Chapter 3

Raw Materials

The packaging cycle begins with and additionally, via recycling, may return to the raw materials that make up materials in finished packages. This section is included as a starting point for considering the packaging cycle. As our societies become more aware of the need for recycling raw materials, and the supplies of raw materials become more uncertain, the packaging engineer can no longer assume that supplies of the basic materials that make up the components in a food package will be stable in either availability or price. The most obvious examples of this are oil and natural gas that are used both as a general source of energy and a source of raw hydrocarbon feedstock for polymer production. It has been estimated that the current world supply of oil may be approximately 50% depleted and whether this figure is accurate or not is of less consequence than the reality that oil supplies are becoming concentrated in fewer and fewer locations, and have long been connected with political problems and price instability for industrialized countries.

This, in turn, feeds back into the packaging and food-processing industry as uncertainty of prices and supplies that will impact the feasibility of a particular product design or choice of materials. Given that the food and packaging industries are highly competitive and price- and marketing-driven, these kinds of supply swings can be quite disruptive to the production flow of food-processing and packaging operations. Also of importance are ongoing environmental and sustainability concerns that may limit the cutting of timber for wood pulp, or the excavation of mineral stocks such as iron ore or bauxite, or beach sand used in the glass production industry. These can affect availability of basic materials and therefore of finished package components as well. The globalization of supply and demand have reduced or eliminated spot shortages of materials for the interim, but increased demand in developing economies and price fluctuations may affect the basic economics of packaging design and drive a move toward flexible sourcing of materials to avoid production losses.

Wood and Fiber

Although some wood is used for the manufacture of crating and palletization products, as well as fabrication of reusable bulk shipping containers, wood and fiber products are used in the packaging industry primarily for the manufacture of paper and related products. Because of increased financial costs and environmental impact of harvesting and processing timber, and increased competition for supplies of wood and pulp, the market for recycled paper fiber has become lucrative enough that paper mills, once only found near access points for timber, have been constructed to operate solely on recycled content. In some instances, paper manufacturing

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of this type has been situated to very profitably utilize the huge supply of recycled paper fiber coming from large urban areas and the low cost of *backhaul* – shipping containers returning empty – to ship waste paper to be remanufactured into paper for expanding Asian markets. Unfortunately, one of the other adaptations has been to situate paper manufacturing facilities in locations where the cost of harvested timber is low and the environmental impact is deliberately overlooked. The long-term cost of this in terms of economic and ecological degradation can be severe.

Paper can be made of many types of plant fibers, but with few exceptions, pulped wood fibers of a few species are preferred. As production of paper and paperboard products decreases in the United States, the types of species used for paper manufacture are becoming less distinct as wood pulp is shipped from one country to another, but the overwhelming source of paper fiber is from softwoods such as various species of pine and eucalyptus. In regions where paper production has escalated to match industry's increased demand for packaging and other paper products, the limitations on paper production facilities and pulp supplies can drive up the price of paper, but also can motivate the use of recycled paper fiber [1].

Paper Production

Wood fiber-based paper begins as trees of various species, typically softwoods, that are harvested in any number of ways depending on local economics and regulations. Logging may be very different in Bhutan than it is in Finland, and many operations, particularly those in more remote regions, still rely on manual cutting. The United States, with its enormous variety of forests, relies on everything from small hand-cutting operations and commercial dragline operations, where cut timber is carried by a powered cable out of the forest, to highly automated harvesters that clamp and cut a tree in a single operation. Countries with high labor costs or extensively engineered forest stock production economies may rely on these more automated cutting devices. Regardless of the felling method, logging is generally dependent on the ability to transport cut timber from the forest to the point of use – typically a chipping, paper, or lumber mill. This transportation is typically a combination of water transport, rail, and over-the-road truck, and from there the finished products will be distributed by truck and rail, with the exception of wood pulp for export that is almost universally carried by bulk cargo ship. When received at a paper mill, wood and wood chips are turned into cellulose fibers and converted into paper and paperboard products as described in detail in Chapter 4.

Resource Outlook

Because of environmental, political, and economic issues revolving around large-scale logging operations and the large amounts of land involved, cutting operations may be very controversial. In the United States, concerns about clearcutting practices, erosion, wildlife habitat loss, and forest replenishment are often strongly debated against issues of resource supply to the public, local economics, fire hazard, and profitability. Much of the timber and pulp in the United States and other countries (particularly New Zealand) comes from private land. Additional resources are cut on public lands, and the conflict between the profitability of logging on public lands and conservationists' objections has created a great deal of discord, particularly due to the fact that the government agencies charged with protecting these lands also handle the timber leases and resource estimates, with inevitable problems. In some cases, allegations have been made that the agencies have severely overestimated the available resources in order to allow more timber cutting, and in others that the Forest Service themselves cut profitable trees from protected resources [2, 3]. Environmental restrictions have been seen as both meddlesome and economically disastrous by people dependent on logging income – the spotted owl habitat preservation that closed millions of acres of the Pacific Northwest to logging has become an icon for the contention and economic disruption caused by conservation efforts.

In other countries, particularly those with developing economies, the logging issue has the potential to incite civil unrest as populations are impacted by the logging operations. In regions such as the Amazon Basin, New Guinea, and Indonesia, among others, the impact on indigenous peoples has often been one of displacement without compensation as well as deforestation. The contention regarding these issues is similar to that in the United States, although there are often fewer effective regulations of any type in place allowing logging to operate in any convenient fashion. In response to the complex nature of forest product utilization, several certification schemes have been put forward to assure customers that products are produced in a responsible manner, although the final impact of this has yet to be determined [4].

Pulp and paper supplies are impacted by these large-scale issues in addition to more mundane issues of energy and production capacity as well as the supply of recycled paper fiber, resulting in global shifts of price and production. Broadly speaking, pulp and paper production is slowly shifting to lower-cost areas of the world, as is much of manufacturing, with new species of wood such as eucalyptus becoming more common among the paper stocks. Capacity in the United States and Canada is slowly diminishing as capacity in Latin America increases, with Asian production increasing to meet the exploding production needs there [5]. The demand for paper and pulp imports by Asian and European markets will continue to pressure supplies, and the increased awareness of environmental impacts on both long-term sustainability and facets of the economies of many countries may create pressure on pulp and paper supplies.

Ceramic Materials

The primary raw material for ceramic materials used in packaging and processing applications is sand, typically taken from beaches or sand pits, as well as other minor mineral feedstocks, and usually chosen for a particular mix of minerals that will provide an approximate composition for a particular set of attributes, most often a particular color. Although sand is a plentiful resource, sand of the proper quality may be located in areas that have competition for use, such as beach areas for tourism or in areas where removal may have significant ecological impact. Because of the nature of glass manufacturing, recycling of broken glass moldings is standard procedure within plants, and the incorporation of post-consumer recycled glass materials is therefore relatively easy, but the demand for specific qualities in the final remanufactured glass product can impose some limitations on the ability for reuse of specific types of recycled glass. Typically the criterion is color – for example, *Flint* (clear) containers cannot be made from amber or green recycled glass – and purity as the inclusion of metallic labels may contaminate the glass batch. Unfortunately, glass also has a huge energy component when compared with other types of materials, and the escalating costs of energy have made the use of glass increasingly economically unfavorable for common products as more durable and lightweight substitutes become available from the plastic and laminate industries.

Glass Production

Glass and ceramics start as sand or clay deposits that are mined either from pits or surface deposits with large-scale earth-moving equipment. The sand must be of the correct type and grade for the intended purpose (for example, optical-grade glass requires a much purer raw material than fiberglass home insulation). Because of the energy content of glass and ceramics, production facilities are usually located near a convenient source of thermal energy (most often a gas pipeline or storage facility), a convenient means of delivering a raw material supply, and a suitable means of distributing the finished containers. With an increasing amount of recycled glass available, it is possible to construct glass plants that operate primarily on recycled materials, although cullet is always a large component of the furnace charge. Ceramics require kiln firing of castings made of ceramic *slip*, although uses in the packaging industry are very minor and the majority of production is for household fixtures and industrial components.

Resource Outlook

The costs of producing glass containers will continue to escalate with the rising prices of energy because container glass requires approximately 6.7 MJ/kg to manufacture [6]. Although the vast majority of glass manufacturers operate furnaces with natural gas that has been somewhat less subject to price fluctuations than oil, the costs of glass containers will make them increasingly subject to scrutiny for replacement by alternate materials. These replacements are primarily plastic containers for food, drug, and cosmetic applications, which have an additional benefit of not being a dangerous product contaminant if they fail. The glass industry is both mature and somewhat unstandardized in its methods and machinery, and the transportation costs of the heavy containers limit the economically feasible distribution radius of containers – this being subject to impact by energy prices as well [7]. Glass containers will not easily be completely replaced either for reasons of chemical resistance and inertness, such as with pharmaceuticals, or for reasons of the perception of quality that the perfume and high-value beverage industry depends on. However, the cost premium will continue to push the development of lighter and more efficient glass structures.

Metals

Aluminum

Aluminum is manufactured by the electrolysis and reduction of aluminum oxide found in bauxite ores, almost universally by the electrode smelting method first developed by Hall and Heroult in 1886. This is an energy-intensive method because of the highly stable nature of aluminum oxide, and the aluminum industry has been actively recycling metallic aluminum since the 1970s because of the energy savings and cost reduction involved. Aluminum-refining plants are often located near large electricity sources, often hydroelectric facilities or similar power plants, and will import bauxite as needed. Packaging consumed approximately 20% of North American production [8] in 2005. Aluminum has the paradoxical advantage that the same surface oxide stability that makes aluminum hard to refine makes it ideal for many applications because the oxide coating on metallic aluminum provides protection against further external corrosion. Under common usage conditions, this oxide layer may allow items made of aluminum, including beverage cans, to remain externally uncoated without fear of corrosion damage, which makes it ideal for high-volume beverage applications. Additionally, although the total tonnage used is relatively small, aluminum plays an increasingly important role as a barrier both as thin foils and as vacuum-deposited coatings on polymer substrates.

Aluminum Production

Bauxite ore is surface-mined from deposits that are on the order of 4–6 meters thick [9] at any number of locations, often quite remote. The ore usually requires transportation to a refining site because many of these are situated near energy sources rather than ore supplies. Most often, bauxite ore is directly exported via rail or bulk cargo ship to refining and smelting sites elsewhere, and the refined metal can be converted at the smelting site or distributed as aluminum ingots for further processing and conversion into sheet, foil, or extrusions.

Resource Outlook

The aluminum industry has been undergoing restructuring since the early 1980s and has undergone substantial changes, with primary production of aluminum migrating to countries with lower energy costs either as a result of natural power supplies, such as hydroelectric or geothermal power, or as the result of excess petroleum production. Aluminum production has been used as a means of converting power production into goods for world trade in some countries, and has proven lucrative enough for the import of bauxite ore for refining and smelting operations. World bauxite production, led by Australia, Brazil, and China, was 201 million tons in 2009, and listed world reserves are approximately 27 billion tons (approximately a 180-year supply), although the estimated total resources are thought to be 55–75 billion tons [10]. The developing economies of China and India will put pressure on increased production, and the substantial level of aluminum recycling that has been established and is being increased will provide an alternative source, so once again energy costs – approximately 25% to 35% of the final cost of production – will substantially affect the price of refined aluminum.

Steel

Steel is a very strong material but is seldom used in packaging beyond the fabrication of tinplate cans where corrosion can be managed. The steel and aluminum industries compete for market share among the non-beverage can markets in particular locations, and thinwall steel cans similar to the common aluminum beverage cans are available in some markets. Although steel can be recycled in a manner similar to aluminum, the relative energy savings are much less because of the smaller energy component involved in reducing elemental iron oxides to metallic iron. Steel, because of its high modulus and strength, is also incorporated into structural applications in nearly every kind of building and vehicle, so that the packaging industry is a relatively small market segment but is also affected by other demands for steel-based materials.

Steel Production

Steel is manufactured from reduced iron ore, typically surface-mined as oxides and converted to a more concentrated form such as taconite pellets before being transported to a production steel mill. At this point, the ore is combined with carbon and other minerals in a basic oxygen furnace that uses a series of chemical reactions and oxygen injection to convert the impure carbon-iron mix into purified steel melt. Recycled steel may be converted in the same manner, or an electric arc furnace may be used in smaller operations (so-called mini-mills that may have production levels as low as 50,000 tons per year). From this it may be cast into slabs and rolled into sheet to be used as can fabrication stock. Ferrous foils are not used in the food industry because of their lack of corrosion resistance. Sheet steel may be plated with tin or coated with a polymeric surface layer to prevent corrosion, and is then used as can stock for container fabrication.

Resource Outlook

With the globalization of the steel market and the explosive growth of Asian and Indian economies, iron ore as well as finished steel is in great demand. The increased demand for steel has driven the cost of both finished and scrap steel upward, increasing the cost of finished products such as food cans. Iron ore production is expected to increase to match demand, but there is substantial lag, particularly in the construction of new facilities to process ore or recycle scrap steel. The limiting factor is not the availability of ferrous ores, which are very common minerals, but the ability to efficiently mine, transport, and refine them. The packaging industry has responded by either replacing steel cans with ones made of polymers or composites, themselves subject to the increased cost of petrochemical feedstock materials, or by creating lighter-weight steel containers via structural modifications.

Tin

Tin as an alloying element for copper to make bronze dates back at least 5,000 years in southern England, and was traditionally mined in small pits and traded around Europe, the Mediterranean, and Africa at least as early as the 6th century BCE. Approximately 27% of the world tin market is used for the nontoxic anticorrosive coatings on steel food containers, described elsewhere in the book, and approximately twice that as a constituent in solder used primarily in electronic assemblies. Most electroplated steel that is utilized for structural applications uses a thick zinc coating unsuitable for food contact use.

Tin Production

Tin ore is smelted in a reverberatory furnace that isolates the heating fuel from the ore deposits while subjecting them to the hot combustion gasses [11]. Tin may also be recovered from scrap, typically in tin and electronics-recycling operations. Tin may be further refined by boiling or electrolytic processes as required, and then is cast into ingots. Food can coatings are typically made with Grade A tin (99.80% Sn), to avoid problems with residual compounds from the smelting process, such as bismuth or lead.

Resource Outlook

Tin in historic deposits in England, Europe, and even Africa required relatively difficult manual mining for relatively high-grade ore for use in making bronze. Currently, the largest principle tin production resources are located in China, Indonesia, and Peru, with several other South American countries producing substantial quantities mined from alluvial deposits either by surface removal, dredge, or hydraulic mining. Consolidation of tin producers and the increase in demand for low lead/high tin content solder for electronic devices has driven the price upward and caused several mines to be reopened. Tin is often recovered during the recycling of tinplated steel and electronic circuitry, so there is a mitigating source of supply. As alternative polymeric coatings for cans are implemented and there is progressively reduced solder content in ever smaller electronic devices, the effect on container costs may be reduced.

Petrochemicals – Oil and Natural Gas

Oil and natural gas are used as energy sources for all types of manufacturing, as well as the raw material for many types of polymers. Although the energy requirements for the manufacture of polymers is lower than that for glass, the politically volatile nature of the petroleum and natural gas supply is reflected in the fluctuating price of polymer resins. Apart from resin manufacturing, energy costs that are often tied to the price of oil and gas are frequently reflected in manufacturing and processing costs because many of the processes are dependent on a high-energy input in materials such as glass, aluminum, and steel. Indirect costs related to energy, such as transportation and manufacturing facility operation, will also be affected by fluctuations in petrochemical prices, supply, and availability.

Petrochemical Production

Oil and natural gas are primarily obtained by drilling wells into deposits locked in porous rock strata located in regions where prehistoric plant matter has been compressed and heated over time. Alternative sources of crude oil involve mining tar sands or oil shale and extracting the oil content from them, as well as the relatively inefficient conversion of mined coal into other petrochemical forms. Once the oil or gas is extracted, it is transported by pipeline or tanker either to refineries or to loading terminals for large vessels to transport them to refineries. Oil refineries use a combination of heat, pressure, and catalysts to break the oil down into its constituent components ranging from light gasses to asphalt. These products are distributed by ship, rail car, truck, barge, and pipeline. Natural gas is typically distributed by pipeline but may be shipped intercontinentally in specialized LNG (Liquefied Natural Gas) tanker ships. When separated into its constituent parts (primarily methane, ethane, propane, and butane), these gasses may be used in the polymerization processes that produce many packaging polymers.

Resource Outlook

As the primary source of energy for transportation as well as numerous other applications such as domestic heating and electricity generation, the petrochemical supply is central to the world economy, and as such is the subject of an extraordinary amount of concern, debate, and speculation (both philosophical and financial). Marion King Hubbert proposed in 1956 that world petroleum production would peak near the end of the 20th century at a level of 12 billion barrels a year (Figure 3.1), and although the model was elegantly simple, data has shown that the world's oil supply reached a peak in approximately 2000 (at 12.775 billon barrels per year) and is decreasing [12].

Many arguments revolve around these figures, but the inescapable reality is that the current mode of energy production and usage cannot continue indefinitely, and that alternatives must be developed. Hubbert, a geophysicist, argued that nuclear power was the only sustainable energy alternative. Other energy alternatives such as solar, wind, and geothermal sources may also supplement or replace the current means of electrical generation, but alternatives for simple,

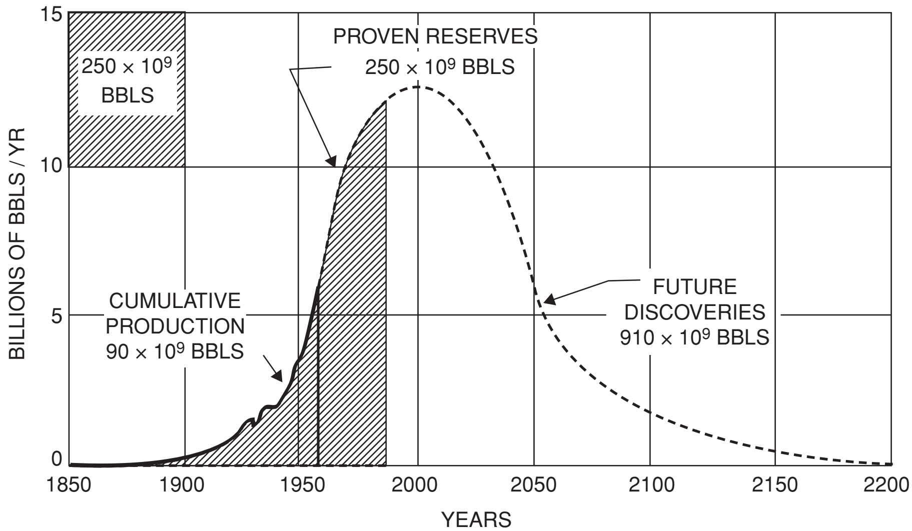

Figure 3.1. The Hubbert Curve
Source: M. King Hubbert (1956), "Nuclear Energy and the Fossil Fuels". Drilling and Production Practice, American Petroleum Institute & Shell Development Co. Publication No. 95, Figure 20, 22. http://www.hubbertpeak.com/hubbert/1956/1956.pdf

cheap, and durable polymer materials will be more difficult to produce, although there are promising biopolymers.

Other Gases – Propellants and Industrial Gases

The increasing use of gases in processing and packaging, both in the traditional areas of aerosol propellants and in the increased use of gas flush and modified atmosphere packaging, require that the supply and forecast for these are considered. Some aerosol propellants are simple petrochemical gasses (propane, for example) whereas others are more complex synthetics such as the HCFC propellants, but nearly all of them have a petrochemical base and are subject to price volatility induced by the world petroleum energy market.

Non-petrochemical gasses such as nitrogen are removed directly from the atmosphere via compression and liquefaction, and then typically separated either by membrane/molecular sieving systems or by pressure and temperature-based separation. Energy costs are a large component of the overall manufacturing costs with these compounds that have free feedstock but require energy-intensive compression for liquefaction. Interestingly, the drive for alternative fuels from agricultural feedstocks, such as ethanol and butanol, has provided a tremendous source of carbon dioxide as an industrial by-product.

Energy

Although energy is a more generalized and indirect concept, all processing and packaging materials and operations are dependent on some type of energy input. Thermal processing, discussed in detail elsewhere in this book, requires an enormous amount of heat input, and many food plants are not designed with large-scale energy use integration and savings in mind.

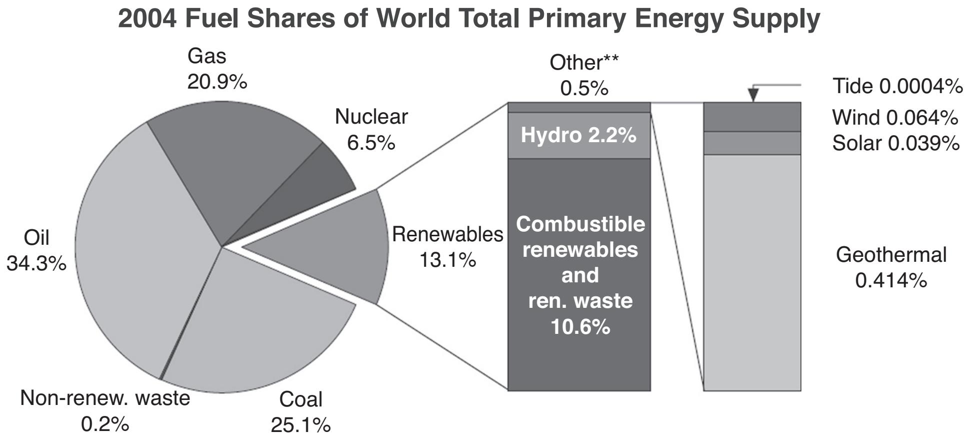

Figure 3.2. 2004 Fuel Shares of World Total Energy Supply
Source: Renewables in Global Energy Supply: An IEA Fact Sheet, ©2007, Figure 1, Page 3. Used with Permission

All too often, immediate cost factors, short-term profit goals, or a lack of basic understanding of the nature of energy consumption and use will hamper the efficiency of processing and packaging operations. Additionally, the energy content of a particular item may be as hard to quantify as its individual cost to manufacture in general. A meat product packed in a glass container and then thermally processed in a steam retort will have an enormous energy budget once one considers the energy contained in the food material – at the apex of the energy use triangle in agriculture – the energy content of the container, and the steam-based processing. Storage, distribution, and transportation costs will add another facet to the energy budget of the particular item, although all of them have alternatives and can be reduced [13].

Resource Outlook

The world consumption of energy was approximately 15 Terawatts in 2005, and is expected to continue to rise by nearly 60% by 2030, with the largest overall increase resulting from the economic expansion of China and India. Although many alternative energy sources are being touted, these contribute a very small component of the world's total energy budget.

As shown in Figure 3.2, 87% of the world's energy consumption in 2004 was from non-renewable resources (coal, oil, natural gas, and nuclear power), and this percentage is unlikely to change quickly, although it will increase over time because of price pressure from traditional fuels. Interestingly, these figures consider hydroelectricity to be a renewable resource when in fact dams and generating stations often have a finite life due to silting, and are subject to the effects of drought. Biofuels such as ethanol, although intermittently fashionable, have been the subject of debate questioning whether the net energy production of the synthetic fuels exceeds the net energy input to grow, harvest, and refine the materials. Other arguments center on the price increases in food resulting from the use of base food ingredient materials such as corn or vegetable oil as a fuel and escalating demand for those materials.

Marion Hubbert, mentioned previously in this chapter, argued that nuclear power would have to be extensively developed because of the finite nature of hydrocarbon power sources and the long-term sustainability of nuclear power production with known isotope reserves. This argument has some merit but, like many others, revolves around the presumed interchangeability of energy sources, which does not work in many practical applications. Although it is possible to convert a steam-generation facility from gas to electricity, the conversion of vehicles is much more difficult due to the inefficiency of current electrical storage devices and the high energy density of gasoline.

What is certain with regard to energy is that demand will remain strong, and that the technological changes that may be necessary to accommodate this are going to be difficult at best. In practical terms, there will be a premium both on energy efficiency and energy awareness in the food-processing and packaging industries, and the efficiencies of new types of processing such as aseptic thermal processing may play a much larger role in food preservation. Packaging, with materials fabricated from petrochemicals that are directly affected by energy prices and supply, or with energy-intensive materials that are subject to the whims of price fluctuation, will continue to be challenged to make better and more economical use of a smaller quantity of more expensive materials.

Additional Resources

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