Chapter 1

The Perfect Material – for Wine

"Fill ev'ry glass, for wine inspires us,
And fires us
With courage, love and joy."

John Gay 1685 – 1732

The Beggar's Opera [1728], act II, sc. I, air 19

Glass is simultaneously one of the most ancient human-made materials and one of today's most sophisticated high-tech products. While born of some of the most common elements of the earth, glass with its transparent and poetic qualities has become central to the appreciation of wine. The histories of this beverage and the material that contains it are intimately intertwined. Over the centuries, improvements in winemaking have emerged, as glass vessels were developed to reveal the liquid within.

Today, after the wine is produced and then aged, generally in wooden barrels or stainless steel tanks, it is transferred to glass bottles for secure storage (and further aging) and transported to the consumer. The bottles are thus utilitarian but also aesthetic, serving as primary marketing tools. Their shape can signal the type of wine, and their appearance can be a contributing factor in the consumer's purchase. Once in our home, we pour the wine from bottle to drinking glass to enjoy in its own right or with food. After leaving the barrel or tank, most wine sees only a glass surface until its journey ends on our lips (Figure 1.1). The great Dutch painter Vermeer immortalized this final step in a seventeenth century painting (Figure 1.2).

In North America, 40 billion glass containers are produced for beverages per year representing 15% of the general beverage market. For many beverages,

The Glass of Wine: The Science, Technology, and Art of Glassware for Transporting and Enjoying Wine, First Edition. James F. Shackelford and Penelope L. Shackelford.

Figure 1.1 Glass is the essential material when wine tasting, in this case at the Wine Resort Leda d'Ittiri on the island of Sardinia. (Reproduced with kind permission of Annamaria Delitala, Wine Resort Leda d'Ittiri.)

plastic, aluminum, and cardboard containers are popular alternatives to glass. On the other hand, nearly 100% of the wine market continues to use glass containers (Figure 1.3). An additional benefit of these glass bottles is the ease with which they can be recycled.

Glass, however, is not without limitations. It is an inherently brittle material and more dense than plastic containers. Modestly careful handling can prevent bottle breakage, but reducing the weight of individual bottles, largely through

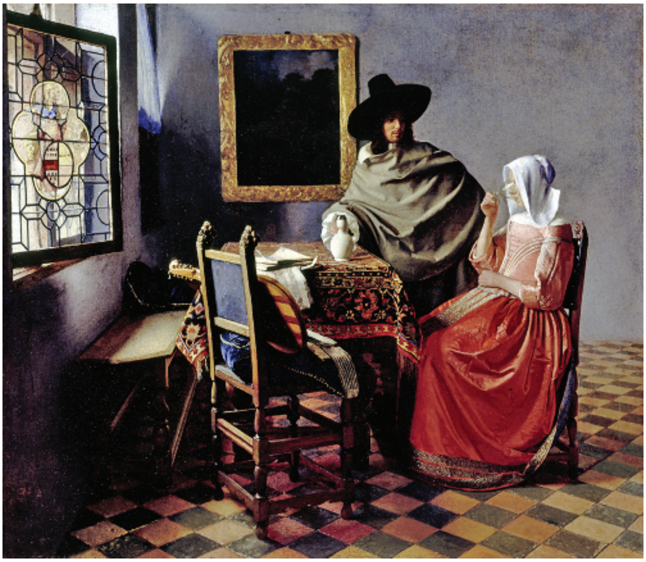

Figure 1.2 The Glass of Wine by Johannes Vermeer c. 1658–1660 (Reproduced with kind permission of Staatliche Museen Preussicher Kulturbesitz, Gemaldegalerie, Berlin/Art Resource Inc.)

Figure 1.3 Bottles are densely stacked while their wine ages at the Château de Beaucastel Winery in the Châteauneuf-du-Pape region of France. (Reproduced with kind permission of Château de Beaucastel.)

reduced wall thickness, is an important consideration to an increasingly energy conscious industry. The cost of transporting thousands of cases of wine is non-trivial even for relatively small wineries.

This book emerges from our research involving numerous wine tours and tastings as well as from our home in Davis, California, where the Department of Viticulture and Enology at the University of California, Davis has played a central role in the history of winemaking in California and especially the renaissance of the past 50 years, as California vintages have become peers of some of the world's great wines. The Department is, in fact, the only one within the University of California mandated by the State Legislature (in 1880 when there was but one UC campus in Berkeley). The Legislature realized even then that California had the potential to become one of the world's great producers of wine grapes and wine. The Department was formally established on the Davis campus in 1935 following the end of Prohibition. This establishment was typical of the Berkeley–Davis relationship. Judge Peter J. Shields who was also a prominent farmer in Northern California had drafted legislation early in the twentieth century to establish an agricultural college modeled after the Pennsylvania State College of his day. The large parcel of land appropriate for this college was located about one hour to the east near a convenient train station in the small town of Davis. The location was originally named the University Farm. These train trips out to Davis were regular journeys for students from the College of Agriculture at Berkeley. By 1960, over 3000 students were now doing their agricultural studies full time on the Davis campus. In that year, the Master Plan of Higher Education, the brainchild of the visionary President of the University of California Clark Kerr, established Davis and several other sites around the state as autonomous campuses.

Growth was rapid, and, by the time the authors arrived in 1973, as James assumed an assistant professorship in the Department of Mechanical Engineering teaching and doing research in the field of materials science and engineering, the campus had grown to over 15,000 students. His material of choice for academic research was generally glass, an interest that went back to an introduction to this material as an undergraduate in the highly specialized field of Ceramic Engineering at the University of Washington. A lecture there by an engineer from Corning Glass was transformative, with the slides showing technologically important materials that were stunningly beautiful (a triumph of industrial photography!). After a senior thesis studying the crystallization of a sodium silicate glass, he was on to UC Berkeley in 1967 to do a Ph.D. thesis on gas solubility in high-purity silica glass. (Yes, some small diameter gas atoms such as helium and neon are quite soluble in glass. It was a successful study that has led him to continue pursuing related research questions to this day.)

The authors' first (blind!) date was during this time and included a visit to the Italian Swiss Colony Winery in Asti, California at the time a major purveyor of better-than-average bulk *vin ordinaire* often sold in gallon jugs. A marriage eventually followed that blind date, and, 2 years later, we settled in Davis. While James settled into the faculty position at UC Davis, Penelope worked in the art world as a curator and gallery owner and eventually as an arts writer reviewing exhibitions on campus, home not only to a premier wine program but also to a leading department of art.

That tour of the Italian Swiss Colony Winery led to a favorite pastime of wine touring. Our journeys into the world of wine have taken us to vineyards throughout Europe, North and South America, and more recently Asia. Over these four decades living in Northern California, we have also had the privilege of watching the transformation of California's wine industry from its largely jug wine identity to the production of world-class vintages. We had arrived separately in this region at about the time Robert Mondavi was becoming a central force in that transformation. He had just opened his landmark Robert Mondavi Winery in 1966 in the heart of the Napa Valley (Figure 1.4). It was astonishing that, within a decade, the "Judgment of Paris" wine tasting would establish the best cabernet sauvignons and chardonnays[1] of the Napa Valley to be the full peers of their finest counterparts from France.

One of our early wine tours included visiting the Robert Mondavi Winery, and, in 1994, we had the privilege of meeting the man himself at a celebratory dinner at UC Davis to honor Professor of Art Wayne Thiebaud for his recent recognition with the National Medal of the Arts from President Clinton. Penelope covered the story of the Thiebaud dinner for the local newspaper. The dinner was also an opportunity for Chancellor Larry Vanderhoef to announce the vision of Robert and Margrit Mondavi to establish a center celebrating the

[1] We will follow the guide of Karen MacNeil, author of *The Wine Bible*, in the capitalization of wine names. For many varietals, such as cabernet sauvignon and chardonnay, the names are not capitalized as they are named after the grape variety. Only those wines named after a specific place, such as Champagne or Barolo, will be capitalized. Note that "variety" refers to a grape and "varietal" to the wine made from that grape variety.

Figure 1.4 Robert Mondavi, a leading pioneer in the production of fine wines in America, toasts with a glass of wine in front of the Robert Mondavi Winery in the Napa Valley of Northern California. (Reproduced with kind permission of Anne Siegel, Robert Mondavi Winery.)

interrelationship of wine, food, and art, a vision that within a decade would be realized with the Robert and Margrit Mondavi Center for the Performing Arts and the adjacent Robert Mondavi Institute (RMI) for Wine and Food Science on the Davis campus (Figure 1.5). Together these serve as a testament to a pioneering winemaker's vision of the role of fine wine and food along with the arts to enhance our quality of life. We certainly share his vision with the convergence of art and wine in our own lives through a lens of glass.

This was also about the time when the program in Materials Science and Engineering was transferred from the Department of Mechanical Engineering to the Department of Chemical Engineering. Now, James found himself a colleague of some who held joint appointments between Chemical Engineering and the Department of Viticulture and Enology. Seeing the world of grape growing and winemaking close at hand while continuing to do research on glass, along with our increasingly sophisticated touring of the wine country, including visits throughout California and north to the States of Washington and Oregon, created the nucleus of an idea – glass plays a unique role in wine culture, and it is a story worth telling.

In this book that relates the interweaving of wine with the glass that contains it, we will next move to the history of wine itself. In Chapter 2, the early history of winemaking and wine drinking does not involve glass, but generally ceramic pottery, animal skins, and metal chalices. The innate affection of humans for fermented

Figure 1.5 The Robert Mondavi Institute (RMI) for Wine and Food Science on the University of California, Davis campus is a fitting tribute to the California winemaking pioneer. Here a spectrum of wine bottles waits to be filled by students in the Teaching Winery at RMI. (Reproduced with kind permission of Andrew L. Waterhouse, Robert Mondavi Institute for Wine and Food Science.)

beverages predates their creativity in developing glass vessels by a few millennia. Wine and related "mixed" fermented beverages appeared in the early Neolithic period (7000–5000 BC) more or less simultaneously across all of Asia from the west (in the modern Middle East) to the east where the earliest fermented beverage discovery to date has been found in the center of modern China.

Chapter 3 provides us with a formal definition of glass, a first cousin of **ceramics** and distinct from the other major categories of engineered materials: metals, polymers (plastics), and composites. Chapter 3 also continues the story of wine storage and consumption, with the development of glass some time before 2000 BC, initially providing a fragile and expensive alternative. While winemaking had a few millennia head start on glassmaking, the two technologies became intimately intertwined in the seventeenth century, as inventions in England led to high-quality glass becoming widely available for bottles and drinking glasses. This period in time served as a fulcrum for the histories of both glass and wine, as increasingly transparent vessels revealed imperfections

Figure 1.6 Venetian glass such as this example from the late sixteenth to early seventeenth centuries was of such high quality that winemakers were inspired to make better, sediment-free wines. (Reproduced with kind permission of the Corning Museum of Glass.)

in the beverage. The convergence of the histories of glass and the wine it contained was most dramatic in the Champagne region of France as the transparent beauty of Venetian glass inspired winemakers to produce crystal clear and sediment-free sparkling wines (Figure 1.6).

Chapter 4 diverges from the general focus of this book on an important inorganic material (glass) and provides an overview of the related and equally important topic from organic chemistry: how wine is made. Humans have been making wine for a considerably longer time than they have been making glass. Contemporary winemaking and the precedent agriculture of grape growing, viticulture, involve a wide variety of materials, with glass playing a minor role. Nonetheless, we shall generally use the menu of materials available to winemakers as a kind of lens through which we view the art and science of winemaking.

Once harvested by hand or by machine, grapes can experience oak barrels (often from France, Hungary, or America) during vinification or, as an alternative, stainless steel tanks. These vessels are environments for a complex variety of reactions that ultimately can be simplified as the process of fermentation – the

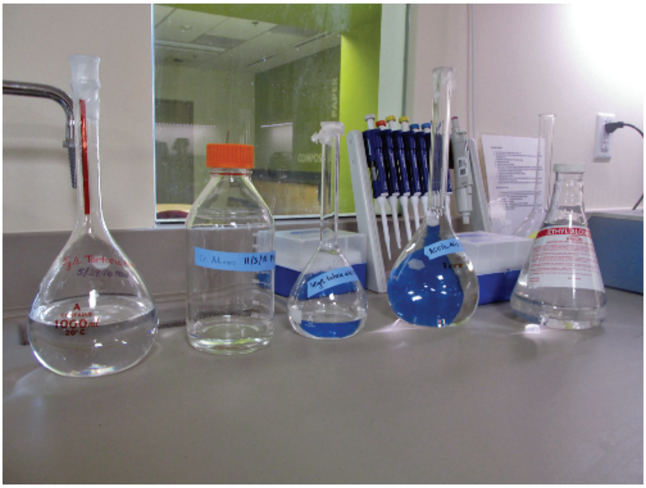

Figure 1.7 Scientific glassware is essential in winery laboratories, in this case at the Robert Mondavi Institute for Wine and Food Science. (Reproduced with kind permission of Andrew L. Waterhouse, Robert Mondavi Institute for Wine and Food Science.)

conversion of sugars in the grape juice into alcohol. While Chapter 4 focuses on the organic chemistry of winemaking and materials other than glass in that service, we see in Chapter 5 that ceramics, the "first cousin" of glass, are important options for winemakers. Concrete tanks are used rather than stainless steel ones in many wineries, and winemakers wishing to embrace traditional, even ancient, methods are turning to ceramic amphorae similar to those used by their earliest predecessors. Although we focus on storing, shipping, and consuming wine in this book, glass also has various roles around the winery. Chapter 6 provides examples of glassware used in barrel tasting and the wide variety of scientific glassware used in the winery laboratory where chemically durable glass compositions are required (Figure 1.7).

Armed with knowledge of the chemistry of wine, we can more fully appreciate the poetic beverage that finally arrives at our lips after its long voyage encased within glass surfaces. Simple and functional drinking glasses are now available for everyday use, but special occasions call for fine "crystal" with its high sparkle and nearly perfect transparency. The specific technology that provides the "sparkle" (one of the seventeenth century inventions) and the manufacturing steps that produce this elegant glassware will be revealed in Chapter 7 within the context of modern glassmaking. We will explore the inorganic chemistry of glassmaking in contrast to the organic chemistry of winemaking.

One of the seminal developments in glass manufacturing was the development of the blowpipe by the Phoenicians around 200 BC, making glass blowing possible (Figure 1.8). This technique is still used to make some expensive wine glasses and large format Champagne bottles, but most bottles and wine glasses

Figure 1.8 This statue at the Corning Museum of Glass memorializes the art of glass blowing. (Reproduced with kind permission of the Corning Museum of Glass.)

are now manufactured by machine. These mechanical technologies will be illustrated in Chapter 7.

In Chapters 8 through 10, we delve deeper into the inorganic world of glass itself and expand on our discussions of the structure and properties of glass. *Glass* science is a subset of the broader field of *materials* science that has a simple foundational principle: *structure leads to properties*. This concept, borrowed from chemistry and physics, means that we explain the behavior (the "properties" or measurable characteristics) of materials in terms of their small-scale structure. By "small-scale," we mean really, really small from the atomic level through the microscopic. For example, the way in which an empty metal soft drink can is deformed when we squeeze it in our hand can be explained ultimately by the way in which individual atoms of metal move relative to each other.

We can define "atomic scale" in terms of the size of individual atoms: typically a few Ångströms in diameter, with an Ångström equaling one tenth of a nanometer in the metric system of measurement. Much attention has been paid to nanotechnology since President Clinton inaugurated the National Nanotechnology Initiative on the Cal Tech campus in 2000, beginning with the words "Imagine what could be done . . ." The excitement about the science and resulting technology that derives from working at this length scale has not subsided in the time since that launch. This more-than-a-decade time frame is a long one in modern technology, with many hot topics rising and falling in considerably shorter fashion. For those not familiar with the nanometer unit of length, the prefix "nano" means that it is one billionth of a meter, and, for those not familiar with a meter (mostly in the United State, the only industrialized country that has not adopted the metric system as the official system of measurement), a meter is about three feet or one yard in length.

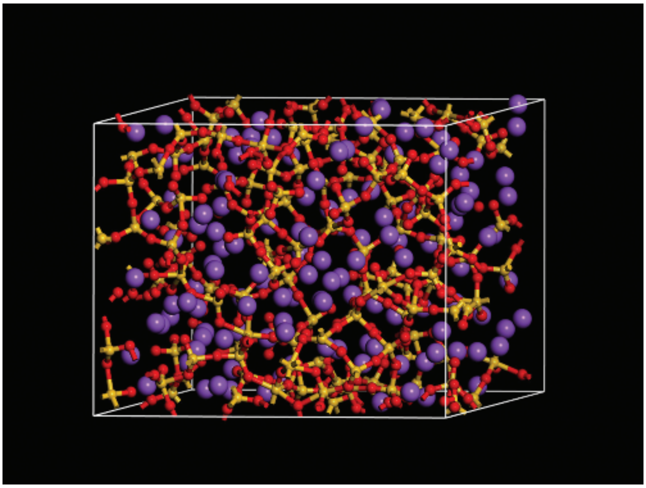

Figure 1.9 This computer-generated image of a sodium silicate glass on the atomic scale shows sodium atoms (large purple spheres) scattered among a rigid network of silicon and oxygen atoms in a "stick-and-ball" configuration (with yellow atoms being silicons and red atoms being oxygens). Such computer models are the focus of Chapter 8. (Reproduced with kind permission of Sabyasachi Sen, Department of Materials Science and Engineering, University of California, Davis.)

So, we will find some properties determined by the nature of the individual atoms that make up the glass and that other properties will be determined by structural features – the size of clusters of atoms (the nanoscale). Chapter 8 will discuss the unique and elegantly disordered atomic-scale structure of glass, with a bonus being the visual beauty of these structures.

Only relatively sophisticated electron microscopes can image individual atoms and nanoscale structures. (The nanoscale is generally defined as a feature being between 1–100 nm in length.) Advances in computing power in recent decades have led to the subfield of computational materials science. The detailed and scientifically rigorous image in Figure 1.9 is produced in this way. When we refer to microscopic-scale structure though, the reference tends to be the conventional optical microscope, with an ability to view structures no smaller than about 1 μm, a small dimension but equal to 1000 nm. The micrometer is often called simply the micron. Such "microscopic" features as micron-scale air bubbles can have significant effects on both mechanical behavior (Chapter 9) and optical behavior (Chapter 10).

In Chapter 11, we discuss the combination of tradition and pragmatics that has emerged to dictate the shape of wine bottles, from the deep "punt" on the bottom of the Champagne bottle to the sloping shoulder of bottles containing pinot noir, the elegant grape of the Burgundy region of France. The deeply indented bottom of the Champagne bottle serves the wholly pragmatic function of containing the internal pressure while giving waiters worldwide the ability to pour the sparkling wine into their guest's glasses with one-handed panache. The

Figure 1.10 These elegant wine glasses from the eighteenth century were a symbol of sophistication and fine dining. (Reproduced with kind permission of the Corning Museum of Glass.)

Burgundy's sloping shoulder is a signature shape for pinot noirs worldwide. On the other hand, the square shoulder of bottles for the red wine of Bordeaux is pragmatic, facilitating the removal of sediment as old and elegant cabernet sauvignons are slowly poured. A discussion of wine bottles is not complete without the related technology of labels, both pragmatic sources of consumer information and, increasingly, canvases for artistic expression. In some cases, glass decoration is replacing traditional paper labels.

The technology of drinking glass manufacturing continued to evolve through the eighteenth and nineteenth centuries when elegant designs produced with meticulous craftsmanship became an essential part of the dining experience in upper class homes in both Europe and the New World (Figure 1.10). We will see in Chapter 12 that, during that time, the focus was generally on the ornate as an unambiguous symbol of the elegance of wine appreciation.

The twentieth century brought a revolution in design with wine glasses being a prime example. The ornate gave way to elegant simplicity. In addition in the last half of the twentieth century, the shapes of wine glasses developed unique relationships to the wines contained within. For example, the Champagne flute avoids the rapid dissipation of the effervescent bubbles and delivers the wine directly to the back of the tongue. The larger glasses for Burgundies (pinot noirs) provide more surface area exposed to air, releasing more intense aromas especially when the wine is swirled. We find in Chapter 12 that, since the 1950s, more than 2 dozen varietal-specific stemware shapes have been developed. Wine glass manufacturers and many connoisseurs have made a convincing case for serving pinot noir in stemware with a distinctly different shape from that optimized for cabernet sauvignon that, in turn, is distinct from that for sauvignon

Figure 1.11 Contemporary wine glasses come in a variety of sizes and shapes deemed appropriate for a wide array of varietals. (Reproduced with kind permission of Kim Goodwin, Luigi Bormioli Italy.)

blanc, and so on (Figure 1.11). The claim is simply that, when tasting wine, the shape of the glass affects the bouquet, taste, balance, and finish. Research primarily done by the Riedel family of the famous Austrian wineglass company involved evaluation of a wide range of varietals in a wide range of shapes by professional tasters to settle on the optimal matches. Recently, a number of important wine writers have begun to rebel and recommend instead a one-size-fits-all shape to simplify life for connoisseurs (and themselves).

Chapter 13 reminds us that cork has been the dominant technology for sealing wine bottles for roughly five centuries and has made the international appreciation of wine possible, but alternate technologies now challenge that dominance. A significant lapse in quality control in the Portuguese cork industry in the 1980s accelerated the development of these alternatives. Synthetic corks of various types have been used, and metallic screw caps have become especially popular in the New World markets of Australia and New Zealand. Another of the challengers to cork is the glass stopper that has an interesting history from its traditional role in the scientific laboratory to substantial research and development in the past two decades, specifically for the purpose of sealing wine bottles. These stoppers are widely used for German white wines and are finding increasingly wide acceptance around the world. Could the wine bottle of the future be all glass all the time? Well, not exactly. The success of the glass

Figure 1.12 Decanters are sometimes helpful for aerating wine and to minimize sediment. This is especially true for powerful tannic wines such as the Barolos from the Piedmont region of Northern Italy.

stopper rests on a small, polymeric o-ring. Nonetheless, the *nearly* all glass bottle stopper system is now an important option for the wine industry.

Despite the romance surrounding the long-term cellaring of “collectable” wines, most wine is consumed shortly after purchase. Whether or not the consumer stores the wine for many years “in bottle,” the final enjoyment of this nectar of the gods and goddesses is invariably in glass stemware, and, just prior to drinking, the wine is sometimes transferred from the bottle to glass carafes or decanters (Figure 1.12). This is especially true for older, tannic wines. Just as the Bordeaux bottle shape facilitated the removal of sediment in cabernet sauvignon, pouring the contents of the bottle into a decanter can also allow the settling of the sediment before pouring. Equally important, pouring wine out of the bottle and swirling it in the decanter can provide substantial aeration. The relationship of wine to oxygen is fascinating and complex. Isolating wine from oxygen is a major role of cork (and metal screw cap and glass stopper) bottle closures. On the other hand, when the bottle is subsequently opened, time for exposure to air may be required to optimize the wine’s character. Those sediment-laden tannic wines often benefit from this oxygenation turning a harsh wine straight from the bottle into a balanced and refined masterpiece. There is considerable art and science in the preparation of wine in many different decanter designs, as we shall see in Chapter 14.

Finally in Chapter 15, we critically explore whether the ubiquitous role of glass in wine appreciation is secure or if glass bottles and stemware will go the way of the chrome bumpers on automobiles of a half-century ago. Of course, it is hard to imagine ordering a fine wine in a Michelin-starred restaurant and

Figure 1.13 Glass stemware enhances the experience of fine dining. All of these varied glasses can find their way to the table when experiencing the full tasting menu at the Quince Restaurant in San Francisco, California. (Reproduced with kind permission of Zoe Simonneaux, Quince Restaurant.)

having that wine arrive at the table in anything other than a glass bottle. Similarly, we expect the table to be set with elegant glass stemware (Figure 1.13). So while the chrome bumper analogy may be far fetched, the adjective "ubiquitous" could be the endangered species, as *vin ordinaire* is increasingly available in packaging imitative of the beer, soft drink, and milk industries.

Throughout these 15 chapters, our goal will be to enhance the readers' appreciation of wine by better understanding the vessels from which that wine is delivered to their lips. So, now let us begin by exploring the history of wine.

BIBLIOGRAPHY

Callister, William and David Rethwisch, *Materials Science and Engineering: An Introduction*, 9th Edition, John Wiley & Sons, Inc., New York (2014).

Clinanti, Pino, *El Fuoco, Il Vetro, Il Vino*, Fondazione Banfi, Montalcino (Italy) (1992).

Ellis, William S., *Glass*, Bard/Avon, New York (1998).

MacNeil, Karen, *The Wine Bible*, 2nd Edition, Workman, New York (2015).

McGovern, Patrick, *Uncorking the Past*, University of California Press, Berkeley (2009).

Shackelford, James, *Introduction to Materials Science for Engineers*, 8th Edition, Pearson, Upper Saddle River, NJ (2015).

Taber, George M., *Judgment of Paris: California vs. France and the Historic 1976 Paris Tasting that Revolutionized Wine*, Scribner, New York (2005).

Taber, George M., *To Cork or Not to Cork: Tradition, Science, and the Battle for the Wine Bottle*, Scribner, New York (2007).