Additional Slides

Prepared for Tanzania Partnership

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- These slides have more detail on various aspects of the US Natural Gas System
  - Processing
  - Transmission
  - Distribution, and
  - Storage

The Natural Gas Gathering System

- A natural gas pipeline system begins at a natural gas producing well or field.
  - In the producing area many of the pipeline systems are primarily involved in "gathering" operations.
  - That is, a pipeline is connected to a producing well, converging with pipes from other wells where the natural gas stream may be subjected to an extraction process to remove water and other impurities if needed.
  - Natural gas exiting the production field is usually referred to as "wet" natural gas if it still contain significant amounts of hydrocarbon liquids and contaminants.
- At this stage it is a mixture of methane and other hydrocarbons, as well as some non-hydrocarbons, existing in the gaseous phase or in a solution with crude oil.
- The principal hydrocarbons normally contained in the natural gas mixture are methane, ethane, propane, butane, and pentane.
- Typical non-hydrocarbon gases that may be present in reservoir natural gas are water vapor, carbon dioxide, helium, hydrogen sulfide, and nitrogen.

Pentane

- **Pentane** is an organic compound with the formula C_5H_{12} — that is, an alkaline with five carbon atoms.
- Pentanes are components of some fuels and are employed as specialty solvents in the laboratory. Their properties are very similar to those of butanes and hexanes.
- Pentanes are some of the primary blowing agents used in the production of polystyrene foam and other foams. Usually, a mixture of n-, i-, and increasingly cyclopentane is used for this purpose.
- Because of its low boiling point, low cost, and relative safety, pentane is used as a working medium in geothermal power stations. It is added into some refrigerant blends as well.
- **Laboratory use -** Pentanes are relatively inexpensive and are often used in the laboratory as solvents that can be conveniently evaporated.

The Natural Gas Gathering System

- In proximity to the well are facilities that produce what is referred to as "lease condensate“:
  - That is, a mixture consisting primarily of pentanes and heavier hydrocarbons which is recovered as a liquid from natural gas.
  - Other natural gas liquids, such as butane and propane, are recovered at downstream natural gas processing plants or facilities
- Once it leaves the producing area, a pipeline system directs flow either to a natural gas processing plant or directly to the mainline transmission grid.
- Non-associated natural gas, that is, natural gas that is not in contact with significant quantities of crude oil in the reservoir, is sometimes of pipeline quality after undergoing a decontamination process in the production area, and does not need to flow through a processing plant prior to entering the mainline transmission system.

The Natural Gas Processing Plant

- **The principal service** provided by a natural gas processing plant to the natural gas mainline transmission network is that **it produces pipeline quality natural gas**.
  - Natural gas mainline transmission systems are designed to operate within certain tolerances.
  - Natural gas entering the system that is not within certain specific gravities, pressures, Btu content range, or water content level will cause operational problems, pipeline deterioration, or even cause pipeline rupture.

- **Natural gas processing plants** are **also** facilities designed to **recover natural gas liquids** from a stream of natural gas that may or may not have passed through lease separators and/or field separation facilities.
  - These facilities also control the quality of the natural gas to be marketed.
  - Several types of natural gas processing plants, employing various techniques and technologies to extract contaminants and natural gas liquids, are used to produce pipeline quality "dry" gas.
  - At many processing plants the primary objective is the production of dry gas (demethanizing).
  - Any remaining natural gas liquids extraction stream is directed to a separate plant to undergo what is referred to as a "fractionation" process.

The Natural Gas Processing Plant

- But a number of natural gas processing plants do include these fractionation facilities, where saturated hydrocarbons are removed from natural gas and separated into distinct parts, or "fractions," such as:propane, butane, and ethane.
- Essentially, natural gas is methane, a colorless, odorless, flammable hydrocarbon gas (CH_4).
- Also present in natural gas production, especially that in association with oil production, are a number of petroleum gases.
  - They include (in addition to ethane, propane and butane) ethylene, propylene, butylene, isobutane, and isobutylene.
  - They are derived from crude oil refining or natural gas fractionation and are liquefied through pressurization.

The Transmission Grid and Compressor Stations

- The natural gas mainline (transmission line) is a wide-diameter, often-times long-distance, portion of a natural gas pipeline system, excluding laterals, located between the gathering system (production area), natural gas processing plant, other receipt points, and the principal customer service area(s).
- A lateral, is usually of smaller diameter, and branches off the mainline natural gas pipeline to connect with or serve a specific customer or group of customers.
- A natural gas mainline system will tend to be designed as either a grid or a trunkline system. The latter is usually a long-distance, wide-diameter pipeline system that generally links a major supply source with a market area or with a large pipeline/LDC serving a market area. Trunklines tend to have fewer receipt points (usually at the beginning of its route), fewer delivery points, interconnections with other pipelines, and associated lateral lines.

The Transmission Grid and Compressor Stations

- A grid type transmission system is usually characterized by a large number of laterals or branches from the mainline, which tend to form a network of integrated receipt, delivery and pipeline interconnections that operate in, and serve major market areas. In form, they are similar to a local distribution company (LDC) network configuration, but on a much larger scale.
- Between the producing area, or supply source, and the market area, a number of compressor stations are located along the transmission system. These stations contain one or more compressor units whose purpose is to receive the transmission flow (which has decreased in pressure since the previous compressor station) at an intake point, increase the pressure and rate of flow, and thus, maintain the movement of natural gas along the pipeline.

The Transmission Grid and Compressor Stations

- Compressor units that are used on a natural gas mainline transmission system are usually rated at 1,000 horsepower or more and are of the centrifugal (turbine) or reciprocating (piston) type. The larger compressor stations may have as many as 10-16 units with an overall horsepower rating of from 50,000 to 80,000 HP and a throughput capacity exceeding three billion cubic feet of natural gas per day. Most compressor units operate on natural gas (extracted from the pipeline flow); but in recent years, and mainly for environmental reasons, the use of electricity driven compressor units has been growing.
- Many of the larger mainline transmission routes are what is generally referred to as "looped." Looping is when one pipeline is laid parallel to another and is often used as a way to increase capacity along a right-of-way beyond what is possible on one line, or an expansion of an existing pipeline(s). These lines are connected to move a larger flow along a single segment of the pipeline system. Some very large pipeline systems have 5 or 6 large diameter pipes laid along the same right-of-way. Looped pipes may extend the distance between compressor stations, where they can transfer part of their flow, or the looping may be limited to only a portion of the line between stations. In the latter case, the looping often serves as essentially a storage device, where natural gas can be line-packed as a way to increase deliveries to local customers during certain peak periods.

The Transmission Grid and Compressor Stations

- To address the potential for pipeline rupture, safety cutoff meters are installed along a mainline transmission system route. Devices located at strategic points are designed to detect a drop in pressure that would result from a downstream or upstream pipeline rupture and automatically stop the flow of natural gas beyond its location. Monitoring the pipeline as a whole are apparatus known as (SCADA Systems Control and Data Acquisition) systems. SCADA systems provide monitoring staff the ability to direct and control pipeline flows, maintaining pipeline integrity and pressures as natural gas is received and delivered along numerous points on the system, including flows into and out of storage facilities.

Natural Gas Market Centers/Hubs

- Natural gas market centers and hubs evolved, beginning in the late 1980s, as an outgrowth of natural gas market restructuring and the execution of a number of Federal Energy Regulatory Commission's (FERC) Orders culminating in Order 636 issued in 1992.
- Order 636 mandated that interstate natural gas pipeline companies transform themselves from buyers and sellers of natural gas to strictly natural gas transporters. Market centers and hubs were developed to provide new natural gas shippers with many of the physical capabilities and administrative support services formally handled by the interstate pipeline company as "bundled" sales services.
- Two key services offered by market centers/hubs are transportation between and interconnections with other pipelines and the physical coverage of short-term receipt/delivery balancing needs. Many of these centers also provide unique services that help expedite and improve the natural gas transportation process overall, such as Internet-based access to natural gas trading platforms and capacity release programs. Most also provide title transfer services between parties that buy, sell, or move their natural gas through the center.
- As of the end of 2008, there were a total of 33 operational market centers in the United States (24) and Canada (9).

Underground Storage Facilities

- At the end of the mainline transmission system, and sometimes at its beginning and in between, underground natural gas storage and LNG (liquefied natural gas) facilities provide for inventory management, supply backup, and the access to natural gas to maintain the balance of the system. There are three principal types of underground storage sites used in the United States today: depleted reservoirs in oil and/or gas fields, aquifers, and salt cavern formations. In one or two cases mine caverns have been used. Two of the most important characteristics of an underground storage reservoir are the capability to hold natural gas for future use, and the rate at which natural gas inventory can be injected and withdrawn (its deliverability rate).
- Most underground storage facilities, 327 out of 399 at the beginning of 2008, are depleted reservoirs, which are close to consumption centers and which were relatively easy to convert to storage service. In some areas, however, most notably the Midwestern United States, some natural aquifers have been converted to natural gas storage reservoirs. An aquifer is suitable for natural gas storage if the water-bearing sedimentary rock formation is overlaid with an impermeable cap rock. While the geology of aquifers is similar to that of depleted production fields, their use in natural gas storage usually requires more base (cushion) gas and greater monitoring of withdrawal and injection performance. Deliverability rates may be enhanced by the presence of an active water drive.
- During the past 20 years, the number of salt cavern storage sites has grown significantly because of its rapid cycling (inventory turnover) capability coupled with its ability to respond to daily, even hourly, variations in customer needs. The large majority of salt cavern storage facilities have been developed in salt dome formations located in the Gulf Coast States. Salt caverns leached from bedded salt formations in Northeastern, Midwestern, and Western States have also been developed but the number has been limited due to a lack of suitable geology. Cavern construction is more costly than depleted field conversions when measured on the basis of dollars per thousand cubic feet of working gas capacity, but the ability to perform several withdrawal and injection cycles each year reduces the per-unit cost of each thousand cubic feet of natural gas injected and withdrawn.

Peak Shaving

- Underground natural gas storage inventories provide suppliers with the means to meet peak customer requirements up to a point. Beyond that point the distribution system still must be capable of meeting customer short-term peaking and volatile swing demands that occur on a daily and even hourly basis. During periods of extreme usage, peaking facilities, as well as other sources of temporary storage, are relied upon to supplement system and underground storage supplies.
- Peaking needs are met in several ways. Some underground storage sites are designed to provide peaking service, but most often LNG (liquefied natural gas) in storage and liquefied petroleum gas such as propane are vaporized and injected into the natural gas distribution system supply to meet instant requirements. Short-term linepacking is also used to meet anticipated surge requirements.
- The use of peaking facilities, as well as underground storage, is essentially a risk-management calculation, known as peak-shaving. The cost of installing these facilities is such that the incremental cost per unit is expensive. However, the cost of a service interruption, as well as the cost to an industrial customer in lost production, may be much higher. In the case of underground storage, a suitable site may not be locally available. The only other alternative might be to build or reserve the needed additional capacity on the pipeline network. Each alternative entails a cost.
- A local natural gas distribution company (LDC) relies on supplemental supply sources (underground storage, LNG, and propane) and uses linepacking to "shave" as much of the difference between the total maximum user requirements (on a peak day or shorter period) and the baseload customer requirements (the normal or average) daily usage. Each unit "shaved" represents less demand charges (for reserving pipeline capacity on the trunklines between supply and market areas) that the LDC must pay. The objective is to maintain sufficient local underground natural gas storage capacity and have in place additional supply sources such as LNG and propane air to meet large shifts in daily demand, thereby minimizing capacity reservation costs on the supplying pipeline.

About U.S. Natural Gas Pipelines - Transporting Natural Gas

- **Overview**
- A principal requirement of the natural gas transmission system is that it be capable of meeting the peak demand of its shippers who have contracts for firm service.
- To meet this requirement, the facilities developed by the natural gas transmission industry are a combination of transmission pipelines to bring the gas to the market areas and of underground natural gas storage sites and liquefied natural gas (LNG) peaking facilities located in the market areas.

What is Firm Service

- **Firm services**, also called **uninterruptible services**, are services, such as electricity and natural gas supplies, that are intended to be available at all times during a period covered by an agreement. Also, the service is not subject to a prior claim from another customer and receives the same priority as any other firm service. **Conditional firm service** is similar to firm service in that it is reserved and has priority over interruptible service. However, it can have restrictions, such as times when it would be curtailed before firm service but after interruptible service. The cost per unit with this service is called a **firm rate** or **uninterruptible rate**. The opposite of firm service is **non-firm service**, also called **interruptible service** or **as-available service**. The cost per unit for this service is called a **non-firm rate** or **interruptible rate**. The **interruptible load** is the portion of a utility's load that comes from customers with interruptible service.
- Firm service cannot be interrupted during adverse conditions, such as periods of high demand. However, firm service may also refer to service that is covered by a long-term contract, such as a year or more. There are extreme cases when firm services may be interrupted, such as emergencies and when system reliability is threatened. Services to homes and small businesses are usually firm. Some businesses that cannot afford interruptions also have firm service. Businesses that can afford to have services interrupted or that can significantly reduce their consumption when notified by the provider can get better rates by having non-firm service. Customers that have non-firm service may have a low level or baseline firm service that is guaranteed so that they do not have to shut down completely. Firm and non-firm service is also available for companies that rent or lease pipeline or electrical transmission capacity.
- Firm service for natural gas pipelines and electrical transmission lines often include two charges. The first is a reservation charge related to how much capacity the customer reserves. This charge is paid regardless of how much capacity is actually used. The second charge is based on how much capacity is used. Interruptible rates are volumetric, being based only on the volume of gas or electricity delivered.

Sizes of Transmission Lines and Integrated Storage Sites

- The design of natural gas transmission pipelines and integrated storage sites represents a balance of the most efficient and economical mix of delivery techniques given the operational requirements facing the pipeline company, the number and types of transportation customers, and available access to supplies from production areas or from underground storage.
- Many natural gas pipeline systems are configured principally for the long-distance transmission of natural gas from production regions to market areas. These long-distance systems are often referred to as trunklines.
- At the other extreme are the grid systems, which generally operate in and serve major market areas. Many of the grid systems can be categorized as regional distribution systems. For the most part, they receive their supplies of natural gas from the major trunklines or directly from local production areas. The grid systems transport natural gas to local distribution companies and large-volume consumers.

Design Criteria and Pipeline Size

- The design process includes the development of cost estimates for various possible combinations of pipe size, compression equipment, and inter-station distances to find the optimal combination that minimizes the transportation cost, given the desired flexibility and expandability goals.
- New trunklines typically are built with a larger diameter pipe than will be needed initially but with compression capacity limited to meeting current needs. Compressors can be added, in either new or existing stations, to increase capacity as growth in load occurs.
- A number of factors are involved in calculating how much natural gas a pipeline can carry. However, the most important factors are the diameter of the pipe and its operating pressure.
- Standard design codes require that all pipelines passing through populated areas reduce its maximum operating pressures for safety reasons.
- It had become common practice to maintain nominal pipe diameter but increase wall thickness where a line had to be derated for its surroundings (change in external stresses due to earth or traffic loads) in order to keep the working pressure rating more constant along the line. Increasing the pipe wall thickness or strength of the pipe will enable the pipe to withstand a greater pressure between operating and design pressure to adhere to safety requirements.

Importance of Underground Storage Integration

- Underground storage is an essential component of an efficient and reliable interstate natural gas transmission and distribution network. The size and profile of the transmission system often depends in part on the availability of storage.
- Access to underground natural gas storage facilities, particularly those located in consuming areas, permits the mainline transmission pipeline operator to design the portion of its system located upstream of storage facilities to accommodate the level of total shipper firm (reserved) capacity commitments and the pipeline operator's potential storage injection needs, commonly referred to as "baseload" requirements.
- The portion of the transmission system located downstream of the storage area (including LNG peaking facilities) is designed to accommodate the maximum peak-period requirements of shippers, local distribution companies, and consumers in the area. It is generally sized to reflect the total peak-day withdrawal (deliverability) level of all storage facilities linked to the system and estimated potential peak-period demand requirements.
- The daily deliverability from storage can also be factored into the design needs of a new pipeline or the expansion needs of an existing one. Some underground storage facilities are located in production areas at the beginning of the pipeline corridor and, in contrast to storage near consuming markets, can be used to store gas that may not be marketable at the time of production.
- For instance, natural gas produced in association with oil production is a function of oil market decisions, which may not coincide with natural gas demand or available pipeline capacity to transport the gas to end-use markets. Another example is the storage of natural gas produced from low-pressure wells, which may be injected into storage during the off-peak season and delivered, at high pressure, to the mainline during the peak season.
- These sites can be used by shippers to store short-term incremental supplies that exceed their reserve capacity on the pipeline system and the reverse when supplies fall below reserved capacity. Thus, the pipeline is relieved of additional demands for capacity brought on by temporary swings in the transportation demands of its customers.

Overall Pipeline System Configuration

- The overall pipeline system configuration should result in a comparatively lower usage level (load factor) for downstream facilities in the summer season but a much higher, albeit shorter term, usage level during the peak-demand season. The upstream trunkline portion of the system, on the other hand, could operate at a more sustained high load factor throughout the year. (This design minimizing is oftentimes referred to as peak-shaving.)
- With underground natural gas storage and LNG peaking facilities configured into a natural gas pipeline system, especially one serving climate-sensitive markets such as the Midwest and Northeast, system operators can minimize the facilities and costs involved in building the "trunkline" portion of their system. Natural gas shippers, on the other hand, could avoid unnecessary costs incurred if they reserved additional firm capacity on an entire transmission system, rather than only a portion that would be used only on a few days during the winter season.
- During the nonheating season, for instance, when shippers do not need all the contracted capacity to meet their customer's current consumption requirements, natural gas can be transported and injected into storage. By the beginning of the heating season (November 1), inventory levels are generally at their annual peak. Working gas, the portion of natural gas in storage sites available for withdrawal and delivery to markets, is then withdrawn during periods of peak demand.
- In addition, the pipeline company can avoid the need to expand transmission capacity from production areas by using existing, or establishing new storage facilities in market areas where there is a strong seasonal variation in demand and where the system may be subjected to operational imbalances.