HSE Evolution in Conversion of LNG Import Terminals to Export

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With the abundance of natural gas (NG) in the U.S. in recent years, companies that had built marine terminals for the import of LNG and subsequent re-gasification for pipeline transportation are now considering converting those facilities for liquefaction of pipeline gas in order to export LNG. This has brought challenges in the HSE area as well as in the regulatory arena regarding plot plan development and the handling of high-pressure liquid hydrocarbons. Besides the need to address the increased hazards of NG liquefaction versus LNG re-gasification, government agencies are faced with application of regulations and codes to the liquefaction that were intended mainly to address the re-gasification. As the regulation tries to apply the consequence-based codes to new materials used in the liquefaction process, such as refrigerants that may include propane, ethane, ethylene and butane, and other heavier hydrocarbons that may be present in the NG, the need for tools and techniques to evaluate safe alternatives becomes evident. This paper describes the methodology used in an LNG liquefaction project to address these needs, which among other aspects include a combination of traditional vapor dispersion and thermal radiation modelling tools with computational fluid dynamics (CFD) models.
Keywords: CFD, Computational Fluid Dynamics, FLACS, Liquefied Natural Gas, LNG, PHAST, Thermal Radiation, Vapor Cloud Dispersion

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Introduction

With the abundance of natural gas (NG) in the U.S. in recent years, companies that had built marine terminals for the import of Liquefied Natural Gas (LNG) and subsequent re-gasification for pipeline transportation are now considering converting those facilities for liquefaction of pipeline gas in order to export LNG

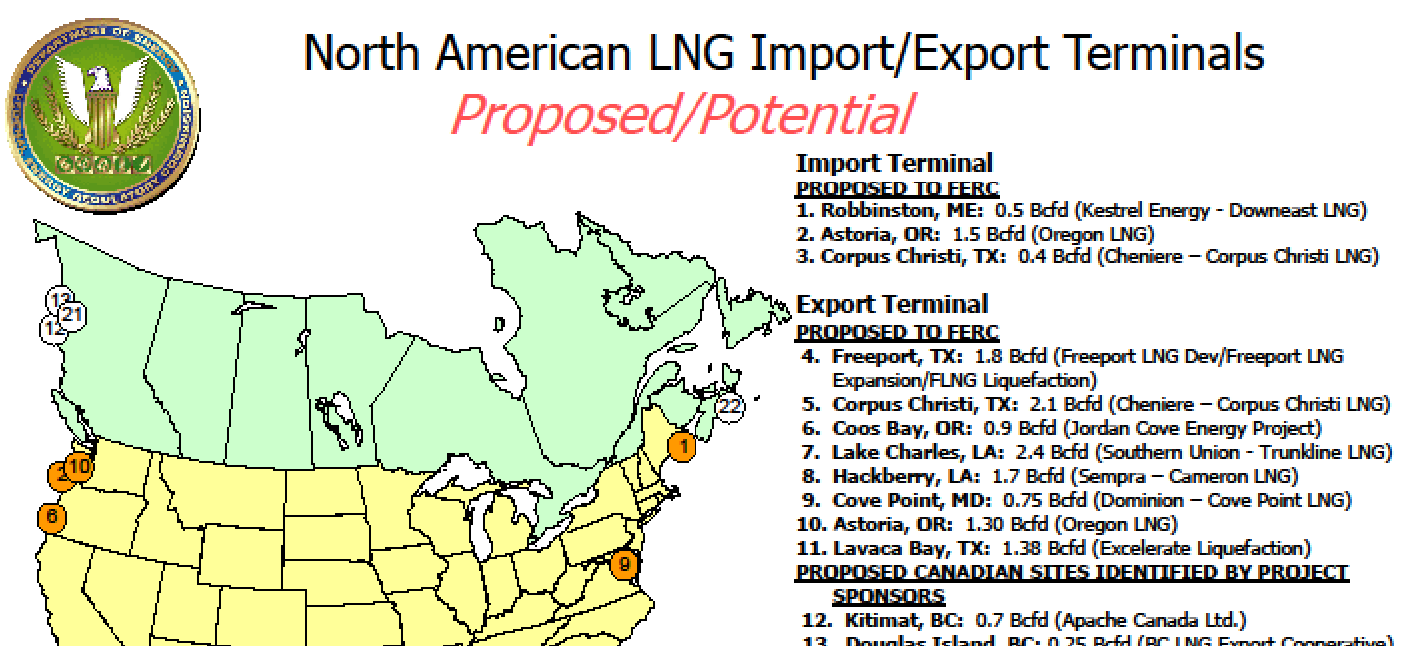
(Figure 1). This has brought challenges in the Health, Safety & Environment (HSE) area as well as in the regulatory arena regarding plot plan development and the handling of high pressure liquefied hydrocarbons. Besides the need to address the increased hazards of NG liquefaction versus LNG re-gasification, government agencies are faced with application of regulations and codes to the liquefaction of NG that were intended mainly to address LNG re-gasification terminals earlier. As the regulations try to apply the consequence-based codes to the variety of materials used in the liquefaction process, such as refrigerants that may include propane, ethane, ethylene, butanes, and other heavier hydrocarbons that may also be present in the NG, the need for tools and techniques to evaluate safe alternatives becomes evident. In addition, the environmental perspective also changes from regasification to the liquefaction of NG. This paper will describe the methodology used in an NG liquefaction project to address these needs, which among other aspects include a combination of traditional vapor dispersion, vapor cloud explosion, and thermal radiation modelling tools, with computational fluid dynamics (CFD) modelling.

The environmental factors, as well as the use of barriers to screen equipment noise and to limit the extent of vapor clouds will also be discussed.

Many US LNG Import Facilities are Being Converted to LNG Export

Domestic supplies of natural gas are growing rapidly due to availability of extensive shale gas resources. As a result, US natural gas prices have dropped to a fraction of their peak several years ago and US LNG imports have decreased dramatically.

At the same time, LNG prices in Japan, in other parts of the Asia Pacific region, and in Europe have remained high. Contributing factors are the Japanese decision to shut down nuclear power generation after the Fukushima tragedy, and the growing global demand for natural gas. Yet another factor is the environmental advantages of natural gas as a fuel when compared with coal.



Chosnek and Edwards (1) discussed the hazards of conversion of LNG Import Facilities to LNG Export. These hazards include the following:

- Natural gas liquefaction facilities required for LNG export are more complex and congested due to higher number of processing equipment involving different processing steps with multiple products, and require more space than corresponding LNG regasification facilities.
- Plot space at existing LNG import sites for new LNG export facilities may be limited.
- The risks of fire and explosion may be increased by the presence of more reactive chemicals (e.g., propane, ethylene) and higher congestion typical of liquefaction and other gas processing facilities.
- These risks are also increased by the use of more reactive heavy hydrocarbon streams as by-products from natural gas purification.
- Liquefaction often requires large inventories of refrigerants such as ethane, ethylene, propane, propylene, and butanes or their mixtures, at comparatively high pressures.
- Hydrogen sulfide streams may result from purification of natural gas prior to liquefaction, although the primary impact is on potential emissions of sulfur oxides resulting from oxidation of the hydrogen sulfide by-product.

Current US LNG Regulations are Consequence-based

Chosnek and Edwards (1) highlighted that current US LNG regulations are consequence-based instead of a preferred risk-based approach (2). Summarized below are the current criteria (3-6):

- Exclusion Zones (at property line) from a release caused by a “design spill”
    - ½ Lower Flammable Limit for flammable vapor dispersion
    - 1,600 BTU/hr-ft^2 Thermal Radiation Limit for pool fires
    - 1 psi Overpressure Limit for Vapor Cloud Explosions (although not in the regulations and never an issue for LNG import facilities, this is now an important criterion for liquefaction facilities in the US)

These existing US regulations were adequate for LNG import, although the constraint that only passive mitigations (impoundments, vapor fences) could be used to reduce the hazard footprint was a disadvantage.

Consequence modeling of existing US import terminals was done in most cases using the following two software products:

- LNGFIRE3 for Thermal Radiation
- DEGADIS for Flammable Vapor Dispersion

These tools model the design spill as an LNG pool on an otherwise empty horizontal plane, which is a reasonable approximation when the major hazard is an LNG spill that can be controlled by impoundment.

Advanced Consequence Modeling is needed to Safely Design LNG Export Facilities

As mentioned above, natural gas liquefaction facilities introduce new hazards, such as overpressures from vapor cloud explosions, because of C2+ hydrocarbons and increased congestion.

Comparatively recently (October 2011), FERC approved two additional software packages for LNG vapor dispersion hazard analyses: PHAST^{TM} from DNV, an analytical tool described by Witlox, *et al*. (7), and FLACS from GexCon, a CFD tool described by Hansen, *et al*. (8).

The two models now available for LNG hazard analysis offer a number of advantages over the previously allowed DEGADIS:

- Model verification and extensive validation with field data
- Wide variety of source terms
- Mixtures of gases can be considered
- Both vapor dispersion and vapor cloud explosion can be modeled
- Tabular and graphic outputs can be generated (2D in the case of PHAST, 2D or 3D in the case of FLACS)

The main differences between the two models are as follows:

- PHAST is based on analytical data and correlations (Unified Dispersion Model), which allows for rapid calculations; FLACS is a 3D CFD model that solves the Navier-Stokes and turbulence closure equations in each of several hundred thousand computational grid cells, therefore requires longer times to complete a calculation;

- The correlations implemented in PHAST do not account for the presence of obstacles or terrain features, therefore its results are less accurate and it does not allow all mitigation measures to be evaluated; FLACS can include any obstacle or obstruction (as long as they are built into the geometry model used for the simulations) and therefore provides more realistic results.

While both tools have pros and cons, an efficient and effective approach can be achieved by combining the use of PHAST and FLACS in order to take advantage of each model's strengths. This approach can make thorough and detailed consequence modeling possible within the typical time frame of LNG facility design development, leading to a safer and regulatory-compliant plot plan:

- Use PHAST to rapidly screen a large number of scenarios, involving releases of hazardous fluids from different process streams and locations (approximately 100 scenarios can be examined for a single LNG project).
- Rearrange equipment on the plot plan to minimize adverse consequences of releases of hazardous fluids.
- Validate the safer plot plan using FLACS.
- Establish and evaluate passive protections, such as vapor fences, using FLACS.
- Quantify location specific overpressures from vapor cloud explosions using FLACS.

Atmospheric Emissions will Increase and Amended Permits may Face Stricter Regulations

Natural gas liquefaction requires energy, so greenhouse gas (CO_2 and CH_4) emissions may increase if power is generated onsite.

- Emissions of ozone precursors (NOx and VOCs) may increase.
- Greater fugitive emissions may result due to increased process size and complexity.
- To a smaller extent in the US pipeline gas, emissions of SOx may increase.
- Amendment of existing permits may require meeting new and more demanding regulations.
- Best Available Control Technology (BACT) emission controls may be required.

Modest Increases in Aqueous Discharges

- LNG import terminals have few aqueous streams to treat

    - Storm water with potential lube oil contamination
    - Demineralization by-product water
    - Fire water system test water
    - Hydro-test water
    - Sanitary waste
- LNG export terminals have a few more:
    - All of the above aqueous streams
    - Higher potential for lube oil contamination of storm water (larger plot plan and significantly more rotating equipment)
    - Storm water with potential amine contamination
    - Amended permit may need to achieve newer and stricter regulations

It should be possible to minimize storm water contamination through segregation, containment and rigorous maintenance and housekeeping practices.

Noise Sources and Mitigation

New export facilities add new piping and equipment to the existing site that are new noise sources. Examples include air-cooled heat exchangers, compressors, and turbines. FERC has very strict limitations on noise from LNG facilities.

In addition to buildings, enclosures, silencers, and sound insulation, a noise barrier wall may be required. Computer modeling of noise from equipment and piping will be required during both FEED and Detailed Design. Noise modeling during FEED can give guidance on plot plan modification to minimize noise exposure to any nearby noise sensitive areas.

Design should also incorporate features to permit easy provision of additional noise controls if as-built facilities are noisier than predicted during design phase. Examples include building foundations for noise barrier walls strong enough for an increased wall height and providing spool pieces in compressor piping to allow easy provision of silencers if needed.

Conclusions

LNG import and export facilities are among the safest and most environmentally friendly fossil fuel processes. Conversion of a number of US LNG import facilities to either export or bi-directional facilities is being proposed. Fitting major new natural gas liquefaction facilities into an existing site can be challenging.

Challenges include the following:

- Limited plot space
- Increased fire and explosion hazards
- Increased emissions and stricter regulations
- Increased noise levels

This paper discusses how these challenges can be overcome.

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Biographies

Jack Chosnek, Ph.D., P.E., Knowledge*One* LLC, www.knowledge1.net
Jack is a consultant in Process Safety Management and Knowledge Management and has over thirty-five years of experience in the petrochemical industry. He has consulted for companies in the chemical, oil and gas, offshore, waste management and mining industries, developing policies and implementing process safety management systems, facilitating PHAs, writing operating procedures and conducting incident investigations and process safety audits. He has developed commercial, full-featured software for PHA facilitation and Management of Change (MOC). Jack consulted as the principal risk engineer for two multi-billion-dollar projects carried out by large engineering firms.

Before becoming a consultant, Jack worked for Celanese Corp. for 25 years in various positions in process safety management, technology management, operations, process engineering, piloting, tolling and R&D. Jack was a member of a project team that developed one of the first commercial scale-ups in the biotechnology industry.

Jack is the Chairman of the Process Safety Workshops at the South Texas Section (STS) of AIChE. He chaired the Process Plant Safety Symposium (PPSS) at the 4th Global Congress on Process Safety, and has chaired and co-chaired other process safety sessions in other years. He is the chair of the Technical Advisory Committee at Texas A&M's Mary Kay O'Connor Process Safety Center.

Jack is the holder of three patents related to chemical production. He has a BS and MS from the Technion—Israel Institute of Technology, and a PhD from the University of Missouri at Rolla, all in Chemical Engineering, as well as an MBA from Texas A&M—Corpus Christi

Filippo Gavelli, Ph. D., P. E.
Dr. Filippo Gavelli is the Head of the Dispersion Consulting group at GexCon and is responsible for GexCon's LNG safety consulting business worldwide. He specializes in the analysis of heat transfer and fluid flow phenomena, including multiphase flows and cryogenic fluids. He has over 10 years of engineering consulting experience and 20 years of experience in computational fluid dynamics (CFD) modeling, using several research and commercial codes. He applies his expertise to modeling the atmospheric dispersion of hazardous gaseous releases, and has extensive experience modeling hazard scenarios for Liquefied Natural Gas (LNG) facilities, including vapor cloud dispersion, pool fires and vapor cloud deflagrations; his experience includes more than 20 LNG installations worldwide, including onshore, offshore and floating (FLNG) facilities for LNG import, export (liquefaction) and peak shaving. Dr. Gavelli is a member of the technical committees for NFPA 59A (LNG facilities standard) and NFPA 2 (hydrogen technologies code) and was the lead in the model validation effort that led to FLACS' approval by the U.S. DOT under 49 CFR 193. Dr. Gavelli is the lead author of several gas dispersion and explosion safety-related papers and has been a regular contributor to LNG-related technical committees and expert panels for several years. He is a member of the GexCon docents group, which develops and delivers safety seminars to facility owners and operators, safety

engineers, and regulatory agencies, on the hazards associated with gas explosions, dust explosions and LNG. Dr. Gavelli is also responsible for software technical support and training for FLACS customers in North America and has provided training to over 100 users, including staff from regulatory and government agencies.

Victor H. Edwards, Ph. D., P. E. is Director of Process Safety for IHI E&C International Corporation, Houston, TX 77077 (832-379-7742; e-mail: vic.edwards@ihi-ec.com). Responsible for health, safety, and environment in design, Vic has worked for IHI and predecessor companies for 29 years. His experience includes process engineering, process safety management, and process, biochemical, environmental, and mineral processing technologies. His project assignments have included biochemical and chemical processes, biomass energy resources, coal gasification, coal liquefaction, liquefied natural gas, chemical weapons demilitarization, hazardous waste disposal, offshore hydrocarbons facilities, and extraction of metals.

Dr. Edwards has received three DuPont awards for safety and environmental engineering excellence and two DuPont awards for health, safety, and environmental excellence during 28 years as an alliance engineering contractor. In 1998, Kvaerner Engineers and Constructors named him employee of the year. In 2007, Vic's Houston HSE team was recognized by Aker Kvaerner with the Process and Construction Excellence Award for HSE in Design.

Vic's earlier experience included Assistant Professor of Chemical Engineering at Cornell University, Program Manager at the National Science Foundation (on leave from Cornell), Research Fellow at Merck, alternate energy research at United Energy Resources, Visiting Professor of Environmental Engineering at Rice University, and process engineering at Fluor.

Vic has contributed more than sixty publications to the engineering literature, including several book chapters. He chaired the 1992 Process Plant Safety Symposium, the 1997 International Plant Operations and Design Conference, and the 2013 Global Congress on Process Safety, as well as numerous technical sessions at other conferences. Vic received the 2003 Service Award from the Process Safety Center at Texas A & M University, where he chaired the Technical Advisory Committee from 2004 to 2011. In 2009, Vic was elected to the Centennial Council of the Department of Chemical and Biomolecular Engineering at Rice University. He also serves on the Editorial Advisory Board of CHEMICAL PROCESSING magazine. Edwards earned his B. A. from Rice University and his Ph. D. from the University of California at Berkeley; both degrees in chemical engineering. A registered professional engineer in Texas, he is an AIChE Fellow, and a member of ACS, AAAS, NFPA, NSPE, and the New York Academy of Sciences.