ETHANE TRANSPORTATION WITH LNG – AN OPTION FOR BALANCING THE GLOBAL SUPPLY AND DEMAND OF ETHANE

Rajeev Nanda, George Hu, Sylvain Vovard

TechnipFMC

Demand for ethane and for ethylene production is growing worldwide while the USA and other LNG producing regions have surplus ethane available. Despite the recent inauguration of refrigerated ethane trading, a low-cost alternate can be considered when the trade is in parallel with LNG. This paper describes a significant market opportunity for transporting ethane with LNG for recovery at the LNG regasification terminal.

The paper discusses the economics of transporting ethane with LNG as well as technical challenges in recovery of ethane from LNG. Several different configurations of the regasification terminal and options to minimize changes and cost including TechnipFMC’s Dual Column process (US Patent 7,530,236 B2) are presented.

A comparison is made with the primary route of ethane recovery, liquefaction as a pure product & transportation which provides marketing flexibility against which is the cost of dedicated terminals and shipping.

The paper also illustrates the impact on LNG liquefaction terminal design.
1.0 Introduction

In times of high oil prices ethane from natural gas has traditionally been a cost competitive alternative to naphtha as the precursor for petrochemicals. Most of the ethane based petrochemical projects in the world are located close to the source of rich natural gas. A number of major changes have occurred in the past decade:

- The rapid growth of North American natural gas production including for LNG export. The low HHV specifications for natural gas pipelines in the USA have created an ethane surplus far beyond the requirements of local petrochemical projects where the local market is saturated.
- The continued fast growth of LNG production and trade, bringing new possibilities for the coproduction of ethane in large quantities, often in locations which are remote and where construction costs make the addition of a petrochemical industry unattractive.
- Fast growing Asian economies exhibit high ethylene demand and plant construction and operating costs for world scale ethane based steam crackers that are lower at least when compared to the USA.
- High oil and therefore naphtha prices means ethane is significantly cheaper than other petrochemical feedstocks.
- The steady decline of ethane availability from oil and gas fields over the years has resulted in shortfalls that threaten the continued operation of major petrochemical complexes such as Grangemouth, Scotland.

These new conditions have driven the petrochemical industry towards new solutions including:

- A revival of new petrochemical projects in the USA close to the new source new ethane.
- International trade of ethane using dedicated ethane liquefaction, shipping and receiving infrastructure.
- New ethane based steam crackers in China and India based on imported ethane.
- Ethane transportation from the US to mature European petrochemical sites.

There is, however, an economical solution to co-transport ethane with LNG, that could supplement indigenous ethane or pure ethane imports to trigger ethane-based petrochemical projects in the areas with large petrochemical demand. The market size for ethane transportation solutions is very large globally as illustrated in the subsequent sections of this paper.

The paper further presents the economic benefits and opportunities for future petrochemical plants to be co-located with LNG import terminals.

It is also worth mentioning that contracts will have to be structured to deal with the relative commercial complexity of co-importing ethane with LNG. The authors believe that the economic benefit for doing so will exceed the effort required for the new commercial arrangement.
2.0 **Shortfall of Ethane & Ethane market**

There are several opportunities globally for Ethane import where the existing LNG terminals are located close to the existing petrochemical plants. For example, there are currently 37 petrochemical plants operating within 50 miles radius of existing LNG receiving terminals in South America, Europe, and Asia as illustrated in Figure 2.1 below. This number will increase on expanding the 50 miles radius and also accounting for planned terminals and the petrochemical plants.

**Figure 2.1**

<table>
<thead>
<tr>
<th>Continent</th>
<th>Ethane /LPG/Naphtha Crackers w/in 50 miles of LNG terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. America</td>
<td>3</td>
</tr>
<tr>
<td>Europe</td>
<td>7</td>
</tr>
<tr>
<td>Asia</td>
<td>27</td>
</tr>
</tbody>
</table>

Some of the global opportunities for importing ethane with LNG is illustrated in the figures below.

There are several opportunities in Brazil and Argentina where the LNG regasification terminal is close to the Petrochemical project as shown in Figure 2.2 below.

**Figure 2.2**

**OPPORTUNITIES: S. AMERICA**

- Brazil
  - Ethane, mixed feed and Naphtha crackers.
  - Looking to convert Naphtha cracker to Ethane cracker
  - Ethane import from USA

- Argentina
  - Ethane cracker getting Ethane feed from gas fields 600km away
In middle East, as shown in Figure 2.3 there is a potential to make certain petrochemical project more cost effective with imported ethane from US.

**Figure 2.3**

**OPPORTUNITIES: MIDDLE EAST**

- **Kuwait & UAE**
  - Ethane crackers facing shortage of cheap natural gas

- **Egypt**
  - Light feed crackers using domestic supply. C2 supply from LNG will be more economical

- **Israel**
  - UFG/Naphtha cracker looking to upgrade to Ethane feed

- **Turkey**
  - Naphtha crackers with moderate cost constraints

Figure 2.4 illustrates the Petrochemical projects in France, Spain, Portugal, Netherlands and Italy close to the LNG regas terminal.

**Figure 2.4**

**OPPORTUNITIES: EUROPE**

- **France**
  - Flexi crackers using LPG & Naphtha, push to shift to Ethane

- **Spain & Portugal**
  - Naphtha crackers but high Ethane supply potential from nearby LNG terminals

- **Netherlands & Italy**
  - Flexi/Naphtha crackers using LPG & Naphtha. Possibility to convert to Ethane

Several LNG terminals & Petrochemical projects in close proximity of each other in Asia are indicated in Figures 2.4, 2.6 & 2.7 below.
**Figure 2.5**

**OPPORTUNITIES: S. EAST ASIA**

- **Singapore**
  - **Opportunity**
  - Flexi cracker that can use economically attractive Ethane feed

- **Thailand**
  - **Opportunity**
  - Flexi and Ethane crackers facing domestic supply constraints.

- **Philippines**
  - **Opportunity**
  - Naphtha crackers with moderate cost constraints

**Figure 2.6**

**OPPORTUNITIES: N. EAST ASIA**

- **S. Korea**
  - **Opportunity**
  - Naphtha crackers facing cost constraints with high Ethane supply potential from LNG terminals

- **Japan**
  - **Opportunity**
  - Lots of Naphtha/LPG cracker facing significant cost constraints. Ethane supply potential from LNG terminals low to high

**Figure 2.7**

**OPPORTUNITIES: REST OF ASIA**

- **India**
  - **Opportunity**
  - Ethane crackers that can economically benefit from price advantaged Ethane from LNG
  - Naphtha crackers with high Ethane supply potential from nearby LNG terminals

- **China**
  - **Opportunity**
  - Naphtha crackers facing moderate cost constraints with low-high Ethane supply potential from nearby LNG terminals
  - More push towards alternate technologies for Ethylene production (coal, Ethanol etc.)
3.0 Solutions to Transport Ethane

In the current market, ethane and LNG are treated as two separate products for obvious reasons: LNG is mainly a solution for fuel transportation (long distance and overseas), while ethane is mainly used as feedstock for petrochemical plants. Due to the separation of the two markets, the two products are usually being produced, transported, and delivered separately.

Separated Transportation Solution

The following scheme (Fig. 3.1) is an illustration of the traditional solution – the Separated Transportation Solution, i.e. the ethane and LNG is transported separately. In this solution, ethane is separated from natural gas at an early stage of the value chain and marched to their respective markets independently. Separate pipelines, liquefaction facilities and export terminals, ship tankers, receiving terminals, and deliver pipelines are built independently for ethane and LNG.

Figure 3.1 – Separate Value Chains of LNG and Ethane

Note that above scheme is more of a representation of the North American market, where midstream is an important play in the natural gas value chain. In this market, the ethane extraction usually occurs at the midstream NGL extraction facility where the midstream players can monetize the ethane as a petrochemical feedstock either for domestic petrochemical plants or to overseas markets.

In other markets with traditional gas fields (associated or non-associated), the midstream market may not exist and the NGL extraction will be part of the LNG facility. In this case, the ethane may be required to be extracted from the natural gas in order to meet the LNG product spec depending on the end user market. If there is no market nearby for the extracted ethane, the ethane has to be consumed as fuel within the LNG facility or exported as a low temperature, semi-pressurized product.

Synergized Transportation Solution

As an alternate solution, the two products can be synergized to reduce the overall cost of the natural gas value chain. Figure 3.2 is an illustration of the Synergized Transportation Solution. In this solution, ethane and LNG are co-produced and transported together until the receiving terminal, where the ethane is extracted from LNG in a much later stage of the value chain closer to the end users.
This solution utilizes the current LNG value chain as much as possible for ethane transportation. However, the synergized solution requires careful design and operation of following:

- Adding Ethane Extraction unit at LNG regasification facilities.
- Potentially designing the LNG liquefaction facility to receive an external source of ethane to produce an enriched LNG with higher ethane content.
- Shipping of LNG with higher ethane content.

Section 5 provides insight into these units and their design and operation.

4.0 Liquefy Ethane in the LNG Liquefaction Facility for Separated Transportation Solution

Export of ethane as a separate product is a current solution. The ethane in this case can go into a pool of supply and is not necessary tied to an off-taker. Extraction of ethane can happen either upstream of the LNG liquefaction facility such as in United States with mature midstream market, or within the LNG liquefaction facility. Extracted ethane can be liquefied either in an independent ethane liquefaction facility or independent unit within the LNG facility, or co-liquefied with LNG in an LNG liquefaction facility. This section will discuss various ethane extraction and liquefaction processes.

Ethane Extraction

Ethane extraction from natural gas has a long history and there are many processes available in the market. TechnipFMC developed a Cryomax LNG process (US patent 4,689,063) which is suit for deep ethane recovery (99% Ethane Recovery achievable along with 99% Propane Recovery). This process can be implemented in a standalone midstream NGL extraction unit or as part of a LNG liquefaction facility. It provides a unique feature to handle feed gas composition variation, which is common for pipeline gas processing as well as for aged gas fields. In combination with the liquefaction unit, overall efficiency is increased thanks to the NG Booster Compressor raising the liquefaction pressure above 80-85 barg.
This process has been further engineered under the US Patent 7,237,407 to allow the retrofit of existing LNG Plants with Scrub Column HHC Removal Unit in order to extract the ethane from LNG. Specific case studies have been already conducted at FEED Stage.

Sometimes the NGL extraction unit design is required to have the flexibility of operating between propane recovery only and deep ethane recovery according to Petrochemical feedstock demand. TechnipFMC’s Cryomax Flex-E process (US patent 7,458,232) is developed to provide this flexibility. With this process, the operator can adjust the level of ethane recovery to meet market demand. Any ethane recovery from low (2%) to high (90%) while maintaining high propane recovery of 99% is achievable.

**Figure 4.1 – Cryomax Flex-e Process**

CRYOMAX® processes designs provide energy-efficient and cost-optimized solutions for a wide range of gas processing requirements. Investment cost per ton of produced ethane or propane is reduced as compared to conventional expander plants.

Shell has also worked the integration of NGL Extraction Unit and Liquefaction under US Patent 8,534,094 to optimize compressor arrangement and process efficiency demonstrating the benefits of integrating the C2 Extraction inside the LNG Train.

**Ethane Liquefaction**

Similar to LNG liquefaction, ethane liquefaction can be realized through cryogenic process. Compared to liquefying methane (LNG), ethane liquefaction requires much less refrigeration power. Jointly with Air Products, TechnipFMC has developed several technologies for ethane liquefaction including single-product liquefaction and multi-product liquefaction. In the multi-product liquefaction process, ethane and LNG are liquefied in separate tubes bundles in a common MCHE and can be rundown to separate storage tanks and exported as separate products (Patent pending).
5.0 Regasification terminal Ethane Extraction Technology

The scheme consists of LNG feed to the C2+ Extraction unit from the LNG regasification facility. Rich LNG stream from the storage tanks is sent to the LNG Feed Pumps. The discharge stream from the LNG Feed Pumps is heated and partially vaporized in the LNG Feed/Product Exchanger and sent to the Flash Absorber. Figure 5.1 indicates the location of Ethane Extraction unit in LNG regasification facility.

The lean gas (with low C2 content) exiting the top of the Flash Absorber is compressed by the Absorber Overhead Compressor. The C2+ enriched LNG liquid from the Flash Absorber is pumped by the Demethanizer Feed Pumps to the Demethanizer Column. This column removes ethane, to meet the overall 95% C2 recovery, and almost all (>98%) of the heavier hydrocarbons C3+ from the LNG.
The Demethanizer overhead is combined with the discharge of the Absorber Overhead Compressor and then condensed in the LNG Feed/Product Exchanger. The Lean LNG product stream is then sent back to the regasification facility via the Lean LNG Product pumps. Some of the Lean LNG is sent to the Flash Absorber and Demethanizer as reflux. If required the bottom stream from the Demethanizer can be sent to a Deethanizer for ethane and C3+ (LPG) separation.

Figure 5.2 – TechnipFMC Ethane+ Recovery From LNG Process

Advantages of TechnipFMC’s Ethane Extraction Technology

Most design correlations are questionable when the column is close to the critical point. TechnipFMC’s patented (Dual Column Regas Splitter (DCRS) for C2+ extraction from LNG, operates in combination with any existing/new LNG receiving terminal plant to separate Ethane (C2) and LPG Products (C3+ hydrocarbons) from LNG stream. The C2+ extraction unit operates to recover more than 95% of the C2 and allows more than 98% of the C3+ contained in the LNG, meeting required product quality.

The Dual Column Core scheme is optimally designed to process liquid LNG from the receiving terminal, extracting the C2+ components and returning a pressurized warmer liquid LNG to the existing vaporization equipment in the regasification terminal.

TechnipFMC’s DCRS process for C2+ extraction from LNG features a low power consumption scheme with a compact design for the same quantity of C2+ recovered as compared to a typical NGL extraction unit. The process is designed to operate efficiently at moderate temperature and low pressure conditions. The scheme eliminates the extensive gas compression which saves on capital and operating costs.

Key Highlights of TechnipFMC’s DCRS
Patented dual column design utilizing proprietary Flash absorber to overcome performance issues with a single column system

- Two columns (Absorber and De-Methanizer) stacked into one tower, operating at different pressures.
- The two columns operate at farther away from critical points than a conventional single column process giving the process an edge in operational flexibility.
- No pipeline compressor required.
- Lower Power consumption.
- Significant reduction in Capital and Operating cost due to low pressure operating system.
- Compact design provides possibility of locating the unit inside the existing facility saving plot space.
- Fully utilized refrigeration from LNG for ethane recovery.

**Figure 5.3 – Composition on Phase Behavior of Methane/Ethane Mixture**

(TPFMC's two columns are operated farther away from the critical points than the single column processes)

**6.0 Impact on LNG Value Chain for Ethane Production**

This section will discuss the potential impact to the LNG value chain of the Synergized Transportation Solution.

**Impact on NGL Extraction/Fractionation Unit Design**

In the Separated Transportation Solution, to maximize the ethane recovery, the NGL extraction unit needs to be designed for ‘deep-cut’ operation, i.e. high ethane recovery mode. Usually a cryogenic process such as TechnipFMC’s Cryomax or equivalent process will be employed for this purpose as presented in section 4.0. A deethanizer needs to be installed in the fractionation unit to separate ethane from C3+.

In the synergized solution, ethane is not required to be extracted from the feed gas going to the LNG liquefaction unit. The NGL extraction/fractionation unit can be simplified. First the NGL extraction can be designed for LPG and/or condensate extraction only where a simplified turbo-expander process (or sometimes a scrub column) can serve the purpose. Secondly, the deethanizer is not required for ethane separation if self-making of refrigerant ethane is not required. In this case the synergized solution can reduce the investment cost in the NGL extraction/fractionation unit.
Impact on Liquefaction Unit Design

Leaving ethane in the to-be-liquefied natural gas has no significant impact to the liquefaction system design. In fact, since the natural gas becomes relatively ‘heavier’ with higher ethane content, it will be relatively easier for liquefaction, and thus the specific power will be reduced on the total product basis. Possibility of blending LNG from another external Ethane source has also to look at to ensure maximizing the benefits of this solution.

Impact on Storage and Shipping Tanks

Due to the density difference between the high-ethane-content LNG (rich LNG) and the low-ethane-content LNG (lean LNG), owners have to be extra cautious about the ‘rollover’ hazards. LNG rollover is a phenomenon of rapid release of large amount of LNG vapor due to spontaneous mixing up of two separate layers of different densities in a tank. To prevent rollover, different density LNG should be stored and shipped separately. When it’s not avoidable to store different density LNG in a tank, stratification shall be avoided by good mixing and proper filling of a tank.

Impact on Receiving Terminal

For the synergized solution, an ethane extraction unit is required in the LNG receiving terminal to extract ethane from the LNG to: 1) recover ethane as a petrochemical feedstock; 2) adjust the LNG heating value before being sent to the gas pipeline. This ethane extraction unit can be integrated with the LNG regasification unit to further reduce the overall cost. TechnipFMC has a patented technology for this solution. If the ethane cracker can be built nearby the LNG receiving terminal, further cost savings can be realized by utilizing the LNG to provide refrigeration to the ethylene recovery unit.

7.0 Impact on Existing LNG Plant when Modified for Synergized Transportation of Ethane

This section will discuss the impact to an existing LNG liquefaction plant to handle high ethane content feed gas. A case study is presented to show the potential benefits of the synergized solution.

Most of the LNG liquefaction facilities are designed based on certain feed composition range depending on the feed gas sources. LNG liquefaction plants taking feed gas from traditional gas fields (especially associated gas) are most likely already designed to handle high ethane content gas. For those plants, processing high ethane content feed is more of an operational adjustment issue and will have less concerns.

In recent years, development in non-traditional gas fields such as shale gas and coal seam gas (or coal-mine methane) fields not only significantly increased the abundant of natural gas supply, but also provided a much leaner (compared to most of the traditional gas fields gas) feed gas source to LNG liquefaction plants. These non-traditional gas sources have made some recent LNG liquefaction plants being designed to process lean gas only. For example, some of the recent projects developed in United States only designed for processing lean pipeline gas which contains of 2% or less of ethane. Part of the reason is that in US the midstream companies have extracted most of the ethane (to feed to local petrochemical plants) before the gas reaches LNG plants which are usually at end of the pipeline. However, with more shale gas production there is a potential ofethane rich feed gas to LNG plants due to surplus of ethane.

On the other hand, ethane demand has been increasing in the world market especially Asia market. So instead of going the traditional route, i.e. extract, liquefy, and transport ethane separately, an alternate solution is to leave the
ethane in the natural gas feed to the LNG facility, liquefy and transport with LNG as mentioned above. However, what will be the potential impact of process ethane rich gas in an existing LNG plant which was designed for processing low ethane content feed gas? A case study was performed to answer this question.

The case study was based on a TechnipFMC designed LNG plant which was designed to process less than 2% ethane content feed gas. Simulations were conducted to check the impact to the plant by increasing ethane content in the feed gas. The study was performed based on the assumption that the plant is running at its maximum capacity already and no equipment design margin is left. Following are the findings from this case study.

**Impact to NGL Extraction/Fractionation Unit**

In this study, the existing LNG plant has a NGL extraction unit using TechnipFMC’s CRYOMAX process for benzene removal and ethane refrigerant recovery from the lean feed gas. This process was provided to handle pipeline gas which is usually lean in heavy components but still have enough benzene which can potentially cause freezing in downstream liquefaction. It provides a robust design for processing the pipeline gas which is usually uncertain in gas composition. The study shows that the unit can handle up to about 7% ethane content feed gas by adjusting operation conditions with existing equipment. Further increase of ethane content will require some revamp of the existing equipment (such as pumps).

**Impact to liquefaction Unit**

With higher ethane content in the feed gas, liquefaction process specific power (refrigeration power used to liquefy a unit of LNG) is reduced. Thus, with the same amount of refrigeration power, more production is expected. Figure 7.1 below shows the production change with the ethane content. It is interesting to note that while the production on mass basis increases with the ethane content, the production on mole basis decreases with the ethane content but to a less degree.

![Figure 7.1 – Total Liquefaction Production vs. Ethane Content in Feed](image)

The other interesting to see is the ‘net’ LNG production, i.e. the LNG production after subtracting the co-liquefied ethane. It provides an indication of how much LNG production will be reduced while co-producing and shipping ethane, which will be used to analyze the cost comparison between the two solutions in next section. Figure 7.2 below shows the ‘net’ LNG production change with the ethane content in feed.
8.0 Conclusions and the Cost-Effective Approach

From the preceding sections we can conclude that:

- Extraction of ethane from the feed gas to an LNG export terminal for export as a separate product provides flexibility. With time, systematic ethane extraction could lead to a new LNG trade in pure methane for use as fuel and pure ethane as petrochemical feed stock.

- Co-Transportation of Ethane with LNG is clearly a most cost effective and attractive solution to transport ethane to existing petrochemical projects. This will also require significantly shorter schedule compared to developing a dedicated & separate Ethane liquefaction and transportation facility. However it comes with commercial constraints that means it is of interest in certain conditions – long term contract; good links between the natural gas importer and the petrochemical company in the importing country and year round high send out rates of regasified methane.

- Long term solution could still be a dedicated & separate ethane liquefaction, storage and transportation solution due to independent nature of these two markets and where it may make more commercial sense. However, this solution is also prone to risk in case the field gas composition become lean over time as no long-term data is available for the shale plays.

References

1) “Multi-product Flexible Production Facility” Dr Annemarie Weist et al, Air Products And Chemicals Inc./ TechnipFMC. WGC2018, Washington DC, USA