor of "goop." By the end of 1943, when it was still producing 1.5 million pounds of ingot a month, the company had invested roughly $28 million in magnesium plant and had racked up several million dollars in losses.[89] Although PMC was still making plenty of money in its shipbuilding division, there was no denying, as one journalist put it, that a significant fraction of these profits had been "disappearing into a pit of magnesium deficits."[90] Now, by supplying CWS, the company had its best chance to turn red ink into black. In the early weeks of the "goop" effort, hopes ran especially high. According to one early PMC projection, the company hoped to be able to sell 6 million pounds of "goop" per month at a price of 47.5 cents a pound. At that rate of production this price, which would provide a 49 percent margin on sales, would allow the company to rake in $1.4 million in profits per month.[91] Although the price in its first "goop" contract turned out to be only 36 cents, this was far more favorable than selling metal at the OPA price ceiling, which PMC was now

86. HJK to Calhoun et. al., September 25, 1943, folder Bombs—Misc., Carton 131, HJK Papers.

87. Undated "Goop Chronology" [c. April 1945], folder Magnesium—Bombs—2,000,000 lb order 1945, Carton 135, HJK Papers.

88. R.E. Knight to Trefethen (VP PMC), November 6, 1943 and Trefethen to Sterling J. Foster (RFC), December 6, 1943, both in folder Magnesium Bombs/ Bomb Loading, Carton 131, HJK Papers.

89. Trefethen to Lyon (Chemical Warfare Service), December 2 1943, folder Bombs—14,000,000 lb order, Carton 131, HJK Papers.

90. "Magnesium by the Ton," 188, 191.

91. "Summary of 1 lb of Mix," undated [1943], unsigned notes, folder Bombs—Misc., Carton 131, HJK Papers.

being compelled to meet again, thanks to the recent removal of RMC subsidies. (After a brief scare, caused by a letter from OPA officials indicating that they would impose price controls on "goop," the company, with the help of the CWS, won an exemption. OPA officials, who had obviously been pressured by CWS and PMC, explained that the decision had been reversed, "to the end that nothing may be done which might vitally interfere with the production of this product so vitally needed in our war effort."[92]) At the beginning of 1944, when PMC willingly turned its entire magnesium operation over to production for the CWS, the company's metals division was finally able to look forward to a profitable year.

PMC did make some money on "goop" in 1944, but less than it expected. Like many other contractors, PMC found that the path to high profits was blocked by irregular demand. In January and February, the company's contract for 3 million pounds of "goop" was augmented by two supplemental orders, worth a total of $9.7 million, which together called for the delivery of 39.1 million more pounds of "goop." In the summer of 1944, as deliveries on these contracts neared completion, it appeared that PMC would enjoy steady business through the end of the war. All summer, the CWS and USAAF worked on plans to increase the production of the "goop"-filled 10-pound M74 bomb, while ending the M50 program and scaling back the manufacture of the napalm-filled M69. Their discussions at this time suggested strongly that "goop" had been selected as the preferred incendiary technology; the M74, which according to the CWS had been "designed . . . for Japanese houses," seemed to be the chosen weapon of terror against Japanese civilians. At the end of July, PMC received a new order, for 7.4 million more pounds. Just four months later, however, PMC, having completed all deliveries, had its contract terminated; it did not receive a new order until February 1945.[93] This abrupt change was clearly not the work of the CWS, which remained enthusiastic about "goop"; instead, it had everything to do with the course of the war. In Europe, the conflict seemed to be winding down

92. Maurice A. Harband to Trefethen, February 3, 1944, folder Bombs—Goop—Expansion, Carton 131, HJK Papers.

93. Unsigned 10 June 1944 memo on "Conference on M74 Bomb" (Edgewood Arsenal, June 6, 1944), folder 471.6, box 14, e.2A; Memo on CWS General Policy Board Conference, Niagara Falls, NY, July, 19–21, 1945, folder 337, box 143, e.4A; Gen. William N. Porter to Commanding General, Army Service Forces, 21 Aug. 1944, folder 471.6, box 14, e.2A; CWS General Policy Board conference agenda and notes, September 1, 1944, folder 461, box 153, e.4A, all in RG 175; Undated "Goop Chronology" [c. April 1945], folder Magnesium—Bombs—2,000,000 lb order 1945, Carton 135, HJK Papers.

quickly, while in Japan, stockpiles of older incendiaries were still unused. By August 1944, the army already had 30 million pounds of "goop" on hand, as well as plenty of napalm.[94] Like many other war contractors, PMC found that military demand from month to month could be surprisingly uneven.

PMC's "goop" business also proved less profitable than expected, despite the company's success in shopping for a venue that allowed it to avoid strict OPA price controls. This was because the CWS, after engaging the company's services, insisted that prices be regularly renegotiated downward. This too was a common experience among World War II contractors. By 1944, much of the price resetting was being negotiated by contracting officers in the military procurement bureaus, who had become savvy about contractors' costs and how they changed over time.[95] For PMC, the price adjustments demanded by CWS cut sharply into its margins. Starting the year off in January with a price of 36 cents a pound for "goop," the company saw its contract price drop in February to 20 cents. In May, the CWS demanded a price reduction to 15 cents, to apply to the last 11 million pounds of "goop" to be delivered under the February contract. This reduction alone cost the company $570,000 in prospective profits.[96] According to what the PMC told CWS early the following year, the 15 cents price allowed the company only a little over a penny a pound in profit, and that only if the Permanente plant was producing "goop" at a high volume of 6 million pounds a month.[97] (table 3).

Together, price readjustment and irregular demand took much of the shine off of the "goop" business. Still, for PMC, it was at least a slight improvement over the heavy losses it had taken in 1941–43 on magnesium metal production. In early 1944, when the company was still delivering "goop" at prices of 36 cents and 30 cents a pound, the profit margin on sales was running at about 15 percent.[98] All in all, from November 1943 to September 1944, the magnesium division

94. William Rawn Jr. to Lindbergh et al., August 22, 1944, folder Bombs—Chemical Warfare Service, Carton 134, HJK Papers.

95. Smith, *Army and Economic Mobilization*, 343–50; Connery, *Navy and the Industrial Mobilization,* 243–65; Miller, *Pricing of Military Procurements*, 188–201; Wilson, "'Taking a Nickel Out of the Cash Register'."

96. Undated "Goop Chronology" [c. April 1945], folder Magnesium—Bombs—2,000,000 lb order 1945; Lindbergh to Donald Browne, June 2, 1944, folder Magnesium Bombs Cost Estimates 1944, Carton 135, HJK Papers.

97. H.V. Lindbergh to Trefethen, February 1, 1945 and February 5, 1945, folder Bombs—10,500,000 lb order, Carton 135, HJK Papers.

98. Lindbergh to Col. J.W. Lyon, July 10, 1944; Jack Olney to Lindbergh, July 24, 1944; both in folder Bombs—Cost Estimated, Carton 134, HJK Papers.

Table 3 PMC contracts and supplemental orders for "goop," 1943–45

Contract/order	Date	Quantity (million lbs)	Price	Total of order
Contract 1	November 23, 1943	3.00	$0.36/lb	$1,080,000
Supplemental 1	January 12, 1944	8.00	$0.36/lb	$2,880,000
Supplemental 2a	February, 1 1944	6.28	$0.30/lb	$1,884,394
Supplemental 2b	February 1, 1944	24.77	$0.20/lb	$4,953,737
Price reduction	May 31, 1944		Retroactive reduction; refund to United States)	($570,000)
Supplemental 3	July 31, 1944	7.40	$0.15/lb	$1,110,000
Contract 2	February 13, 1945	10.00	$0.15/lb	$1,500,000
Supplemental 1	February 28, 1945	0.25	$0.15/lb	$37,500
Supplemental 2	April 5, 1945	2.00	$0.20/lb.	$400,000
Contract 3	? June 1945	55	$0.15/lb (presumed)	
(Approx. 26 million lbs delivered before cancellation)				$3,900,000
Totals		86		$17.18 million

Sources: Undated "Goop Chronology" memo, folder Magnesium—Bombs—2,000,000 lb. order 1945, Carton 135; Lindbergh to Army Service Forces, 25 April 1945; Lindbergh to W.P. Lind, 12 June 1945, folder 55,000,000 lb order, Carton 135; Calhoun and Paul Cadman memo, "Material for Letter to Jesse Jones, Norman Baxter, et. al.," in folder Steel—Misc.—1944-1946, carton 137, HJK Papers.

recorded a $1.1 million loss, but it could point to a net book profit of over $750,000 (about 6 percent of its $12.2 million in sales) if plant costs were amortized over a reasonable 10-year period, instead of the abbreviated five-year term allowed under World War II tax laws to certified war plants. However, between October 1944 and January 1945, when the lack of a contract left the Permanente plant mostly idle, PMC suffered an additional loss, using the five-year depreciation rate, of over $3.5 million.[99] Although the plant would have another six months of high output in 1945, when the USAAF started to use huge quantities of incendiaries in the Pacific, profit margins would remain modest. When the company finally got a new contract in February 1945, for 10 million pounds of "goop," the contract price remained at 15 cents.[100]

Although its margins in 1945 may have been relatively small, PMC did at least see a revival of its "goop" business. The company ended up delivering roughly 38 million more pounds of "goop" in 1945, nearly as much as it had done the previous year.[101] The reason for this revival was the USAAF's commencement of large-scale firebombing in Japan, which was pushed by top generals in Washington and overseen by Gen. Curtis LeMay, chief of the XXI Bomber Command.[102] In February 1945, only days after LeMay took command in the Pacific, PMC received its new "goop" contract and started producing again, at the rate of 5 million pounds a month. A new order in late May allowed the company to maintain this level of production through the end of the war.[103] This was part of a broader revival of the magnesium program in May and June 1945, when mobilization authorities ordered a 50 percent increase in incendiary bomb production, raising the annual output target to 514,000 tons.

99. "Permanente 'Goop' Figures, 1944 Experience" and "Permanente Financial Experiences since First Goop Deliveries," [January 1945], Magnesium—Bombs—2,000,000 lb order 1945; Undated "Summary" [c. April 1945], folder Magnesium—Bombs—2,000,000 lb order 1945, both in Carton 135, HJK Papers.

100. Undated "Goop Chronology" [c. April 1945], folder Magnesium—Bombs—2,000,000 lb order 1945, Carton 135, HJK Papers.

101. Permanente's total wartime output included 20 million lbs of magnesium and 86 million lbs. of "goop." Calhoun and Paul Cadman memo, "Material for Letter to Jesse Jones, Norman Baxter, et. al." in folder Steel—Misc.—1944-1946, Carton 137, HJK Papers.

102. Sherry, *Rise of American Air Power*, 266.

103. Undated "Summary" [c. April 1945], folder Magnesium—Bombs—2,000,000 lb order 1945; H.V. Lindbergh to Chemical Warfare Procurement District, New York, April 25, 1945, folder Bombs—55,000,000 lb Order; H.V. Lindbergh to W.P. Lind, June 12, 1945, folder Bombs—55,000,000 lb Order, all in Carton 135, HJK Papers.

This required the temporary reopening of Dow-Velasco, and a doubling of output at several other plants.[104]

By June 1945, a WPB publication was touting the PMC product as "the much talked-of goop bomb—the latest thing in incendiaries." Now, according to the WPB, the military actually favored goop-filled M74 bombs, but continued to order the napalm M-69s as a supplement to satisfy the growing demand.[105] In practice, the commanders of American bombers were content to use a combination of napalm and "goop," and they demanded more of both.[106] By March 1945, PMC "goop" bombs—both the 10-pound M74, dropped in clusters, and the giant 500-pound M76—were apparently being dropped by American bombers over Japan and Germany.[107] As Calhoun's excited telegram to his fellow PMC officers suggests, the company may not have become aware that its product was being used until May. By that time, Americans were well acquainted with the M69 napalm bomb, which had been used in the devastating March 1945 raid over Tokyo. Widely used by the USAAF and hyped by Standard Oil of New Jersey, the M69 became the firebomb best known to the public.[108] Many CWS officers, annoyed by Standard Oil's publicity effort, sided with PMC in the continuing rivalry between the two companies. Through the last weeks of the war, PMC and Standard Oil continued their jockeying, with each company touting the superiority of its product and complaining to army officials about the overuse of the others.[109]

In the end, the dispute about the relative virtues of napalm and "goop" bombs proved difficult to settle, because both weapons, which were dropped in enormous quantities and often in combination,

104. U.S. War Production Board, *War Progress* [bulletin], No. 249 (June 23, 1945), 9-11, copy in folder War Progress Reports, box 208, entry 118 (War Production Board files of Sec. Forrestal), RG 80.

105. Ibid.

106. Gen. Brehon Somervell to Commanding General, AAF, April 24, 1945; Gen. R.C. Ditto memo, May 2, 1945, folder 381.3, box 146, e.4A; Lt. Col. F.L. Anderson memo on "Expansion of Napalm Facilities," June 18, 1945, folder 600.1, box 14, e.2A, all in RG 175.

107. Goop-filled M76 bombs were apparently used in mid-March raids on Kobe and Nagoya. See Werrell, *Blankets of Fire,* 165; U.S. Strategic Bombing Survey, *Effects of Incendiary Bomb Attacks on Japan*, 231. On March bombings in Europe, see "Fire-Bomb Havoc Focus of Attack," *New York Times* (March 23, 1945): 10.

108. "Incendiary Jelly," *Time* (April 2, 1945): 73; Standard Oil Co. of N.J., *M-69.*

109. Calhoun to HJK and EET, May 15, 1945, folder Magnesium—Goop, carton 136, HJK Papers; memo on CWS General Policy Board Conference, Niagara Falls, NY, July 19–21, 1945, folder 337, box 143, e.4A (Security-Classified Correspondence, Subject Series, 1942–45), RG 175.

proved to be effective in practice at burning Japanese cities. There is little doubt that "goop" succeeded in causing overwhelming conflagrations of Japanese urban areas. In a short midnight raid on the small city of Aomori on 28–29 July, a force of 61 B-29s used 79,116 M74 bombs (547 tons worth) and no other weapons. Once on the ground, each of the 19-inch bombs proceeded to emit its "gobs of lava," [110] which, as designed, clung to ceilings and other surfaces and burned at high temperatures, overwhelming the efforts of firefighters. The exclusively "goop"-based bombing of Aomori succeeded in destroying 88 percent of the city, while killing at least 728 people and leaving over seventeen thousand families homeless. Judged "excellent" by the U.S. Strategic Bombing Survey, this result nonetheless did little to indicate the relative effectiveness of "goop" and napalm. Indeed, the Strategic Bombing Survey itself explained that although it had hoped to use cases such as that of Aomori to make such a comparative assessment, "on arriving at the targets [all over Japan] it was found that the areas were so completely devastated," that this was impossible.[111] The PMC "goop" bombs apparently worked well—but perhaps no better than napalm and other incendiaries.

Conclusion

On August 29, 1945, two weeks after the surrender of Japan, the Permanente plant was presented with the Army-Navy "E" Award, an honor given to war factories for outstanding achievements in military–industrial production. At the ceremony, Capt. G.W. Dawson of the CWS praised PMC and its workers for their contributions to the incendiary bomb program. This included their production of magnesium alloy for M50 bomb casings, but Dawson was especially enthusiastic about their work on the "new goop M74 bomb that did so much to help bring the Japanese to their knees."[112]

A disinterested observer at the "E" Award ceremony might have easily questioned, upon hearing Dawson's words, how much "goop" had actually contributed to the end of the Pacific War, which would

110. "Science in Review: The Bomb that Fires Japanese Cities Spouts A Spreading, Quenchless Synthetic Lava," *New York Times* (June 3, 1945): E9.

111. U.S. Strategic Bombing Survey, *Effects of Incendiary Bomb Attacks on Japan*, 1, 121–46.

112. Calhoun and Paul Cadman memo, "Material for Letter to Jesse Jones, Norman Baxter, et. al.," in folder Steel—Misc.—1944–46, Carton 137, HJK Papers.

forever be associated with Hiroshima and Nagasaki. However, for the leaders of PMC, this moment was undeniably sweet. Three years earlier, top U.S. mobilization officials had dismissed the Permanente plant as a "lemon." Its output of magnesium was disappointing; its financial performance even worse. In recent months, the situation had improved dramatically. Thousands of bombs filled with "goop" had been used in the final months of World War II. Equally important, the company's magnesium division had stopped bleeding cash. At the end of November 1945, more than five years ahead of schedule, Henry Kaiser would make the final payment on the RFC loan he had used to build the Permanente plant. Although nearly all of the $28.5 million in principal and interest payments were drawn from shipbuilding profits, the company's turn to "goop" at the end of 1943 had limited losses, making the early retirement of the debt easier.[113] For the entire war, PMC's operating losses on magnesium and goop amounted to $2 million; counting the write-off of the full value of the plant that was allowed under war plant amortization laws, the book losses came to $28.7 million. Because PMC's pretax profits on ships came to $56.8 million, the losses on magnesium provided a significant tax deduction. For the whole war, PMC's net after-tax earnings on all its business amounted to about $8.7 million.[114]

Now that they owned a substantial magnesium plant, free of debt, Kaiser and his lieutenants held out at least some hope that they might enjoy even more success. Kaiser himself dreamed of a postwar economy that might use large quantities of magnesium in trucks, trailers, aircraft, and other products. In the end, the Kaiser men did end up having considerable success with light metals—but in the field of aluminum, which they entered energetically in 1946 by buying several wartime GOCO plants.[115] No such postwar triumphs occurred with magnesium. As it had during the war, PMC found itself a high-cost magnesium producer, competing with Dow for a share of a market in which demand proved to be lower than expected. And as they had early in the war, safety problems continued to bedevil the company. On July 29, 1946, an explosion of some goop in storage at the Permanente plant killed two employees.[116] By the autumn of

113. Foster, *Henry J. Kaiser*, 197; "The Earth Movers, III," 142.

114. "Permanente Metals Corp. Combined Profit and Loss Estimate to Date to May 31, 1946," 12 Oct. 1945, in folder Magnesium—Reports—PMC, Carton 136, HJK Papers.

115. Foster, *Henry J. Kaiser*, 200–10.

116. Unidentified newspaper clipping, July 30, 1946, in folder Magnesium—Permanente Metals Corp., Carton 136, HJK Papers.

October 1947, the PMC plant was closed; Dow again became the country's sole producer.[117] Although there was a limited revival of the industry during the Korean War, after which the United States maintained a sizeable strategic stockpile of the metal for two decades, magnesium never became the essential material in the way that Kaiser and other early boosters had envisioned.[118] (In recent decades, the center of global production of magnesium, as with so many other materials and manufactured goods, has shifted from the United States to China.)

As this essay has shown, the story of PMC's magnesium business is one of remarkable volatility, full of miscalculations and unexpected turns. More than many American companies in World War II, PMC felt the sting of reversals and defeats that are characteristic of war, and not just the profits and triumphs that some winners are lucky enough to enjoy. Just weeks after it seemed to win the status of the nation's designated challenger to the Dow monopoly, the company learned that it would actually be just a small piece of a giant expansion program in which most of its competitors' costs were fully covered by the government. To make matters worse, it soon became evident that the unproven production technology Kaiser had chosen was so troublesome that the company could never come close to matching Dow's costs. For PMC's magnesium division, "goop" became the means to salvage its reputation and rescue its bottom line. Although it proved an inefficient way to deliver metal ingot, the company's unique process created an intermediate product that turned out to be useful in making weapons that were very good at burning urban neighborhoods. By turning waste into weapons, PMC helped itself financially, while providing the USAAF with a new variety of arrow in its already hefty quiver.

For those who would characterize the modern American military economy as a thoroughly corrupt system of socialized risk and private gain, the story of PMC and the U.S. magnesium industry should stand as a challenging case, if not a fully negative one. The record of PMC provides a microlevel view of the World War II economy in which there was still ample room for serious competition, risk, failure, and loss. In the aggregate, we know, American corporations enjoyed large dollar profits during World War II, albeit in the context of a major national economic expansion and an environment of very high taxes,

117. "Loan of $28,000,000 Paid Off by Kaiser," *New York Times* (December 1, 1945): 30; "Kaiser Closes Plant," *New York Times* (November 1, 1947): 23.

118. "Authorizing the Disposal of Magnesium from the National Stockpile," 2; Lieberman, "Magnesium Industry in Transition," 74.

which reduced net margins to relatively modest levels. We still know very little, however, about the wartime experiences of individual companies, or parts of them. Certainly, the World War II experiences of PMC's magnesium division with production, competition, and loss cannot be characterized as somehow "typical" of modern American defense contractors. But they do suggest that historians of the MIC, as they do more to connect broader patterns of political and economic development with the historically specific experiences of particular firms and industries, may end up modifying traditional assumptions about the pleasures of doing business with the Pentagon.

Despite PMC's troubles, it managed to limit its losses; at the end of the war, its magnesium division was coming close to breaking even and could even boast of success in making a major contribution to the war effort. On the surface, this result seems to confirm traditional views of the MIC, in which state officials were understood to be hungry for weapons and insensitive to costs. Certainly, PMC did enjoy public subsidies, as well as second chances, thanks to public officers with money to burn. But part of PMC's relative success in World War II came from its aggressive efforts to abandon those relationships with parts of the wartime state that were proving least remunerative, so that it could find new ones in which there was more prospect of profitability. How common this sort of venue shopping was in the American economy during World War II, and how prevalent it has been in the defense sector at other times and in other places, remains an open question. Exploring it may help to suggest that firms in the military–industrial sector have been somewhat more enterprising—and therefore perhaps more interesting to students of business history—than traditional accounts of the MIC have allowed.

Bibliography of Works Cited

Books

Adams, Stephen B. *Mr. Kaiser Goes to Washington: The Rise of a Government Entrepreneur.* Chapel Hill: University of North Carolina Press, 1997.

Biddle, Tami Davis. *Rhetoric and Reality in Air Warfare: The Evolution of British and American Ideas about Strategic Bombing, 1914-1945.* Princeton, NJ: Princeton University Press, 2002.

Brandes, Stuart D. *Warhogs: A History of War Profits in America.* Lexington: University Press of Kentucky, 1997.

Chemical Corps Association. *The Chemical Warfare Service in World War II: A Report of Accomplishments.* New York: Reinhold Publishing, 1948.

Connery, Robert H. *The Navy and the Industrial Mobilization in World War II.* Princeton, NJ: Princeton University Press, 1951.

Crane, Conrad C. *Bombs, Cities, and Civilians.* Lawrence: University Press of Kansas, 1993.

Dow Chemical Co. *Annual Report[s] for the Year[s] ended May 31.* Midland, MI: 1941–1946.

Foster, Mark S. *Henry J. Kaiser: Builder in the Modern American West.* Austin: University of Texas Press, 1989.

Freyer, Tony A. *Antitrust and Global Capitalism, 1930-2004.* New York: Cambridge University Press, 2006.

Heiner, Albert P. *Henry J. Kaiser, American Empire Builder: An Insider's View.* New York: Peter Lang, 1989.

Hooks, Gregory. *Forging the Military-Industrial Complex: World War II's Battle of the Potomac.* Urbana: University of Illinois Press, 1991.

Jones, Jesse. *Fifty Billion Dollars: My Thirteen Years with the RFC.* New York: Macmillan, 1951.

Koistinen, Paul A. C. *Arsenal of World War II: The Political Economy of American Warfare, 1940-1945.* Lawrence: University Press of Kansas, 2004.

Lauderbaugh, Richard A. *American Steelmakers and the Coming of the Second World War.* Ann Arbor: University of Michigan Research Press, 1980.

Miller, John Perry. *The Pricing of Military Procurements.* New Haven, CT: Yale University Press, 1949.

Mountcastle, John Wyndham. *Flame On! U.S. Incendiary Weapons, 1918-1945.* Shippensburg, PA: White Mane Books, 1999.

Nash, Gerald D. *World War II and the West: Reshaping the Economy.* Lincoln: University of Nebraska Press, 1990.

Russell, Edmund. *War and Nature: Fighting Humans and Insects with Chemicals from World War I to Silent Spring.* New York: Cambridge University Press, 2001.

Schaffer, Ronald. *Wings of Judgment: American Bombing in World War II.* New York: Oxford University Press, 1985.

Sherry, Michael S. *The Rise of American Air Power: The Creation of Armageddon.* New Haven, CT: Yale University Press, 1987.

Smith, R. Elberton. *The Army and Economic Mobilization.* Washington, DC: Office of the Chief of Military History, 1959.

Sparrow, Bartholomew H. *From the Outside In: World War II and the American State.* Princeton, NJ: Princeton University Press, 1996.

Standard Oil Company of New Jersey. *M-69: The Fire Bomb that Falls on Japan.* New York: Standard Oil Company of New Jersey, 1945.

Waddell, Brian. *The War Against the New Deal: World War II and American Democracy.* DeKalb: Northern Illinois University Press, 2001.

Wells, Wyatt. *Antitrust and the Formation of the Postwar World.* New York: Columbia University Press, 2002.

Werrell, Kenneth P. *Blankets of Fire: U.S. Bombers over Japan during World War II.* Washington, DC: Smithsonian Institution Press, 1996.

Articles and Essays

Bernstein, Barton. "The Automobile Industry and the Coming of the Second World War." *Southwestern Social Science Quarterly* 47 (June 1966): 22–33.

Fagerberg, Dixon Jr. "A World War II Cost Accounting Assignment." *Accounting Historians Journal* 17 (June 1990): 81–88.

Ferguson, Robert G. "One Thousand Planes a Day: Ford, Grumman, General Motors and the Arsenal of Democracy." *History and Technology* 21 (June 2005): 149–175.

Gemery, Henry A., and Jan S. Hogendorn. "The Microeconomic Bases of Short-Run Learning Curves: Destroyer Production in World War II." In *The Sinews of War: Essays on the Economic History of World War II*, edited by Geofrey T. Mills and Hugh Rockoff, 150–165. Ames, IA: Iowa State University Press, 1993.

Gholz, Eugene. "The Curtiss-Wright Corporation and Cold War-Era Defense Procurement: A Challenge to Military-Industrial Complex Theory." *Journal of Cold War Studies* 2 (Winter 2000): 35–75.

Heinrich, Thomas B. "Jack of All Trades: Cramp Shipbuilding, Mixed Production, and the Limits of Flexible Specialization in American Warship Construction, 1940-1945." *Enterprise & Society* 11 (June 2010): 275–315.

Higgs, Robert. "Private Profit, Public Risk: Institutional Antecedents of the Modern Military Procurement System in the Rearmament Program of 1940-41." In *The Sinews of War: Essays on the Economic History of World War II*, edited by Geofrey T. Mills and Hugh Rockoff, 166–198. Ames, IA: Iowa State University Press, 1993.

Holley, I. B., Jr. "A Detroit Dream of Mass-Produced Fighter Aircraft: The XP-75 Fiasco." *Technology and Culture* 28 (July 1987): 578–93.

Karch, Andrew. "Venue Shopping, Policy Feedback, and American Preschool Education." *Journal of Policy History* 21 (January 2009): 38–60.

Lieberman, Marvin B. "The Magnesium Industry in Transition." *Review of Industrial Organization* 19 (August 2001): 71–80.

Mishina, Kazuhiro. "Learning by New Experiences: Revisiting the Flying Fortress Learning Curve". In *Learning by Doing in Markets, Firms, and Countries*, edited by N. Lamoreaux, D. Raff and P. Temin, 145–184. Chicago, IL: University of Chicago Press, 1999.

Nickel, Robert V. "Dollars, Defense, and the Desert: Southern Nevada's Military Economy and World War II." *Nevada Historical Society Quarterly* 47 (December 2004): 303–327.

Ralph, William W. "Improvised Destruction: Arnold, LeMay, and the Firebombing of Japan." *War in History* 13 (November 2006): 495–522.

Searle, Thomas R. "'It Made a Lot of Sense to Kill Skilled Workers': The Firebombing of Tokyo in March 1945," *Journal of Military History* 66 (January 2002): 103–34.

Thompson, Peter. "How Much Did the Liberty Shipbuilders Learn? New Evidence for an Old Case Study." *Journal of Political Economy* 109 (February 2001): 103–137.

Wilson, Mark R. "'Taking a Nickel Out of the Cash Register': Statutory Renegotiation of Military Contracts and the Politics of Profit Control in the USA during World War II." *Law and History Review* 28 (May 2010): 343–383.

Zeitlin, Jonathan. "Flexibility and Mass Production at War: Aircraft Manufacture in Britain, the United States, and Germany, 1939-1945." *Technology and Culture* 36 (January 1995): 46–79.

Magazines and Newspapers

Fortune.
Life.
New York Times.
New Yorker.
Newsweek.
Time.

Unpublished Work

"Case History of Permanente Project, San Jose, Calif." (n.d.), reel 33012, Air Force Historical Research Agency, Maxwell Air Force Base, Alabama.

Roberts, Lucien E. "Light Metals and Other Critical Aircraft Materials." U.S. Army Air Forces, 1944, typescript report, reel 2040, Air Force Historical Research Agency Microfilm, Maxwell Air Force Base, Alabama.

Archival Sources

Henry, J. Kaiser Papers [HJK Papers], *Bancroft Library*, University of California, Berkeley, California.

General Records of the Department of the Navy, 1798-1947. RG 80. *National Archives and Records Administration*, College Park, Maryland.

Records of the Chemical Warfare Service [U.S. Army], 1917-1963. RG 175. *National Archives and Records Administration*, College Park, Maryland.

Government Documents

Minutes of the Office of Production Management, December 21, 1940, to January 14, 1942. Washington, DC: GPO, 1946.

Minutes of the Supply Priorities and Allocations Board, September 2, 1941, to January 15, 1942. Washington, DC: GPO, 1946.

United States House of Representatives. "Authorizing the Disposal of Magnesium from the National Stockpile." House Report 769, 89th Congress, 1st Session. Washington, DC: GPO, 1965.

United States Senate. *Centralization of Heavy Industry in the United States: Hearing before the Special Committee to Investigate the Centralization of Heavy Industry in the United States, United States Senate, Seventy-Eighth, Second Session, Part 1, March 27, 1944: Basic Magnesium, Inc.* Washington, DC: GPO, 1944a.

United States Senate. *Investigation of the National Defense Program, Additional Report. . . Magnesium.* Washington, DC: GPO, 1944b.

United States Senate. *Investigation of the National Defense Program: Hearings before a Special Committee Investigating the National Defense Program, United States Senate, Seventy-Eighth Congress, Second Session. . . Part 24.* Washington, DC: GPO, 1944c.

United States Strategic Bombing Survey. *Effects of Incendiary Bomb Attacks on Japan: A Report on Eight Cities.* Washington, DC: GPO, 1947.