LNG: Basics of Liquefied Natural Gas

THE UNIVERSITY OF TEXAS AT AUSTIN · PETROLEUM EXTENSION SERVICE

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About the Authors

Dr. Stanley Huang has a specialty area in cryogenic applications, particularly in LNG and gas processing. He has worked on many projects of LNG baseload plants and receiving terminals since 1996. Dr. Huang has contributed to the process and technology improvements through more than 20 publications and corporate reports. He worked for IPSI (an affiliate of Bechtel) and KBR, before joining Chevron. Currently he is a Staff LNG Process Engineer.

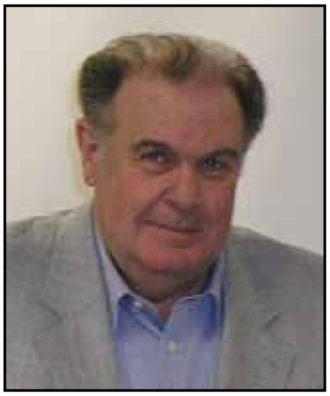
By training Dr. Huang is an expert in thermodynamics, in which he still maintains keen interest. He graduated from National Taiwan University with a B.S. degree and attended Purdue University in 1981. He earned his Master and Ph.D. degrees there, all in Chemical Engineering. Additionally, he also acquired a Master of Science in physics. After leaving school he worked for Exxon Research and Engineering Company as a post-doctoral Research Associate. Then he joined DB Robinson and Associates in Alberta, Canada for six years. Dr. Huang contributed more than 30 papers and corporate reports before 1996, including a molecularly-based equation of state, called Statistical Associated Fluid Theory (SAFT), which is still popular in polymer applications today.

Dr. Huang is a Registered Professional Engineer in Texas. He gave seminars on thermodynamic applications at Chinese Petroleum Corporation, National Chung-Yan University, and National Institute of Industrial Technology in Taiwan. In recent years he also gave seminars on gas processing and LNG industry at Association of Chinese American Professionals (ACAP) meetings, Universities of Houston and Wyoming.

Dr. Chen-Hwa Chiu has worked on many baseload LNG and LNG receiving terminal projects, and participated in the startup of Arun LNG plant. He has contributed to technological development, energy integration, safety, and cost reduction in large-scale baseload LNG plants and LNG terminals. A Fellow of American Institute of Chemical Engineers, he served as the Chair of its Fuels and Petrochemicals Division. He has won the George Lappin National Program Committee Service Award, AIChE, 2006, and the Distinguish Service Award, Fuels and Petrochemicals Division of AIChE in 2004.

Dr. Chiu was an author of a Chapter in a Wiley Encyclopedia on Environmental Remediation and Analysis. He has over 80 publications, encyclopedia chapters, proceedings, and 2 patents. A frequent speaker on major international conferences on LNG, he is the chief organizer of the LNG sessions for the Topical Conference on Natural Gas Utilization and editor of its 7 proceedings from 2001 to 2007 for AIChE.

He has established and conducted the popular "Fundamentals of LNG Technology" for the Chevron professionals since 2000. He has lectured at Chinese Petroleum Corporation, National Taiwan University, National Cheng Kung University, and recently at the Lamar University on LNG Industry. Dr. Chiu graduated from National Taiwan University with a B.S. and earned his Master of Engineering and Ph.D. from the University of Oklahoma, all in Chemical Engineering. He is a Registered Professional Engineer in Texas and Pennsylvania. He has worked for Lummus, Air Products, Exxon, M.W. Kellogg, Bechtel, Fluor, and Texaco, before Chevron. Dr. Chiu is a senior technology advisor of Chevron Energy Technology Company.



Dr. Doug Elliot has over 40 years experience in the oil and gas business, devoted to the design, technology development, and direction of industrial research. Doug is currently President, COO and cofounder (with Bechtel Corporation) of IPSI LLC, a company formed in 1986 to develop technology and provide conceptual design services to oil and gas producing and EPC companies. Prior to IPSI, Doug was Vice President of Oil and Gas with Davy McKee International. Doug started his career with McDermott Hudson Engineering in the early 1970s following a post-doctoral research assignment under Professor Riki Kobayashi at Rice University, where he developed an interest in oil and gas thermophysical properties research and its application. Doug has authored or coauthored over 65 technical publications plus 12 patents.

Doug served as a member of the Gas Processors Association (GPA) Research Steering Committee from 1972 to 2001 and as Chairman of the GPSA Data Book Committee on Physical Properties. Doug served as Chairman of the South Texas Section and Director of the Fuels and Petrochemical Division of the AIChE; and is currently a member of the PETEX Advisory Board. He holds a B.S. degree from Oregon State University and M.S. and Ph.D. degrees from the University of Houston, all in chemical engineering. Doug is a Bechtel Fellow and a Fellow of the American Institute of Chemical Engineers.

1 Introduction

The *liquefied natural gas* (LNG) industry in the U.S. can be traced back to the 1940s. However, the industry never received much attention from the general public until the beginning of this century. Firstly, most LNG produced in the U.S. is used for peak shaving purposes. Even for this function, LNG cannot distinguish itself from other mechanisms for natural gas storage, such as salt caverns. Secondly, domestic gas production, with the help of pipeline imports from Canada, has been mostly self-sufficient until the end of the past century, so there was no need to import LNG in any significant quantity. Using LNG as a *baseload* fuel had a false start in the 1970s. Of the four LNG import terminals built at the time, only two (Everett in Massachusetts and Lake Charles in Louisiana) managed to stay in operation during that time.

With the increased consumption and dwindling domestic natural gas production in recent years, LNG imports are projected to increase significantly in the near future. There have been close to 50 proposals for constructing new LNG *receiving terminals* on both coasts and the Gulf of Mexico areas. The public interest in LNG is also aroused by the unprecedented high natural gas prices.

In response to the heightened interest, this book provides a comprehensive coverage of all domains in the LNG industry. One intended use of this book is for the training classes presented by the Petroleum Extension Service (PETEX) of The University of Texas. The readers of this book are assumed to be managers new to the LNG industry or operating personnel who have already accumulated suitable technical background. The focus of the materials will be on the process side so as to present an overall picture regarding how LNG *liquefaction* and *regasification* facilities work and why the industry has evolved. Of course, no descriptions can be complete without touching the key equipment, particularly those items specific to the industry.

The way we acquire information has changed dramatically in the information age. The pace of change accelerated in the past ten years after high-speed internet connections and powerful search engines became generally available. It is almost a daily experience that we provide only the "key words" and gain access to myriads of information coming from the internet. The presentation style of this book reflects this reality. Instead of detailed descriptions of a chosen topic, we provide brief but comprehensive coverage of the ideas involved. Interested readers can pick up the correct key words to easily gain access to more detailed information from the internet. More importantly, comprehensive coverage will enable the reader to judge the relevance of searched information and not get lost in a sea of information.

Out of the hundreds, probably thousands, of Web sites related to the LNG industry, the site run by the *Oil and Gas Journal* (OGJ) has been heavily referenced. Throughout the years, OGJ has become an industrially recognized leader in providing information in the hydrocarbon industry. Additionally, the database, which is maintained by OGJ after 1990, is user-friendly and comprehensive.

2 Overview of LNG Industry

This chapter provides an overview of the LNG industry, from the development of cryogenic technology to the modern-day gas *monetization* mega-projects. A historical perspective is helpful in appreciating the current status of the industry.

There are four distinctive phases in the life cycle of an industry: development, expansion, saturation, then decline or transformation. Two well-known examples are the coke and steel industries (Anderson and DeLawyer, 1995). In the very beginning, as the developing technology is seeking public acceptance, the industrial scale is small and expansion is usually slow. Once these hurdles in technology development and acceptance are overcome, a fast expansion phase follows. The saturation phase sets in when the widely practiced technology is challenged by other emerging ones or parallel competitions reduce the profit margin to a merely sustainable level. At this point, the industry either can decline or transform and rejuvenate the life cycle.

It is difficult to pinpoint the exact phase of LNG industry at the present moment. However, there are indications that it has passed its development stage and is entering the expansion phase. This is witnessed by the surge of announced LNG projects in the past few years. However, how long this trend will last and to what extent it will continue probably only future historians will be able to tell (True, 2006).

The first section of this chapter provides a brief history of the LNG industry, describing the technological advances that contributed to its wide acceptance nowadays. The second section describes the emergence of the base-load LNG industry and the essential components. The third section provides a snapshot of the current LNG industry and its role in global gas trading. The last section provides a brief description of steps in forming an LNG project.

HISTORY OF LNG INDUSTRY

Although the cryogenic disciplines for gas liquefaction were developed in the late 19th Century, the early commercial efforts were directed toward air liquefaction and separation. Many companies formed at that time, such as British Oxygen Company (BOC), Air Liquide, and Linde, remain familiar trade names today (Scurlock, 1992).

The advantages of using liquefaction to reduce gas volumes and vapor pressures for fluid storage and transportation were noticed by the natural gas industry. The first pilot plant for natural gas liquefaction was built in West Virginia in 1939. The results were so encouraging that in 1941 the first commercial LNG plant was completed in Cleveland, Ohio. In the next few years, several relatively large spherical storage vessels were added. In 1944, a large cylindrical LNG tank with a novel base-construction design failed, because insufficient metallurgical knowledge at the time allowed the tank to be built with 3.5 percent nickel steel. The leaked LNG discharged into the sewage system of a neighboring, congested community and resulted in a catastrophic explosion, which demolished the entire community and caused 128 deaths. This incident halted LNG development for a decade.

The development of the LNG industry resumed after it was concluded that 9 percent nickel steel was adequate for LNG storage applications. This specification is still in use today.

3
Baseload Liquefaction Plant

The liquefaction plant is the most capital-intensive link in the entire LNG monetary chain. This chapter provides some detailed descriptions of the cryogenic liquefaction unit, the technical core of this link. There are other supporting units in an LNG plant, such as *gas sweetening*, dehydration, NGL removal, and nitrogen (N_2) rejection. They will be covered in Chapter 7.

The basis of the following discussion is a single LNG train. Combining several LNG trains to form an LNG plant or complex for utility-sharing will not be addressed. These issues are more related to the plant layout, reliability, and economics. Also, only the onshore applications will be covered in this chapter. Offshore applications are mainly extensions of onshore counterparts and will be covered in Chapter 9.

The first section of this chapter describes three LNG processes to familiarize readers with the technical domain. The second section describes train-capacity trends resulting from technological advances. The last section describes challenges faced by the industry during the construction of a baseload LNG plant. Experiences are provided for references in future projects. It should be emphasized that each project has its own characteristic features and difficulties. Past experiences may serve as useful guidelines to avoid the same traps. However, discretion should be used as to the applicability of these experiences on specific projects.

The development of an LNG liquefaction process is an on-going endeavor. Not only are novel processes being patented, improvements and variations of existing ones are constantly being proposed, studied, and installed. Cumulatively, all these innovations and incremental improvements contribute to the success of the LNG industry today. The LNG plants today are efficient, safe, and cost-effective. In particular, their safety records are exemplary in the energy sector.

LIQUEFACTION TECHNOLOGIES

There are more than 100 patents in the U.S. alone describing different processes for LNG liquefaction. However, only a handful of processes have been installed commercially. Among those installed, some encountered operational and reliability challenges. Afterwards, they were never used again. Others emerged only recently and are still in the process of construction.

Process selection significantly affects the outcome of an LNG project. Extensive discussions are available in the open domain to address issues related to process efficiency, plant constructability and operability, economic performances, and environmental concerns (Chiu, Dimitroff, and Shah, 2006; Mokhatab and Economides, 2006; Yost and DiNapoli, 2003).

Three examples are presented below to highlight the main features of LNG processes. The criteria for choosing the three examples include their commercial success or perceived commercial potential. The three processes are: propane precooled mixed refrigerant (*C3MR*) liquefaction process of the Air Products company, *ConocoPhillips Optimized Cascade*^{SM} *Process* (COPOC), and multi-fluid cascade process (MFC®) of Linde.

4
Receiving Terminal

The receiving terminal is an indispensable link between LNG ships and the targeted pipeline grid. The terminal serves three functions: (1) to receive and store ship-delivered LNG, (2) to regasify the LNG, with optional *compositional adjustments*, and (3) to deliver contracted volumes of gas into the designated pipeline grid at specified times. Thus, the storage capacity in a receiving terminal also provides adequate buffering should inclement marine conditions interrupt the LNG delivery for a finite number of days.

The global operational capacity of LNG receiving terminals should match that of the production, as shown in Table 2.1. Japan is the largest LNG importing country which accounts for about 40 percent of global LNG trade. In contrast, the U.S. currently imports less than 10 percent of global LNG supplies. The scenario is projected to change by the year 2025, when the U.S. is expected to import about 30 percent of the globally-traded LNG, matching the level of Japan at that time. Also, the imported LNG will account for 20 percent of the U.S. domestic gas balance (Shanley et al., 2004; Martin, 2005).

The global-installed capacity of LNG receiving terminals exceeds that of production. This excess receiving capacity is used by some countries as an assurance against possible interruptions in the LNG delivery links. For example, there is no national gas pipeline grid in Japan and each power company is expected to provide its own LNG spare capacity. As a result, there is excess LNG capacity in Japan if viewed from a national perspective. Another example of excess receiving capacity is in the U.S., where two of four terminals were moth-balled due to unfavorable operating economics in the past 30 years.

Since the U.S. market is the major driving force behind the current global LNG boom, this chapter will focus on the U.S. LNG market. The chapter is divided into four sections. The first section describes receiving terminals in the U.S. The second section provides technical descriptions of a typical receiving terminal. The third section discusses the possibility of integrating the refrigeration in a receiving terminal with other facilities in its vicinity in order to improve the overall thermodynamic efficiency of the whole system. The fourth section describes the issue of *gas interchangeability*, which assures that imported LNG, after being regasified and delivered into the existing pipeline grid, is compatible with existing domestically-produced gas. This assurance eliminates possible adverse impacts on end users due to compositional changes.

5

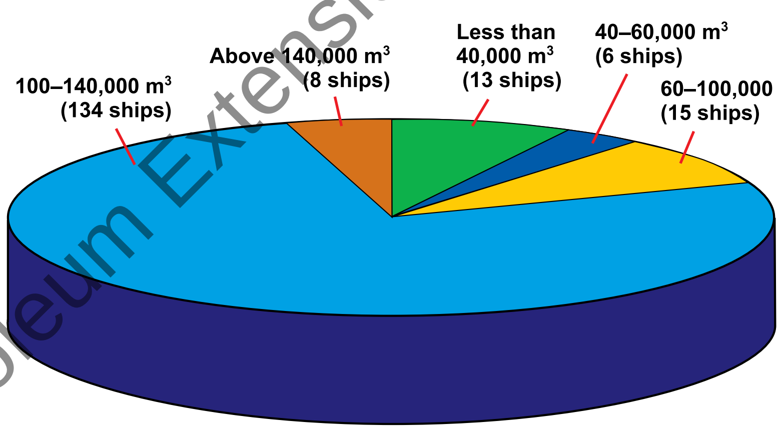
LNG Shipping Industry

Shipping is a key link in the LNG monetization chain. In current LNG commercial practices, where there are minimum activities in spot markets, few LNG ships are built on noncommitted bases. Each LNG project includes its own dedicated LNG fleet. The occasional transportation needs created by spot market activities are met by chartering ships with spare load capacity available at the desired times and locations. LNG spot market transactions are expected to increase in the future, as will the volume of LNG transported by *nondedicated ships* chartered after construction on variable terms.

This chapter is divided into three sections, the first of which provides a global view of the current global LNG ship fleet. As anticipated, the upsurge of LNG capacity in the next few years will be matched by expansion of the LNG fleet. The second section is further divided into three subsections to describe three types of LNG ships: *Moss*, *membrane*, and *prismatic*. The third section describes the measures the LNG shipping industry taken to reduce *greenhouse gas* emissions.

LNG FLEET

Similar to efforts to expand the production capacity of LNG production trains, LNG ship-builders have been striving to increase ship size to capture the economy of scale. However, the advances in ship-building technology appear as quantum leaps compared to the gradual expansion of the LNG train capacities. The maximum size of LNG ships recently increased to 210,000 m^3 after languishing at about 140,000 m^3 since 1975 (Cho et al., 2005). As a result of this long plateau, the capacities of most current LNG ships fall between 100,000 m^3 and 140,000 m^3. Figure 5.1 shows the global ship-size distribution as of 2005 (Rajvanshy, 2005).



Distribution of LNG Ship Sizes
(Total = 176 ships, data as of 2005)

Figure 51 Sizes of global LNG ships in 2005

6 Major Equipment in LNG Industry

There are hundreds of equipment items in an LNG plant. It would be difficult to describe everything in a single book. Fortunately, many of the same equipment items are also used in the gas processing industry. Excellent general references on the Web or in print are available for these items (GPSA, 2000; Perry and Green, 1997). Examples include vessels, towers, air coolers, shell and tube exchangers, centrifugal and piston pumps, compressors and drivers and, optionally, gas expanders.

This chapter focuses on selected items specific to the LNG industry. These items include *cryogenic exchangers*, large compressors and drivers, LNG pumps and liquid expanders, *loading arms*, LNG tanks, and LNG vaporizers used in receiving terminals. Large compressors and drivers are included because their size makes their applications unique.

Each item of LNG equipment is explained in the following seven sections. The photos used to illustrate this equipment have been reprinted with permission from kind many LNG vendors currently supplying the LNG industry.

CRYOGENIC EXCHANGERS

Aluminum, because of its superior thermal conductivity and mechanical strength at low temperatures, is a favored material for cryogenic applications. For clean and *noncorrosive* (NC) fluids, aluminum-based construction should be considered, if the temperature is below 35°C. The large-scale application of aluminum-based cryogenic exchangers is an important factor contributing to the success of modern gas processing and LNG plants.

There are two common methods in constructing the aluminum-based cryogenic exchangers: *spiral-wound heat exchangers* (SWHEs) and plate-fin heat exchangers (PFHEs). Sometimes PFHEs are also called brazed-aluminum heat exchangers (BAHEs). Spiral-wound designs can be traced to the early development of cryogenic processes for air liquefaction by Dr. Carl von Linde in May 1885. In the early days, three important manufacturers were Linde and Hampson in Europe, and Tripler in the U.S. The brazed-aluminum method was developed relatively late, after World War II. This method revolutionized the cryogenic exchanger design because it made possible the complex multipass arrangements and narrow temperature approaches (Scurlock, 1992).

In today's competitive commercial environment, several players in each manufacturing method are competing for the market. The first two subsections below will discuss the two methods separately. The third subsection will describe an insulation technique called "cold box," which can house several pieces of cryogenic equipment items. This method of insulation is common in cryogenic plants.

7 Supporting Functional Units in LNG Plants

There are many functional units inside an LNG plant besides the core cryogenic and liquefaction units covered in Chapter 3. Figure 7.1 presents a schematic showing the relations between different functional units. Those units covered in Chapter 3 are highlighted in the figure. This chapter will cover the other supporting functions, including gas *pretreatment*, natural gas liquid (NGL) recovery, nitrogen rejection, and helium recovery.

There are four sections in this chapter. The first section covers the gas pretreatment unit, which includes gas receiving, NGL stabilizing, gas sweetening, gas precooling, and gas dehydrating. Inlet gas must be sweetened and dried before it can be directed to the cryogenic unit. The second section covers the NGL recovery operation, the purpose of which is to meet a specified LNG heating value as well as compositional specifications. The third section discusses the nitrogen rejection unit (NRU), the purpose of which is to meet nitrogen composition specifications. Finally, the fourth section discusses helium recovery. In some LNG plants, where inlet gases contain relatively high proportions of helium, helium recovery can enhance the economic attractiveness of an LNG project.

These operations are not unique to the LNG industry and also are standard operations in gas processing industries. There are many good technical references (GPSA, 2000; Kohl and Nielsen, 1997; Dinh et al., 2005) to help explain more about these operations in publications and on the Web. This chapter will only provide brief functional descriptions for these supporting units to give readers a complete picture of typical LNG plants.

GAS PRETREATMENT

This section describes the following units: gas reception, NGL stabilization, acid gas removal, molecular sieve dehydration, and sulfur and mercury removal. The first two units sometimes are referred to as *upstream* facilities.

Slug Catcher

A *slug catcher* is a buffering apparatus at the end of a pipeline, which includes a storage vessel sized to hold periodic in-flows of large volumes of liquids created by *pigging* or liquid surges. The slug catcher also acts as a means of ensuring steady outlet flows to downstream liquid handling facilities. Figure 7.2 shows a photo of the slug-catching facilities (foreground) of the Statoil Snøhvit LNG plant in Melkøya Island, Norway.

The initial separation of gas, liquids, and chemicals takes place in the slug catcher. Sometimes chemicals are injected into upstream pipelines to control corrosion or to prevent formation of *hydrates* or solids. Gas continues to downstream pretreatment facilities while hydrocarbon liquids are processed in the NGL stabilization plant. Chemicals, such as hydrator inhibitor, need to be reclaimed in specially designed regeneration facilities.

Structurally, a slug catcher may be a single large vessel or a collection of *manifolded pipelines*. The finger-type slug catching facilities shown in Figure 7.2 are visible in the foreground. When this LNG facility was under construction, the slug catcher was fabricated in a construction yard elsewhere and barged

8 Safety, Security, and Environmental Issues

The U.S. has a long history of working with LNG starting with peak shaving applications. Today there are more than 100 LNG facilities scattered around the country, as shown in Figure 2.1, page 4. Baseload LNG applications have not proliferated since being introduced in the U.S. in the early 1970s. Rapid growth of U.S. LNG-import capacity began in the early 2000s because of dwindling domestic gas production.

Overall, the LNG industry has demonstrated an excellent safety record (Foss, 2003). In addition, dedicated journals address safety issues and concerns periodically to propagate awareness among industrial players (West and Chiu, 2005).

LNG safety, security, and environmental imperatives changed profoundly after the terrorist attack on the World Trade Towers in New York City on September 11, 2001. An LNG ship or storage tank contains a tremendous amount of energy. Upon sudden breach of the containment system, the released LNG poses a real safety concern. How to mitigate the potential hazard is still actively debated.

As a source of energy, LNG will play an evermore important role in U.S. domestic gas markets. With current public focus on mitigating CO_2 emissions and energy efficiency, the LNG industry is proactively responding to these concerns.

This chapter is divided into three sections: industrial safety, security, and environmental issues.

Safety Design of LNG Facilities

In the safety domain, LNG has the following advantages over other industries:

1. The physical and chemical properties of LNG are well understood. LNG exists only under cryogenic conditions. In order to manufacture LNG on a large scale, these properties are required to support industrial designs.
2. The industry has evolved around a tradition of safe designs and operations which includes rigorous personnel training. To create and preserve cryogenic conditions economically, it is of utmost importance to minimize unscheduled process interruptions. Short-cuts lead to increased plant downtime contrary to economic principles. Hence, the LNG industry intrinsically self-regulates toward safe designs and operations.
3. Codes and regulations have been evolving synchronously with the LNG industry rather than being developed only after major industrial accidents.

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