Many gas utilities worldwide are realizing that new piping technologies can improve their market for natural gas. Development of a corrugated stainless steel tubing system in Japan during the 1980s; the introduction of 5 psi nylon tubing systems in New Zealand; and the use of 2 psi copper tubing systems in the United States are all examples of changing trends in interior gas distribution. The impending widespread use of automation technology also clearly indicates that the blind acceptance of low pressure steel pipe technology for gas distribution must be rethought. The objective of the research was to develop and evaluate new concepts not only for gas piping hardware, but also for the way in which gas is distributed and used within residential and commercial buildings.

There are many technical, economic, and institutional issues affecting the usage of new gas piping technology, and how natural gas can and will be distributed as we head into the 21st century. The MULTIFLEX Method is a unique vision of gas distribution which describes the gas piping system as a gas energy distribution network. When gas tubing is combined with quick connect gas outlets, many analogies can be made between the MULTIFLEX Method and the way electrical energy is distributed. Gas Research Institute has sponsored an extensive field evaluation program for innovative piping for residential and commercial building applications, including the rehabilitation market. The results clearly show that semirigid tubing operated at elevated pressures is more cost-effective than traditional low pressure steel pipe systems. The marriage of the gas piping network with electronic surveillance and the impact of "smart" technology on the installation and design of advanced nonmetallic piping hardware will also change the way natural gas is utilized in the future.

INTRODUCTION

The inevitable advance of technology will surely affect everything we now know about building construction, energy distribution and utilization. However, throughout the 20th century, natural gas distribution inside residential and commercial buildings has pretty much avoided the general advance in construction technology. The standard Schedule 40 steel pipe used to distribute natural gas today is the identical approach used at the turn of the century. This persistent dedication to a single approach has occurred despite all the technological advances in piping materials and construction practices over the last 30 years. Unfortunately, this has contributed to a significantly lower use of natural gas in multifamily and commercial buildings as compared to the single family market.

The difficulty and cost of installing the rigid steel pipe has been noted as one of the major reasons for the lower usage of natural gas in the multifamily
and commercial markets. This cost can make gas energy systems less competitive on a first cost basis compared to electric systems. This is especially critical in the minds of many builders who want to maximize their "bottom line." The installation cost of rigid piping systems also tends to rise disproportionately faster as the complexity of the piping installation increases, and as more gas appliances are connected to the system. This has led to a tendency to minimize the size of the gas distribution system, which consequently reduces the potential number of gas appliances and the gas load per household.

The availability of alternative interior gas piping systems, which are safe and reliable, gives the construction industry new choice options. The industry can choose to continue to install conventional low pressure rigid steel pipe technology or to embrace newer approaches using elevated system pressure and semirigid tubing. The newer approaches have been shown not only to be more cost-effective than steel pipe in many applications, but also hold promise for easy future expansion of the gas distribution system. Innovative gas piping systems will help continue to secure not only the traditional residential baseline gas load of space and water heating, but also provide the ability to capture the other smaller gas loads. These loads include cooking, clothes drying and other specialty uses which are traditionally lost to electricity.

**SYSTEM FEATURES**

**Tubing Hardware - Current**

The use of semirigid tubing for natural and LP gas distribution within residential and commercial buildings has been going on for many years. Up to recent years, the tubing used was exclusively copper. In 1988, corrugated stainless steel tubing was introduced to the U.S. plumbing industry. Copper tubing used for gas distribution is either conventional type "L" or "K," assembled with either 45 deg flare type fittings or silver brazed joints. The corrugated stainless steel tubing, which is AGA certified, is manufactured in both the United States and in Japan. It is supplied in coils, typically 30 m in length. The tubing is currently manufactured in different sizes, including 8, 10, 15, 20 and 25 mm diameters. Special mechanical fittings are provided to interconnect the tubing with other components within the overall gas piping system. There are currently three suppliers of this product, each with slight variations in the tubing size, shape and fitting design.

**Tubing Hardware - Advanced**

The search for viable, alternative tubing products, suitable for natural gas applications, has led to research in three unique product areas:

**Modified Copper Tubing.** Industry concern over the potential of copper to corrode on the presence of hydrogen sulfide has led to the evaluation of modified copper tubing concepts. Under investigation are three concepts: an improved metallic lining (tin) for copper tubing; a polymeric lining for copper tubing; and a corrosion resistant copper-based alloy tubing.

**Composite Tubing.** Using a thinwall aluminum tube as a center core, this product is designed as a sandwich arrangement. The aluminum tube is surrounded, both internally and externally, by a polymer (PE) jacket. Two commercially available products (MEPLA pipe and Kitec tubing) are undergoing laboratory evaluation. The driving issue for this approach is the cost of the metallic tubing alternatives. The cost of both copper and the corrugated stainless steel is much higher than the cost of the composite tubing, thus making this approach more cost-effective, on a first cost basis.

**Nonmetallic Tubing.** In an attempt to reduce product and installation cost further, nonmetallic tubing is being evaluated. Precedent has already been set for this approach. A 5 psi, small diameter nylon tubing system, with "push-on" fittings, is being evaluated in New Zealand, on an experimental basis. Industry concerns about fire resistance and hardware robustness have been raised. However, the introduction of home automation, like the SMART HOUSE, promise the availability of full-time surveillance subsystems for such hazards as fire, natural gas and smoke. Under such circumstances,
the robustness of the tubing carrying natural gas may be less of a concern.

System Pressure and Arrangements

Most fuel gas codes allow some variability in the choice of operating pressure. Traditionally, the use of 1/2 psig system pressure has dominated U.S. practice. However, there are several areas where 2 psig systems are used, in which the entire system is essentially pressurized at 2 lb. Only at the appliance, where a pressure regulator is utilized, is the system pressure lowered to less than 1/2 psig. Other single pressure systems are possible up to 5 psig. A 1 psig system may be quite practical for some installations. Ultimately, the choice of pressure depends on several factors, including: availability of pressure in street, installed cost, local gas code/building standards restrictions, gas load, delivery distance, and building appliance configuration.

When using elevated system pressure, it is recommended that the system be subdivided into two parts, and a dual or hybrid pressure approach used to size the tubing runs. Elevated pressure is used to deliver the total required load from the meter to a distribution point centrally located within the structure. Downstream of this point, a 1/2 psig pressure system is utilized.

Using Figure 1 as a reference, the system can be described as follows:

- Gas is delivered to the building at street pressure, where a service regulator drops the pressure to 2 psi.
- The entire household gas load is then delivered through a single small diameter line to a centrally located distribution point where a shutoff valve, pressure regulator, and distribution manifold are located.
- The line pressure is reduced from 2 psi to 8 in. W.C. or lower per local requirements.
- The gas is then redistributed, at low pressure, through relatively short, independent parallel lines to each appliance. The tubing is connected to the appliance according to local practice (shutoff valve and drip leg, stub out and flexible appliance connector, or directly to the control valve).

Since each gas appliance is serviced by a dedicated line, the line can be much smaller than in a traditional series system. The hybrid approach fixes the gas load and line loss between the appliance and the manifold. Thus, the line can be sized for only one set of operating conditions. In the traditional series approach, both the line flow and line losses are variable for most appliance runs, since many lines (in a series system) service more than one appliance. This requires that line sizing be based on the maximum possible gas flow which results in larger pipe diameters.

Gas Outlets

In the future, gas appliances may be connected using a version of a convenience outlet available in Japan. Figure 2 shows a quick-connect gas outlet that is used with portable gas appliances. These outlets are designed with consumer safety and convenience in mind. The gas can be turned on only after the "plug" is inserted and locked into place. A separate on-off valve must be manipulated to start gas flow. Once gas flow is initiated, the plug cannot be removed unless the valve is first turned off and a release bar is depressed. If there is a break in the appliance connector, an excess flow/check valve, which is built into the outlet, is activated. Further use of the outlet is prevented until the problem is corrected, which requires that the outlet be turned off. Currently, two prototype gas outlets are under development in the United States, with market introduction scheduled for 1991.
Retrofitting semirigid tubing runs onto existing steel pipe systems may also be viable, assuming there is sufficient excess capacity available to safely operate the new line. Pipe tapping hardware have been developed for other industrial applications, but have not been proposed for interior use in the United States. An approach used in Japan has been evaluated by Foster-Miller in a field test in Canada. The device, shown in Figure 3, does have an elastomeric seal which is of concern regarding long-term reliability. There are minimum size requirements for the tapped pipe, and for the removal of steel chips generated during the tapping operation. The results of the evaluation indicate the need for improvements in overall reliability and ease of installation before this method can be widely used in the United States.

**FIELD EVALUATIONS**

Extensive field assessments of alternative tubing/piping systems and installation practices have been completed. The field tests included time and material studies in several different single family, multifamily and commercial buildings, including both new construction, retrofitting and rehabilitation. In all test buildings, both low pressure steel pipe and hybrid pressure copper and corrugated tubing systems were designed and installed. The data were analyzed for both installation labor (man-hours) and total cost (labor plus materials). The results, summarized in Table 1, have been calculated using a labor rate and material prices which have been found to reflect average costs in the United States (Torbin and Belkus 1988; Torbin et al. 1988; ACEC/Foster-Miller 1988).

Results from the research clearly indicate that semirigid tubing systems operated at elevated pressure are both safe and reliable, and can be installed for less cost than conventional low pressure steel piping systems. The tubing systems are easier to install for new construction. The ease of installation is especially important for rehabilitation projects. Many variations exist for the choice of system hardware, design approach, arrangement and installation practices.
Table 1. Results from Piping Field Tests Installation Labor and Cost Comparison*

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Percent Average Labor Savings Over Steel Pipe</th>
<th>Percent Average Cost Savings Over Steel Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINGLE FAMILY (All Types):†</td>
<td>30-50</td>
<td>15-40</td>
</tr>
<tr>
<td>Detached/Attached</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood Frame/New Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MULTIFAMILY LOW-RISE:‡‡</td>
<td>10-70</td>
<td>10-40</td>
</tr>
<tr>
<td>Wood Frame/New Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MULTIFAMILY HIGH-RISE:‡‡</td>
<td>40-65</td>
<td>30-40</td>
</tr>
<tr>
<td>Concrete &amp; Steel Frame/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MULTIFAMILY REHAB:‡‡</td>
<td>70-80</td>
<td>50-60</td>
</tr>
<tr>
<td>LIGHT COMMERCIAL BUILDINGS:‡‡‡</td>
<td>40-80</td>
<td>30-60</td>
</tr>
<tr>
<td>(All Types)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Copper/corrugated stainless steel tubing versus Schedule 40 steel pipe

†Reference 1
‡‡Reference 2
‡‡‡Reference 3

INSTITUTIONAL CONSTRAINTS

The use of 2 psig service and semirigid tubing for residential applications will be accompanied by uncertainties and concerns about safety. Some of these concerns are founded on the unfamiliarity of utilities with this approach; some are economic in nature (such as meter-regulator changes); some are institutional barriers (when dealing with code and local inspection officials); and some concerns are related with the use of new gas piping hardware. Extensive utility experience with 2 psig service and copper tubing in some areas of the United States, and the results of field and laboratory studies clearly indicate the viability of the 2 psig approach. However, it may just take time and continued exposure to the benefits of 2 psig residential service and semirigid tubing before this concept is fully accepted by the gas construction and industries. Regardless, there are some obstacles and pre-existing conditions which will restrict the universal use of this approach:

- Availability of high pressure in the distribution main
- Changeover of gas meters and service regulators
- Use of intermediate line regulators inside the house
- Limitations of conventional appliance control valves
- Gas utility restrictions
- Code change process
- Product certification/standards.
INTERIOR GAS DISTRIBUTION
CONCEPTS

Multiflex Approach

As single family house prices continue to escalate, many families are choosing to remodel their existing homes rather than buying larger houses. One of the distinct advantages of the household electric power network is its expandability, its ability to adapt and grow as the household demands change. One never thinks about this unique feature of the power network. We can always add an air conditioner, increase the number of lighting fixtures, extend heating to the new family room, etc. In comparison, the gas distribution network is always thought of as fixed. Once installed, it is usually never altered. What is taken for granted with power systems has never been a part of the gas system: namely, future adaptability at little or no cost. The use of semirigid tubing and the hybrid pressure system can change this shortcoming.

The MULTIFLEX Method provides three critical characteristics necessary in adaptive systems:

- Expandability
- Accessibility
- Adaptability.

Expandability. A builder would never think to wire a house with only the power level necessary to operate the as-built services. The main electric service is always sized with excess amperage for future add-ons. And yet, the gas piping is typically sized only for the as-built load.

The design of the hybrid pressure system can easily accommodate, at little or no extra cost, an excess capacity factor. Because gas will be delivered at 2 psi, the inlet line can comfortably provide gas loads far in excess of traditional requirements. In most single family applications, excess capacity of 30 to 50 percent over maximum as-built load is provided with the same size tubing as would otherwise be installed. Even with excess capacity designed into the system from the start, the 2 psi sized tubing will still be significantly smaller than a low pressure steel pipe sized for the as-built load.

Within limits, the electric power system has always been expandable. New electric lines can be added because extra slots were provided for new service back at the breaker panel. The hybrid pressure arrangement utilizes a similar "panel" in the use of a multiport manifold. Extra ports can easily be provided (as shown in Figure 4), allowing for future retrofits without any rework to the piping system. The number of spare ports can be varied, predetermined before initial system design and installation, depending on a number of factors such as size of house, type of housing unit (owner occupied versus rental), and life-style of the expected occupants.

In the future, the gas tubing system installation could also be enhanced by providing chaseways within the housing structure. These chaseways would provide both a streamlined method for running the tube within the house (for both initial and retrofit installations) and also provide additional protection from any mechanical hazards. Depending on the style of the house, horizontal channels along the top of the concrete foundation and vertical pathways between the lower and the upper floors are ideal locations for chaseways. In most cases, these chaseways can be provided with no extra cost to the

Figure 4. Low Pressure Gas Manifold Located Inside Enclosure
builder, provided it has been incorporated in the house design from the beginning.

Another important concept is the installation of service in areas not currently requiring it. It is less expensive to pre-wire and pre-plumb an area of the home while it is under construction, than to retrofit the service after the home is completed. In many cases, only a furnace and water heater are installed initially in a new house (especially in multifamily structures). This makes the eventual upgrading of an electric stove and/or dryer to gas not only more expensive, but less likely as well. However, if the kitchen and laundry have been pre-piped, then only a flexible appliance connector would be required when replacing electric appliances with gas ones. Pre-piping keeps future gas load expansion viable, especially in rental units where they are not owner-occupied. The cost of the pre-piping must be kept low to encourage plumbing contractors/builders to accept this concept upon its introduction.

Accessibility. Because the power distribution system is decentralized in most homes, a central control panel provides a convenient place where all internal power lines originate. Circuit breakers provide a convenient way to isolate each appliance or power zone within this decentralized system without interfering with other system loads. In addition, this is where the main shutoff is also located. The hybrid pressure approach provides the same capabilities for the decentralized gas distribution system.

A single "control panel" (multiport manifold station) includes a main service shutoff (upstream of the line regulator), the multiport manifold and the equivalent of the circuit breaker in the form of individual appliance line shutoff valves (see Figure 5). By locating the appliance shutoff valves at the manifold, redundant shutoff valves at each appliance could be eliminated. There are many good reasons for locating these valves at the manifold. In many cases, these valves are not accessible at the appliance (such as the range/oven). If there is a hazardous appliance malfunction, it may be dangerous to approach the appliance shutoff valve. By locating the manifold station in an easily accessible spot, one can both facilitate system safety and convenience. The manifold station can be mounted inside an enclosure as shown in Figure 4 or on a mounting board as shown in Figure 6. The manifold station can be located in a number of convenient places such as in a basement, garage or utility closet.

Adaptability. It is common with electric service to add on new power lines after the home is built and occupied. Since most power cable is flexible, like ROMEX, it can be easily snaked through hollow partition walls and pulled to a new electric appliance or convenience outlet. The new service can be wired in a parallel or series fashion to the existing system. The use of semirigid tubing and the hybrid pressure approach can also provide this feature for the gas distribution system.

Semirigid tubing (especially the corrugated tubing) can also be easily snaked through partition walls after the house has been completed. Connecting one end to a spare manifold port, individual lines can be run to new gas appliances anywhere in the structure. Furthermore, if there is adequate capacity, an existing appliance line could be spliced, and an extension line added to accommodate the new load.

Other future system improvements involve alternative distribution arrangements, which depend, in part, on the successful introduction of the MULTIFLEX approach. These include the use of multiple pressure zones within a single housing unit. As more and more gas appliances are utilized, it may be appropriate to segregate the overall household gas load into separate low and elevated...
pressure zones (Figure 7). In the future, it may become common to have appliances that require elevated pressure for combustion, thus eliminating the need for intermediate line regulators. With higher pressures, one may also find that a combination of parallel tubing runs, with some runs having multiple branches (daisy chaining), becomes practical from both a technical and cost point of view.

SMART House Approach

The "brains" of SMART HOUSE are located in the service center, the central element of the core system. Utility power and gas, telephone and TV enter SMART HOUSE at the service center and are distributed from it either to the convenience centers or gas outlets or directly to fixed-in-place appliances. Combining the innovations of semirigid tubing, gas outlets and electronic control communications, the SMART HOUSE gas distribution subsystem offers increased gas service combined with enhanced levels of energy safety. The gas subsystem comprises a whole-house shutoff valve, branch controllers, flexible gas piping, quick-connect outlets, and combination sensors (1 per floor). The gas subsystem operates using the UPS power in order to maintain gas service in the event of utility power outage.

Figure 7. Multiple Pressure Zones

Gas Subsystem Design. The gas distribution subsystem is laid out in a branch/home-run configuration. Figure 8 shows the layout for a typical system. The gas service on entering the house is equipped with a whole-house shutoff valve which consists of an automatic gas valve with a communication connection to the switch/sensor cable. This component serves to interrupt gas service to the house in case of specified problem conditions and at homeowner request.

From there, the gas service is divided in the branch controllers, which consist of a 6-port manifold with a flow sensor (proof-of-flow device) in each port. The branch controllers perform the important function of leak monitoring. They also contain the necessary brains (circuitry) to correlate flow information from the flow sensor in each port and transmit this to the SMART HOUSE system via the switch/sensor cable. From each port in the branch controller there is a direct run (home-run) of flexible gas tubing to the gas outlet in the case of portable appliances, and to the appliance in the case of fixed-in-place units.

The SMART HOUSE gas outlets combine an automatic gas valve with an easy connect/disconnect receptacle and control communication circuitry. This receptacle design enables easy connection of gas appliances by the homeowner without the need for specialized tools for making gastight connections. The electronic features result in enhanced level of safety by making gas available only when a valid request is received from a properly connected
appliance. At all other times, no gas is available from the outlet due to the automatic valve being closed.

The control communications connection is integrated with the gas receptacle and similarly, the appropriate conductors are integrated with the appliance connector piping. This permits making a single connection to access both gas and communications by the appliance. This should make connecting a gas appliance as easy as plugging in a toaster.

In addition to the flow sensors in the branch controller, the system also uses a combination sensor (fuel gas sensor with optional sensors for smoke, CO, etc.) as a backup device for leak monitoring. The flow sensors in the branch controller monitor for leaks in the distribution system and the combination sensor for any leaks in the living space. Historically, occurrences of gas system leaks are very rare. If such leaks were to occur, however, the SMART HOUSE gas subsystem has provisions for monitoring them, which will result in enhanced levels of safety.

Closed-Loop Energy. To enhance energy system safety, SMART HOUSE energy distribution systems are of closed-loop design. Energy (electric or gas) is provided to an appliance only when a valid energy request signal is received from an attached appliance. Receptacles are dead at all other times to reduce shock hazard in the case of electrical outlets, and to reduce the possibility of gas leaks in the case of gas outlets. The SMART HOUSE convenience center continually monitors the status of attached smart products and de-energizes the outlet if the energy request signal is lost (indicating a possible malfunction or other problem).

CONCLUSIONS

The introduction of semirigid gas tubing systems using elevated system pressures and a hybrid approach represents a new approach in interior gas piping technology. This combination of hardware and features will provide enhanced use options to the home builder and owner. This will make gas more competitive compared to electricity and provide the consumer with new uses for natural gas not currently available with low pressure steel piping systems. The new gas piping approach provides an open-ended structure for the supply and distribution of gas that is expandable, accessible and adaptable to future growth in consumer demand and gas appliance technology.

The advent of house automation systems, like SMART HOUSE, will require flexibility in both the gas and electric energy systems. The availability of full-time surveillance subsystems may allow the use of less expensive, nonmetallic tubing systems. This will make the gas tubing system less expensive to install and keep it competitive with electric wiring, which will also be affected by SMART technology.

REFERENCES
