Underground Storage Tanks: A History
Wayne Geyer, Steel Tank Institute
1999, Rev. 2015

The means to store hazardous liquids has changed considerably since the discovery of oil in Pennsylvania in 1859. Wooden barrels were replaced by riveted steel tanks and eventually, welded steel storage tanks. Codes in the U.S. to regulate flammable liquids, and standards for performance testing and construction, were developed in the first quarter of the 20th century.

As the use of motorized vehicles became the most common mode of transportation, storage tanks were installed underground for reasons of safety, convenience, and aesthetics. Around World War II, galvanized tanks were replaced by primed or asphalt painted tanks.

Between 1960 and 1970, the concern for lost inventory became a driving force to prevent underground steel storage tanks from corroding. Non-metallic tanks were developed. Shop-fabricated steel tanks were built with various forms of corrosion protection design through the use of plastic "baggies," thick f reinforced fiberglass coatings, and galvanic anodes in conjunction with coal tar epoxy coatings. Existing non-protected steel tanks were field-upgraded with internal linings and impressed current cathodic protection.

Between 1970 and 1990, a strong concern for the environment further advanced the technologies used to safely store hazardous liquids underground. Secondary containment became a desirable feature in tank design. Steel tanks were fabricated with a second wall of steel or with a non-metallic jacket made of FRP or HDPE. Thick urethane or FRP coated tanks without anodes, such as STI's sti-P3, became popular. Over a quarter million underground sti-P3 cathodic protected tanks were been installed in the U.S. alone 1969-99.

Today, the industry in North America has experienced a further revolutionary change. Tank owners and operators in the non-service station sector are installing their liquid storage systems above grade. As the influence of fire safety and environmental code officials continues in the U.S. and Canada, secondary contained and fire resistant aboveground storage tanks have become very popular.

1. PAST

The American experience of using steel tanks to store petroleum and chemicals represents a microcosm of the efforts in many nations. The story of that experience covers the earliest days of discovering how oil could change society for the better, through more recent times as environmental awareness and public-safety concerns have shown the compelling need to store the energy source safely.

Travel back in time 1859 near Titusville, Pennsylvania, the small town where on an August day, America's first oil-well gusher erupted. Daniel Yergin, author of The Prize, a book that chronicles the history of the oil industry, reports that the locals in Titusville rushed tubs, wash basins and whiskey barrels into use to contain the "black gold."

As the Industrial Age discovered more and more uses for petroleum, oil companies had to find the most effective ways to store the energy source. In the oil industry's earliest days, wooden barrels served as storage vessels. But petroleum producers and sellers soon realized that they needed a reliable, long-term, larger-capacity solution.

During the last two decades of the 1800s, riveted steel tanks were developed to store petroleum – and, eventually, liquid chemical – products. Whether used aboveground or underground, the riveted tank became the standard for storage when the needed capacity was beyond a few barrels.

1.1 Standardizing tanks

The goal of standardizing tanks that held flammable and combustible liquids had great appeal to tank owners, manufacturers, fire officials and insurers in the U.S. Several organizations with a stake in the manufacture and use of tanks began to address oil-storage safety issues in the early 1900s.

An association of steel tank manufacturers -- which later would become the Steel Tank Institute (STI) -- was formed in 1916. Around the same time, a third-party testing laboratory, Underwriters Laboratories (UL), was developing its first safety standards for atmospheric steel storage tanks. UL is a testing agency specializing in certifying product safety through listing procedures.

In 1922, UL unveiled its first atmospheric aboveground steel storage tank standard, UL 142 Steel Aboveground Tanks for Flammable and Combustible Liquids. In 1925, the agency published the first edition of its UL 58 Standard for Steel Underground Tanks for Flammable and Combustible Liquids.

Another standard critical to the development of the storage tank industry preceded the UL developments. It was created by a group that developed and promoted industry consensus standards for protection of the public and firefighters from the hazards caused by fires.

Circa 1904, the National Board of Fire Underwriters published NBFU 30 which, as its title states, covered "Rules and Requirements for the Construction and Installation of Systems for Storing 250 Gallons or Less of Fluids Which at Ordinary Temperatures Give Off Inflammable Vapors, as Recommended by its Committee of Consulting Engineers."

NBFU's codes and standards over time became the responsibility of the National Fire Protection Association (NFPA), which modified the storage system standard's code designation to NFPA 30L (published in 1913). Today that standard is known as NFPA 30 Flammable and Combustible Liquids Code, a document that was first published in 1957. Many governmental bodies in the U.S. today reference the NFPA standard either by legislation, statutes or ordinances to give local or regional officials an enforceable code document. The NFPA code cites various construction standards written by UL and STI, among other groups, as acceptable construction practices.

As the use of petroleum products escalated, the producers of hydrocarbons and the companies that install tanks created their own associations. The American Petroleum Institute (API) was formed in 1919 and the Petroleum Equipment Institute (PEI) was founded in 1951. Both groups have developed several important tank system standards and guidelines that are widely respected in many countries.

1.2 Effects of urbanization, industrialization

As the automobile industry began to grow, petroleum marketers had to adapt their practices to enable mass distribution. Thus were born the first service stations in the U.S., facilities that required minimal storage tank capacity. Compared to modern stations that store thousands of gallons underground, it was common for petroleum product in the early 1900s to be stored within the dispenser itself.

Some fuel tanks were installed aboveground at gas stations, but many were installed below ground, for aesthetic purposes, particularly at public retail service stations.

As urban areas became densely populated – leading to increased numbers of vehicles on the road – underground tanks became a more popular choice for fuel and chemical storage. The burial of USTs freed business owners to use real estate for other, more productive purposes. From a public safety perspective, USTs eliminated concerns about vehicle collisions or other damage that could result in spilled fuel.

1.3 The advent of welding

In the "early days" of steel tank production in the U.S., riveting was the most common method of joining steel. Most tanks were small by today's standards, under 1,100 gallons (4,162 litres), though some were larger. During the 1920s and 1930s, arc welding replaced the riveting process for many steel fabricators, which led to higher quality tanks.

Galvanized steel sheet was often used in producing the tank. However, World War II created a shortage of galvanized product in the U.S. Recognizing the scarcity faced by fabricators, UL began to allow the manufacture of tanks from black carbon steel.

The basic cylindrical design remained virtually unchanged for decades. However, in the mid-1950s, product innovations began to surface. STI advocated placing the product line on the bottom of a heating oil tank to prevent any accumulation of water. This design breakthrough carried the water with the heating oil to the burner, which led to evaporation. And in 1956, STI issued its Midwest 56 Standard, a widely recognized approach to designing the size and location of openings along the top of an underground storage tank.

1.4 Progress in preventing corrosion

The control of corrosion on underground storage tanks in the U.S. has also relied heavily on standards development. During the last 30 years, in particular, tank fabricators have remarkably advanced the expected and actual service life of steel tanks.

1.4.1 Prior to mass concerns about corrosion

Manufacturers during the 1950s generally coated steel USTs with red lead primer or a thin asphaltum-based paint. Such coatings dependably prevented atmospheric corrosion; however, they were nearly useless for protection against corrosion in many underground environments. Some entrepreneurs created magnesium-anode design kits, but they met with no success in a market that knew little about corrosion.

The growth in motorized vehicles created more demand for service stations, which led to demand from petroleum marketers for greater capacity at each fueling site. By the early 1960s, the average atmospheric-tank size had increased to nearly 4,000 gallons (15,137 litres).

1.4.2 The dawn of anti-corrosion sentiment

The 1960s gave rise to a new material and new designs for underground flammable and combustible liquid tanks. The first design breakthrough was a non-metallic tank, made from fiber-reinforced plastic (FRP). Tank buyers hoped to avoid the inevitable problem with steel underground storage tanks releasing product due to corrosion. At that time, environmental concerns did not drive the new product's development. Foremost on the mind of petroleum marketers were inventory conservation and the cost to replace lost product. However, from the chemical industry's standpoint, the FRP matrix posed compatibility questions that in the vast majority of cases were resolved with the use of carbon or stainless steel designs. Structural integrity and compatibility were two of the biggest hurdles that FRP tank producers had to overcome.

Tank owners began to realize that three underground storage tank options were available: replacing the tanks, closing the business or fuel facility, or upgrading to improved technology.

Some owners tried to address corrosion through internal lining, which was first used around 1962 for aboveground heating oil tanks. The technology eventually was applied to USTs. The U.S. Environmental Protection Agency (EPA) in 1988 accepted lining as a method to complement corrosion control requirements. Regulators mandated inspections at least once every 10 years.

Many systems also were upgraded in situ with an impressed-current design featuring the installation of rectifiers and special anodes to protect complete bare steel systems.

The steel industry paid close attention to the efforts to produce a non-metallic tank, as did major oil producers. So steel tank makers responded with their own research efforts focused on methods to make steel tanks corrosion resistant.

1.4.3 The "baggie"

One effort that preceded the debut of the FRP tank was to install the steel tank in a plastic wrap or "baggie". One major oil company had installed a number of baggie systems in the state of Michigan as early as 1959. About 12 years later, steel tanks from this initiative were uncovered and found to be free of any corrosion. Preventing groundwater and corrosive-soil contact against the outer steel tank surface essentially eliminates a corrosion trigger.

During the next decade, the plastic baggie concept was commercialized for nationwide steel tank production. As of 1970, more than 1,000 plastic-wrap tanks had been installed. Although this concept had merit, the plastic was quite thin and prone to tearing. Installers and manufacturers also discovered the difficulty of assuring a long-term seal between the pieces of plastic.

The baggie had limitations, so STI developed a new approach – a standard for covering a steel tank with a thick FRP coating. The concept was simple. If a non-metallic tank could be installed to eliminate corrosion, why not coat the steel tank with that very same material?

1.4.4 The FRP coating

STI published the FRP laminate standard in 1968 and called it STI-LIFE. The standard actively existed for about five years, but fabricators stopped using it for the most part because of aesthetics and cost. The glass strands did not always lay flat and parallel to the steel. Equipment to produce the coating was relatively unsophisticated, unlike today's manufacturing processes in which the steel tank rotates while glass fibers and resin are sprayed onto the exterior.

Though the bulk of STI-LIFE fabricators dropped the product, several fabricators continued to make FRP-coated steel tanks. A different standard was developed in 1987 to represent this type of composite product. The new standard became known as ACT-100®, a tank that gained wide acceptance during the 1980s and 1990s because of a durable 100-mil coating applied through processes that eliminated the unsightly strands that plagued the STI-LIFE product. Each steel tank that combines glass and resin is tested in the factory with high-voltage holiday testers that will spark if any exposed steel is discovered.

1.4.5 The cathodic protection success

During the mid-1960s, the US Steel Company recognized the threat of new materials for tanks, which could undermine its interest in maintaining steel as the material of choice for storage applications. Faced with the non-metallic challenge, US Steel dedicated some personnel from its research center to corrosion control for underground storage tanks.

The researchers came up with a notion – pre-engineered protection against corrosion – that would change the UST industry. The steel tank industry's greatest success followed the US Steel research, which led to development of a cathodically protected underground storage tank known as sti-P_3®. In 1969, the Steel Tank Institute unveiled the sti-P_3® design, which consisted of three major elements: good dielectric coating of the outer shell, galvanic magnesium anodes, and electrical isolation of the tank from steel piping. The earliest coating was a coal-tar epoxy, which was significantly advanced from the industry's prior products of choice. In addition to US Steel, Dow Chemical helped to develop the sti-P_3® design with Kennedy Tank & Manufacturing Co. of Indianapolis, Indiana, an STI member.

There were a number of improvements in the sti-P_3® design during the '70s and '80s, including the development of urethane coatings and enhanced methods of applying FRP as an external corrosion barrier. Magnesium anodes, attached to the tank by wire, were virtually supplanted during that time by an innovative weld-on zinc anode design.

During those decades, STI also developed a national registration program. Manufacturers provided tank owners with a 30-year warranty against failure due to external corrosion. With the warranty came a strong quality assurance inspection program, which STI administers on behalf of licensed manufacturers. Inspectors arrive at a tank shop unannounced and at random to verify that the fabricator is meeting STI's requirements.

The success of sti-$P_3^®$ occurred while American attitudes about USTs were changing significantly.

1.4.6 Environmental and fire-safety awareness grows

Throughout the late 1970s, more and more media attention in the U.S. was focused on leaking underground storage tanks — heightening the tank industry's emphasis on environmental protection. Many efforts were focused on integrity testing of the tank, but tank-integrity testing was fairly new and had limited accuracy. Large leaks were easily noticed, but small microscopic leaks were difficult to spot. This resulted in record-keeping improvements for monitoring inventory. Many of the major oil companies began replacing their bare steel tanks with protected tank technology – cathodically protected steel and non-metallic FRP. In some cases, existing tanks were retrofitted with an internal lining or a field-installed, impressed-current cathodic protection system. However, no national standards existed for either approach.

By 1977, most members of the industry had become aware of leaking underground storage tanks. Fire codes, such as NFPA 30 and the Uniform Fire Code, introduced language into their respective codes mandating corrosion protection. But by current standards, fire codes in the late 1970s were lax. For instance, the codes said steel tanks could be cathodically protected, simply well-coated, or not protected from corrosion at all – each of the three instances dictated by the soil corrosivity for the site at which the tank would be installed.

During the 1970s and 1980s, the pre-engineered sti-$P_3^®$ approach became the leading steel underground storage tank built in America. Nearly 60 manufacturers across the nation were qualified and licensed to fabricate sti-$P_3^®$ tanks, which were visually distinguished in the marketplace by zinc or magnesium anodes most commonly attached to the heads of the tanks. The anodes provided low levels of electrical current that would prevent corrosion underground if the tank's coating should be slightly flawed or damaged during installation.

1.4.7 Tank system performance

The sti-$P_3^®$ system was designed to protection against external corrosion in virtually any soil environment, regardless of corrosivity levels. Did it work?

STI's registration database shows that more than 250,000 sti-$P_3^®$ tanks have been installed across America through 1999. The technology's performance has been nearly flawless, according to a 1993 report by Tillinghast, a U.S.-based risk-management consulting firm.

Tillinghast contacted tank owners and installers to develop a representative sample of sti-P_3® tanks in service. The firm's survey of tank owners "covered over 3,000 sti-P_3® tanks, and the survey of tank installers covered over 5,000 sti-P_3® installations," the report said. "Of the 8,000-plus sti-P_3® tanks, three instances of external corrosion were reported, representing a frequency of 0.04 percent. Only one of the three instances involved a product release."

1.4.8 Regulatory setback

Despite this remarkable record of performance, the sti-P_3® tank suffered in the marketplace after federal regulators in 1988 announced the technical requirements for UST systems.

To address a regulatory mandate for periodic monitoring of cathodic protection, STI in 1988 developed the Watchdog program, which provided monitoring services to owners of registered sti-P_3® tanks. Watchdog technicians gathered the readings at tank sites using a voltmeter and a copper/copper sulfate reference electrode. The information was stored in hand-held computers that eventually were used to transfer test results to a central database. Watchdog program participants received reports of cathodic protection readings for their files.

Prior to the Watchdog program, sti-P_3® tank owners had been able to perform cathodic protection monitoring with pre-engineered monitoring stations known as Protection Prover 1 (PP1) and PP2. After the Watchdog program, an improved model, the PP4 terminal, debuted on sti-P_3® tanks in the early 1990s.

Through 1999, more than 90,000 Watchdog tests have been performed for STI by cathodic protection testers who have used the PP1, PP2 or PP4 monitoring stations.

1.5 The demand for secondary containment

Mass production of dual-walled steel tanks was rare during the 1970's and the early 1980's. However, the tank-manufacturing industry sensed that a growing number of customers were searching for enhanced environmental protection.

In 1983, the Steel Tank Institute formed a special strategic planning committee to address several concerns with underground storage tanks, including secondary containment. The regulatory landscape was changing. Government officials were starting to develop UST requirements for secondary containment.

At that time, most double-wall tank designs provided 110% containment of the primary tank, which required channel or angle iron to separate the primary and secondary vessels. Each steel tank was independent — capable structurally of standing by itself. STI discovered that German tank makers were already building to a double-wall design under a markedly different approach. STI members visited Europe and learned from the German experience, which led to STI's publication in 1984 of America's first secondary containment standard.

STI's standard provides for an outer wall of steel to be intimately wrapped over the primary tank. The external wall can be a thinner gauge of steel. Due to the intimate wrap, the two walls act as a single structural unit, reducing the costs to build the tank. By adding an interstitial monitoring port, the owner can detect leaks either manually or with special continuous monitoring equipment. This design enabled new technology to evolve. Electronic and mechanical means to detect liquids followed. STI members verified that the intimate wrap did not inhibit product or water introduced into the interstice from finding its way to the monitoring port.

1.6 Federal and state regulations

By 1982, many local, state and county officials were addressing the growing problem of leaking underground storage tanks through enactment of regulations. In 1984, the U.S. Congress approved a law to regulate underground storage tanks. By that time, media attention was reaching a peak

The congressional action led to development of a federal regulatory program. The federal government's technical requirements called for corrosion protection for tanks and piping, structural integrity, release detection, proper installation, corrective action, and secondary containment for the storage and handling of hazardous materials other than petroleum products.

A key facet of the regulation was how the Environmental Protection Agency enabled new technology to become accepted, which was important because new approaches to UST systems were surfacing rapidly. Speeding the advent of new tank system technologies was the emergence of smaller, faster, and more powerful computers that provided new automated solutions, especially in leak detection and inventory control. The tank and pipe industry also bred new technological approaches, such as jacketed steel tanks and flexible piping.

A jacketed tank is an outer, non-metallic containment for a steel tank that also provides corrosion protection. The most prominent materials developed for secondary containment have been high-density polyethylene and fiber-reinforced plastic. Typically, these systems were shipped from the factory with a vacuum between the walls of the tank. The jacketed steel tank offered several advantages – lighter weight than a tank with two walls of steel, and a lower cost. Flexible piping, produced with a combination of chemically resistant plastic and elastomer, attached to UST systems and eliminated leaks that traditionally occurred from loose elbows and fittings on steel pipe.

Another noteworthy construction feature emerged as the EPA regulations gained prominence. Sumps and boxes were placed above the tank and under the dispenser to catch releases from fittings and maintenance activities. In 1986, the Steel Tank Institute was the first organization to develop a national sump design standard, known simply enough as STI-86. This concept was designed to allow all fittings and important tank appurtenances to be clustered in one spot with the protection of secondary containment. This included the submersible turbine pump, vapor-recovery equipment, gauges, and fill openings. The sump container was made from steel, and would "catch" any releases from the enclosed equipment. In addition, secondary containment pipe would terminate in the sump, where sensors would be mounted to detect releases from piping as well. STI-86 paved the way for a wave of tank-industry innovation. Within a few years, STI-86 became obsolete, replaced by comparatively lightweight polyethylene sump containers.

2. PRESENT

2.1 A federal regulatory deadline

The U.S. regulatory program spurred significant changes in the tank industry. As noted above, the last decade witnessed the emergence of many new UST system technologies and trends. Manufacturers and system designers trotted out UST enhancements in advance of the December 22, 1998, EPA deadline for upgrading underground tank systems.

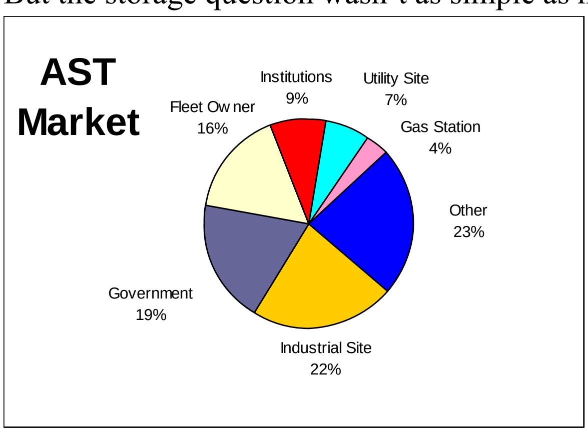
Many small service station operators used the EPA deadline as a reason to sell or shutter their fueling facilities. However, some tank owners embraced the new designs because their businesses were committed to the use of underground storage for the long haul. And increasing numbers of tank owners revisited the question of why petroleum and chemicals had to be stored underground.

The 1990's unexpectedly unveiled a completely new trend – extraordinary demand for aboveground storage tanks. Because of the negative headlines associated with expensive UST cleanups, including contaminated soils and water resources, tank owners began to think seriously about the advantages and disadvantages of owning an underground tank system. Many elected to close their tanks. For those who needed tanks for fueling fleet vehicles, many began sending their drivers to a nearby retail service station.

2.2 AST's market impact

Tank-system owners began to study the advantages of an aboveground tank system. First, the owner/operator could see all of the tank's surfaces. There was no need to depend on other equipment or contractors to verify that a tank system was free from releases. Visual release detection pleases many tank operators because it is simple, cheap, convenient, and trustworthy. Second, the owner/operator did not have to meet the financial responsibility requirements of regulated UST systems. Third, the owner/operator didn't have to worry about regulated, expensive soil clean-ups, which seemed to be constantly in the public eye via local and national headlines. Finally, many owner/operators felt that aboveground tank systems were cheaper to install and less regulated (though that perception was often flawed). The new era of aboveground tanks was about to change the market (Figure 1).

But the storage question wasn't as simple as how to switch from underground to aboveground. Many local jurisdictions in the U.S. did not allow aboveground fueling systems. They followed various national fire codes that imposed severe restrictions upon ASTs, or simply prohibited fuel storage aboveground for dispensing into motor vehicles.



Nevertheless, fleet owners and industrial firms saw tremendous benefit from owning ASTs, as described above. The typical owner of a public-accessible retail service station continued to prefer underground storage tanks (as did most fire inspectors) over often-unsightly and potentially unsafe aboveground tanks.

2.3 Fire code revisions and harmonization during the '90s

With the suddenly strong demand for aboveground tanks in the U.S., the codes needed to find a way to allow the safe siting of aboveground fueling facilities at service stations.

Major provisions were added to codes in the early 1990's, such as allowing:

- An aboveground tank to be installed inside a concrete vault, whether the vault was located above or below grade.
- Other tanks to be installed aboveground, including traditional UL 142 tanks, and another new technology, fire-resistant tanks.
- Protected tanks that had to prevent an internal tank temperature increase of more than 260° F (127° C) when the structure was exposed to a 2,000° F (1093 ° C) two-hour fire – and had to have features that resisted impacts from vehicle collisions and bullets
- Fire-resistant tanks with construction that would prevent:
    - Release of liquids
    - Failure of the supporting structure
    - Impairment of venting for a period of not less than two hours when tested by a fire exposure that simulates a high intensity pool fire

As the fire codes proposed new language, environmental regulators also examined what would constitute safe operation of ASTs. One federal proposal, for example, called for ASTs to employ containment that would be impermeable for 72 hours. As such ideas surfaced for the first time, the shop-fabricated AST market saw a major change in customer demand. Specifiers were asking for steel dikes (or tubs) within which a tank would be installed. Steel, an impermeable material, certainly met the requirements of the federal proposal, but demand for integral double-wall ASTs also was growing.

By 1997, STI had developed a statistically valid database of insulated protected tanks and double wall F921 tanks. The insulated tank was called Fireguard®, the specification for which was published in 1994. STI's data showed that fewer than four percent of these ASTs were installed at public retail service station facilities. Private fleet facilities were the primary and dominant users of aboveground tanks for fueling vehicles. Nearly two-thirds of stored-product applications were for less flammable Class II or III liquids, such as diesel, kerosene or lube oils.

3. FUTURE

3.1 The case for compartment tanks

As of 1999, more and more specifiers in the U.S. are calling for compartment tanks as a storage solution. Compartmentalized designs, whether double-wall or single-wall, often provide dramatic savings to the tank owner. If a tank system needs to hold 20,000 gallons (75,686 litres) of three different products, it's considerably less expensive to build and install one tank divided into three compartments than three USTs with the same aggregate capacity. This reduces costs by requiring only one secondary containment and one interstitial monitoring device, while substantially decreasing excavation costs. The compartmentalized trend has also carried over to the aboveground storage tank market.

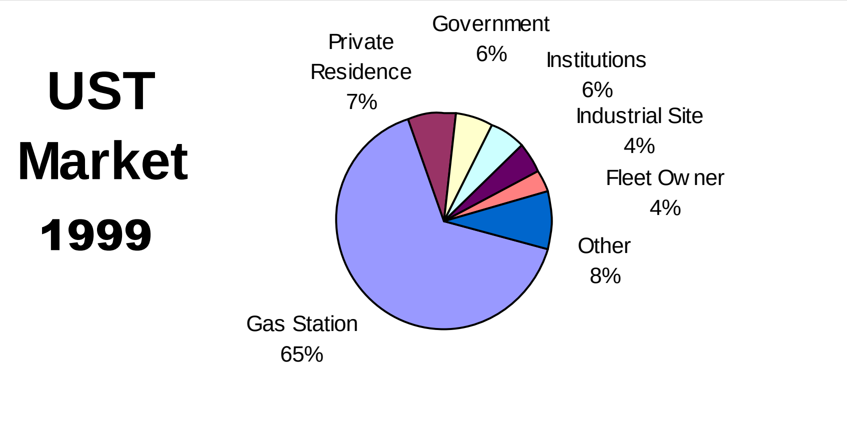


Figure 2 Source: Steel Tank Institute

3.2 Maintenance remains critical

The proper installation of an underground or aboveground storage tank to meet code and regulatory requirements has been clearly defined by industry groups and manufacturers. However, to assure efficient and safe long-term operations, a proper AST maintenance program is essential. Tank operators must remove water from dikes (when applicable) and tanks on a regular basis. Storage systems will work best if subjected to a regular inspection plan for each component. It's best to repaint steel structures and repair concrete components to assure containment. For underground tanks with cathodic protection, periodic monitoring of the corrosion-protection system is required by regulation in the U.S.

3.3 Fewer USTs, but more secondary containment systems

From 1988 to 1998, the underground tank population in the United States fell by more than 60 percent. The number of retail service stations also dropped dramatically from over 207,000 in 1992 to fewer than 183,000 in 1998. The EPA regulation's impact has put many old single-wall tanks out of commission. It also changed significantly the mix of UST end users (Figure 2). And it has opened the market's eyes to the need for aggressive action to prevent contamination of soil or drinking-water supplies. Underground or aboveground, specifiers increasingly are calling for storage systems that provide secondary containment to control leaks.

3.4 Ongoing change

Despite the many significant changes in prominent national codes, especially regarding ASTs, new proposals surface every year. STI expects more revisions as regulators monitor the safety performance of AST systems within their communities. The market-driven developments 1970-1999 in the U.S. have redefined the industries that for decades made – and used – tanks the same way, day after day. Looking back and looking forward, it's clear that we've come a long way from the whiskey barrels and wash basins of Titusville, but improvements are still on the horizon.