QATAR COMMON LNG: DEVELOPMENT CHALLENGES AND OVERALL BENEFITS OF AN INTEGRATED LNG STORAGE AND LOADING FACILITY

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ABSTRACT

By the end of year 2010, Qatar's liquefied natural gas (LNG) exports from the Port of Ras Laffan are expected to reach 77 Mtpa, resulting in the world's largest LNG export terminal that will be over three times the capacity of its nearest competitor. Of this 77 Mtpa, ~56 Mtpa will be exported as lean LNG (LLNG) and will be stored and loaded in a common integrated shared facility operated by Qatargas.

This common product will be produced from 8 production trains with each owned by one of 5 joint ventures (JVs) involving Qatar Petroleum (majority partner), ExxonMobil, ConocoPhillips, Shell, Total, and Mitsui. All 8 trains will start production over the course of a 5-year period. Over 65 ships will deliver this common product to over a dozen different customers. "Multiple-to-multiple" relationships are abundant in this application and it presents the developers with unique opportunities and challenges compared to traditional LNG projects. The developers have employed dynamic supply chain models and analysis capability within ExxonMobil to identify investment and operational synergies for the integrated facility that prove more effective than traditional, standalone[3] individual facilities.

Seven primary benefits result from this integrated facility: (1) reduced storage requirements, (2) enhanced export capabilities, (3) increased export growth potential, (4) reduced stranded costs, (5) improved maintenance planning, (6) enhanced capability to respond to upsets, and (7) improved capability to optimize JV fleets. Coupled with these benefits, there are design and commercial challenges that need to be overcome during project development. This paper discusses the development challenges and benefits offered by the Qatar Common LNG Facility.

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[3] Standalone – refers to storage and loading facilities that support only a single producing JV and is referenced as the traditional LNG storage model.

1.0 INTRODUCTION

The international liquefied natural gas (LNG) trade experienced rapid expansion in the second half of the 1990s and will experience an even greater expansion over the next ten years [1]. More than 40 million tonnes per annum (Mtpa) of LNG capacity from new greenfield projects will become operational during this time frame [2]. In general, the development of the overall LNG supply chain has been designed with an eye toward four major components of a closed system – (1) liquefaction facilities, (2) storage and export facilities, (3) transportation, and (4) receiving & regasification terminals. The liquefaction facilities have usually been designed along a production module or “train” concept. A “train” consists of the separation, cooling, and processing units employed to convert natural gas from a vapor state to a cryogenic liquid. During the early development of value chains in the LNG trade, trains matched the smaller market demands and the remaining components (i.e. storage, transportation, and loading and receiving berths) were designed to match this market demand as well. As market demand has grown, LNG train capacities have increased accordingly. Single trains began from the 0.5 to 1 Mtpa capacity range and grew to 1 to 1.5 Mtpa in the 1970s and 80s. The train size then grew rapidly to 2 Mtpa in the 1990s and 3 to 4.5 Mtpa by the millennium [3]. Today, trains over 4.5 Mtpa are being executed. In the State of Qatar, two-4.7 Mtpa trains will be producing lean LNG at RasGas by mid-2007 and the remaining six-7.8 Mtpa trains will be installed by Qatargas II, Qatargas 3, Qatargas 4, and Ras Laffan 3 in stages with start-up dates spanning from 2008 to 2010.

This growth is being driven by the demand for natural gas, reduced costs of bringing LNG to consumers, and competition for energy sources. As with most rapid growth, change becomes necessary, which is the case with the huge expansion of LNG throughout the world and especially in the State of Qatar. These changes have been in both the technological and business arenas. Liquefaction train unit costs have been reduced as a result of economies of scale and lower equipment costs. In addition, investments have been made to lower the transportation costs for the LNG supply chain downstream of the train. Adjustments in the traditional long-term contracts are being challenged to offer flexibility in selling excess liquefaction capacity [3]. One over-looked area in the past has been the storage and export terminal.

However, in the recent LNG expansion for the State of Qatar this has not been the case. After significant investment in computational analysis during the development stage of the Qatargas II (QGII) project , it became increasingly evident that a common export facility needed to be developed for Qatar's anticipated growth in LNG production. This common storage and loading export facility will be referred to as the Common LNG Facility. The major findings of the computational analysis indicated that integrating the storage and loading facilities amongst the additional LNG trains enabled a number of system benefits, namely:

1) reduced storage requirements
2) enhanced export capability
3) increased export growth potential
4) reduced stranded costs
5) improved maintenance planning
6) enhanced capability to respond to system upsets
7) improved capability to optimize JV fleets

Coupled with these benefits were both design and commercial challenges.

This paper describes many facets of development for the Common LNG Facility. It begins with a description of the design development process and facility. The facility's benefits listed above are then discussed in detail and are followed by a discussion of the design and commercial challenges that resulted from implementing the system. The primary system dynamics that make it possible to realize many of these benefits are presented prior to a brief summary.

2.0 DESIGN DEVELOPMENT

During the FEED and early EPC stage of the Qatargas II (QGII) project, it became increasingly evident that some kind of common export facility would be most appropriate for the anticipated growth in Qatar LNG production. QGII was initiated as a joint venture between Qatar Petroleum (70%) and ExxonMobil (30%). In early 2005, QGII was tasked with designing this facility to meet its own storage needs and start-up dates as well as the aggressive but somewhat undefined growth of the Qatar LNG portfolio which would ultimately include Qatargas 3, Qatargas 4, Ras Laffan 3, and portions of Ras Laffan II[4].

Some of the storage facilities were already under construction by RasGas to support the standalone approach for lean LNG trains scheduled to start up prior to 2008; these storage facilities needed to be incorporated in this new integrated storage and loading facility. After brainstorming sessions and various design iterations, the new integrated concept came to fruition by incorporating the storage facilities under construction with new facilities so it would be beneficial to all ventures[5] in the future.

Extensive, sophisticated supply chain analysis was performed to quantitatively assess various design alternatives under consideration. This analysis dovetailed with simultaneous efforts to optimize shipping and receiving terminal investments for QGII, RasGas, and their primary shareholders Qatar Petroleum (QP) and ExxonMobil (EM). These JVs employed transportation analysis experts within ExxonMobil Development Company to develop sophisticated transportation simulation models and perform optimization studies. These models were used effectively to optimize the overall LNG supply chain for the Qatar ventures and served to avoid less-ideal local optimizations that occur by analyzing individual components in isolation.

3.0 SCALE OF COMMON LNG FACILITY

Although the Common LNG Facility will offer significant storage volume savings over traditional standalone storage and loading facilities, its size is still significant in

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[4] Ras Laffan Liquefied Natural Gas Company Limited (II) (“RLII”) and Ras Laffan Liquefied Natural Gas Company Limited (3) (“RL3”) are joint ventures between Qatar Petroleum (70%) and ExxonMobil (30%). RLII and RL3 are operated by RasGas Company Limited.

[5] Ventures – QGII, joint venture between Qatar Petroleum, ExxonMobil, and Total; RLII, joint venture between Qatar Petroleum and ExxonMobil; RL3, joint venture between Qatar Petroleum and ExxonMobil; QG3, joint venture between Qatar Petroleum, ConocoPhillips, and Mitsui; QG4, a yet to be formed joint venture between Qatar Petroleum and Shell.

comparison to other facilities. In fact, it will be the world's largest combined LNG storage facility and the largest combined LNG export arena.

3.1 Site & Layout

The site for the integrated storage and loading facilities will be located on a total plot space of approximately 500,000 m^2 at the Ras Laffan, Qatar industrial complex. A general site layout is presented in Figure 1. The facility will be equipped with storage and loading systems and gas processing units to handle gas produced as a result of heat addition to the storage system.

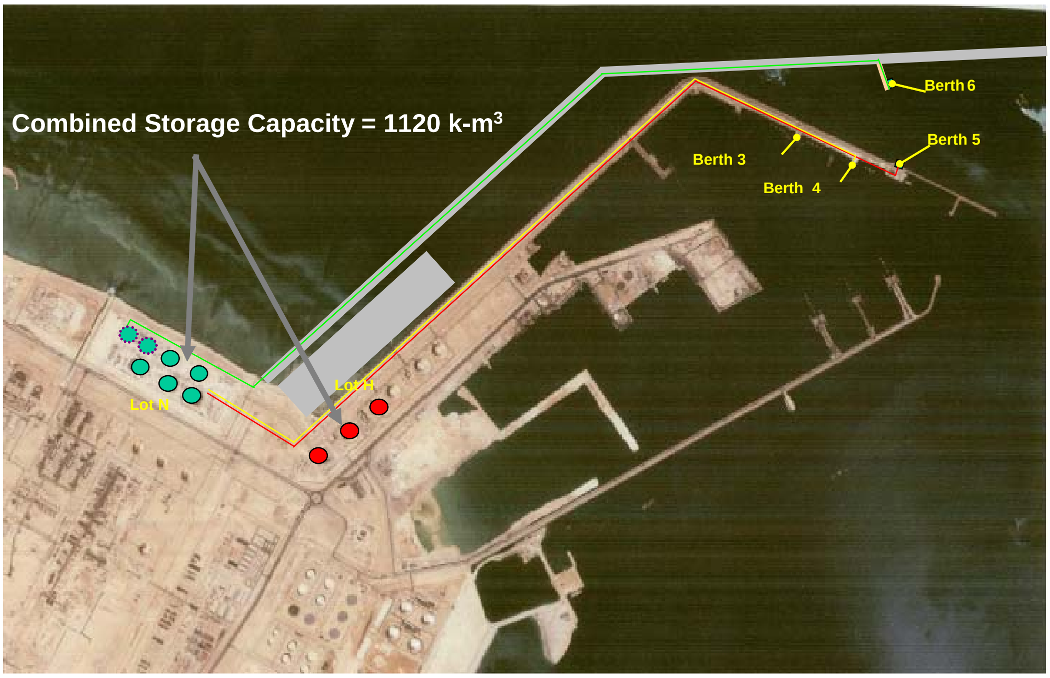

Figure 1. Facility Layout within the Port of Ras Laffan

(The blue-green circles represent the five tanks located in tank farm 1 (Lot N), and the red circles represent the three tanks located in tank farm 2 (Lot H). The circles with the dotted lines represent areas for future storage tank expansion. The colored lines represent the loading pipelines.)

3.2 Tankage

The facility will have a total of eight, 140,000 m^3 storage tanks, resulting in a combined net storage volume of 1,120,000 m^3. This will represent the largest combined LNG export storage facility in the world. This significant leap in storage volume is at least 2 times larger than next largest LNG export storage facility. It will support the total production of 8 lean LNG trains with a combined production of 56 million tonnes per annum (Mtpa). Six trains will produce 7.8 Mtpa and the remaining two trains each will produce 4.7 Mtpa. The storage tanks have double containment walls with internal pumps and vapor connections on the tank roof dome to handle tank boil-off gas.

3.3 Piping Integration

Vapor connections at the top of the tank dome provide the linkage to the 64 inch diameter BOG headers covering over 3 km of plot space that take the gas from the vapor connections to the BOG compression system. LNG entering the storage system is transported via rundown lines ranging from 28 to 32 inches in diameter. Four-36 inch diameter pipes are located inside the tank storage facility to transport the LNG from the individual train rundown pipelines to the storage tanks.

The storage tanks are built on two-plot spaces, Lot H and Lot N, separated by ~1.5 km. A ~2 km long interconnect rundown header and 0.3 km long transfer header link the two tank farms. These two headers act as integrators to link the two tank farms. First, the interconnect rundown header allows LNG from select trains to store LNG in either tank farm depending on the export demand and unoccupied storage volume. Second, the transfer header allows LNG to be moved from one tank farm to the other.

3.4 Berths & Loading Lines

Connected to the tank farms are four sets of export headers referred to as loading lines. Each set of loading lines is linked to a single berth and a single tank farm. The three sets of paired loading lines connected to the five Lot N tanks are 36 inches in diameter. The other pair is 32 inches in diameter and is connected to tanks in Lot H. While in the holding mode (i.e., *not loading ships*), the paired loading lines recirculate LNG in order to keep cool. The combined distance that the cryogenic loading lines cover is over 65 km.

The common facility consists of four berths that are all designed to handle the new QFlex and QMax ships being acquired by the Qatar LNG JVs. These are LNG berths 3, 4, 5, and 6 as shown in Figure 1. The combined export capacity of the four berths is at least 64 Mtpa. The design export capacity is largely a function of an average allowable allocation factor (i.e. *berth allocation*), storage capacity, and loading rate. Berth capacity is discussed in more detail within section 6.3. Three of the berths have a maximum loading rate of 14,000 m^3 per hour, and the fourth berth has a maximum loading rate of 10,400 m^3 per hour. The difference in loading rate is attributable to pumping system design differences between Lot H and Lot N tanks.

4.0 BENEFITS

The Common LNG Facility brings with it a number of benefits to current and future co-owners as well as their customers.

4.1 Reduced Storage Volume Requirements

First and foremost, the facility enables a reduced storage requirement for the given throughput. The storage volume required to support the State of Qatar’s 56 Mtpa of additional LNG is a factor of two less than the storage-to-production ratio for the standalone system associated with smaller scales of production. For example, the storage-to-production ratio for Qatar’s existing RasGas rich LNG trade is ~38 k-m^3 per Mtpa. Similarly, the Qatargas rich LNG storage-to-production ratio is ~40 k-m^3 per Mtpa. Both the RasGas and Qatargas rich LNG storage facilities are based on the traditional storage and export model of standalone facilities for each set of trains rather than an integrated Qatargas-RasGas storage and loading facility. In contrast, the described approach (i.e., an integrated storage and loading facility) for Qatar's ~56 Mtpa of lean LNG has a storage-to-production ratio of 20 k-m^3 per Mtpa.

Sharing tankage alone does not guarantee significant storage reduction. If each JV maintains inventories as it would in its own standalone facility such as suggested generally in Figure 2, a shared facility would resemble only the sum of its parts. The key to designing an optimal facility is using operational synergies to optimize inventory management practices. Although storage capacity required for heel, unpumpable, and warning areas is relatively small and simply scalable, reserve and fluctuation areas can be greatly influenced by operational synergies. The dynamics at work here are discussed later.

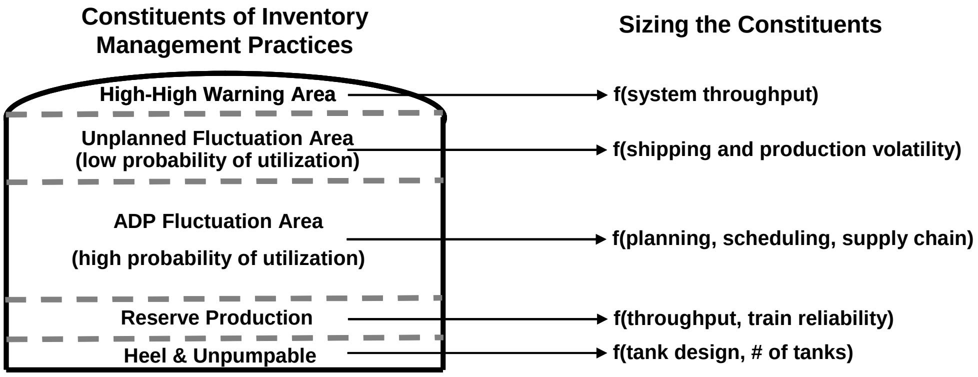

Figure 2. Inventory Management Practices

4.2 Enhanced Export Capability

In order for the facility to handle Qatar's ~56 Mtpa of *average* annual lean LNG exports, the facility must be capable of exporting full production during years of better-than-average train availability. Planned production in any given year may be ~3% greater or less than 56 Mtpa. Analysis has shown that the facility could handle even greater throughput - as much as 10% more - without additional tanks or berths and without significant changes to operational policies. This margin is largely due to excess berth capacity.

4.3 Capable of Efficient Expansion

The facility is well designed for system expansion. Although 5 tanks are contracted to be built in Lot N, the lot and piping tie-ins can accommodate 2 additional tanks. There is excess berth capacity as mentioned above; however, if additional berths are required, it may be possible to construct them along the new north breakwater expansion. Lastly, it may be possible for JVs to jointly purchase additional tanks and berths. In all likelihood, this would reduce the unit cost of production expansion when compared to a standalone environment. In the expansion of a standalone facility, a venture might inefficiently invest in incremental tanks or berths because fairly marginal production increases require the investment.

4.4 Reduced Stranded Costs

The facility's inherent flexibility minimizes stranded export capacity during planned and unplanned train shutdowns because tanks and berths are not physically dedicated to individual trains. Furthermore, if a tank or berth must be removed from service, individual trains are not seriously impacted and the system is still capable of meeting export requirements. Although there is not sufficient capacity to operate efficiently for extended periods with only 3 loading berths or less than 8 tanks, operators have tremendous flexibility to maximize exports and honor customer commitments despite temporary periods of costly inefficiency.

4.5 Improved Maintenance Planning

The Qatar Common LNG Facility enables JVs to efficiently plan downtime of supply chain assets by providing an avenue for treating LNG as a fungible product. Traditionally, LNG producers and shippers endeavor to align planned train maintenance shutdowns with fleet dry-dockings. The Qatar LNG JVs are challenged to do this in an efficient, coordinated process for the following reasons:

- **Quick, clustered ship deliveries** - Shipyard deliveries of the 45+ QFlex and QMax LNG carriers are made intermittently over a 3-year period where as many as 4 ships may be delivered in one month.
- **Unaligned asset maintenance cycles** - QFlex and QMax ships are intended to operate on 5-year dry-docking cycles, but planned train maintenance shutdowns occur every 1.4 to 2 years.

On a standalone level, these very significant misalignments can cause over-investment in storage or shipping and irregularity in customer deliveries. In a common environment, JVs can cooperate as necessary during the annual delivery program (ADP) process in order to minimize the effects of train and ship downtime. Synergistic ADP planning also makes it easier for Qatar JVs to be flexible with customer needs. These synergies require an entitlement system to track LNG that each JV has produced and lifted.

4.6 Capability to Respond to System Upsets

Consistent with traditional LNG systems, the Qatar LNG supply chains are all assumed to be "close" systems where ships are assigned to specific trades. The common facility becomes a focal point for management of major system upsets to any of the Qatar JVs (i.e. shipping loss, major train breakdown, or receiving terminal failure). Similar to the cooperation that may take place when planning around train and fleet maintenance events, JVs can work together to reschedule while allocating inventory costs and shut-in responsibility as appropriate.

The facility is perhaps most adept at minimizing the impact of minor system upsets and large shipping delays. These impacts are minimized in the following ways:

- **Berth flexibility** - Since all JVs have access to all 4 berths, short-term berth rescheduling due to late or early ships can often be accommodated
    - Simultaneous allocation of all 4 berths is expected to occur less than 15% of the time

- **Supply chain diversification** - Although preliminary marketing plans at the time of the system sizing analysis were weighted heavily toward west of Suez sales, deliveries were planned to 13 different markets (see Figure 3). Although the facility receives a ship about every 14 hours it's fairly unlikely that sequential ships will be subject to the same voyage delays (perhaps with exception to Suez Canal delays). If a ship misses its scheduled loading, it's likely that a ship scheduled slightly later can be advanced to fill the delayed ship's slot. This minimizes the logistic impact of minor upset events that may occur at a single receiving terminal, in a region, or along a single voyage.

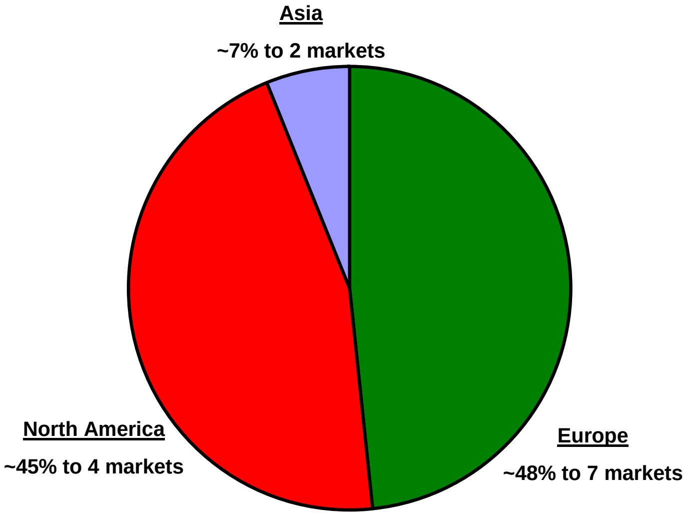

Figure 3. Market distribution of Qatar lean LNG

4.7 Contributing Toward Fleet Optimization

The common facility is an enabler to overall fleet optimization. A basic assumption in the design analysis was that each ship is to be allocated to the cargoes and customers of its charterer. However, there is an expectation that the common facility will enable a JV to optimize its fleet utilization (either during the ADP development or shorter term optimizations) especially during the maintenance periods. Given the scale and production diversity inherent in the system, there is a higher likelihood that product will be available on schedule thus reducing cargo waiting delays. There's also a better chance that additional production or delays on other ships may make it possible for a ship that is returning from a faster-than-planned voyage to be redeployed ahead of schedule. The scale of a standalone facility is less likely to offer these opportunities.

5.0 CHALLENGES

The integrated facility presents design integration difficulties and unique obstacles to development of commercial agreements.

5.1 Design Challenge

As mentioned in section 2.0, in early 2005 QGII was tasked to design this common facility to meet its own storage needs and start-up dates as well as the aggressive but somewhat undefined growth of the Qatar LNG portfolio. At that time, RasGas was actively constructing RLII Trains 4 and 5, the associated storage in Lot H, and an LNG berth. Given this starting point, the common facility was faced with two significant design challenges:

- Integration of existing and new facilities
- Uncertainty in the number of trains and corresponding start-up schedules.

To overcome this challenge, the evolution of Qatar's Common LNG Facility followed a systemic sizing process that is directionally consistent with industry practice such as shown in Figure 4. However, the process for this application had to be flexible enough to foster systemic optimization in an environment of evolving scope requirements and uncertain throughput growth.

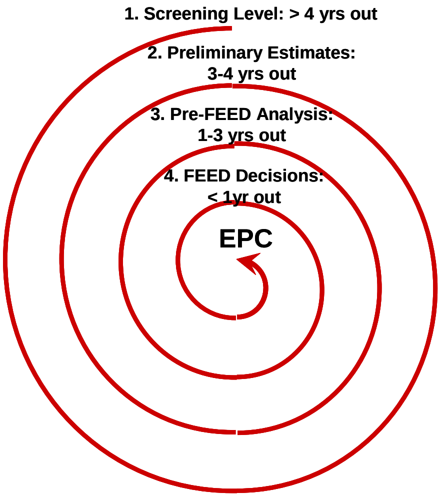

Figure 4. Typical Facility Sizing Process
(within context of a typical project design spiral)

This challenge of merging the series of standalone storage systems for the first set of LNG trains with a seamlessly integrated storage and loading system was overcome by using four key methods – integrating with the new with existing, designing continuous operational tie-in points, employing modular design/construction, and instituting a common LNG specification.

Integrating the new with the existing was accomplished with an interconnect rundown pipeline and transfer pipeline. The interconnect piping linked the existing RasGas lean LNG tank farm (known as Lot H) with the new tank farm (Lot N) by allowing LNG from multiple production trains to have access to both tank facilities. The transfer pipeline allows LNG to be moved from the existing tank farm to new tank farm and in reverse. Both design features aid in management of the storage inventory.

Designing continuous operational tie-ins ensured that production pipelines and storage tanks could be installed while the facility was under operation without a shut down. This was critical since the start up dates for the production trains are staggered over a 5 year time horizon - 2006 to 2010; see Figure 5 and Table 1

Table 1. Summary of Production and Storage Capacity Growth for Qatar's Lean LNG Expansion

QATARGAS AND RASGAS LEAN LNG PRODUCTION & STORAGE CAPACITY LEAN LNG (LLNG) TANK FARM						
Joint Venture	**Train**	**Incremental Production (Mtpa)**	**Cumulative Production (Mtpa)**	**Incremental Storage (k-m^3)**	**Cumulative Storage (k-m^3)**	**LLNG Berths**
RLII	Tr 4	4.7	4.7	140	140	3
RLII	Tr 5	4.7	9.4	280	420	
QGII	Tr 4	7.8	17.2	280	700	3, 4
RL3	Tr 6	7.8	25	140	840	
QGII	Tr 5	7.8	32.8	140	980	
QG3	Tr 6	7.8	40.6	140	1120	3, 4, 5
RL3	Tr 7	7.8	48.4	0	1120	
QG4	Tr 7	7.8	56.2	0	1120	3, 4, 5, 6

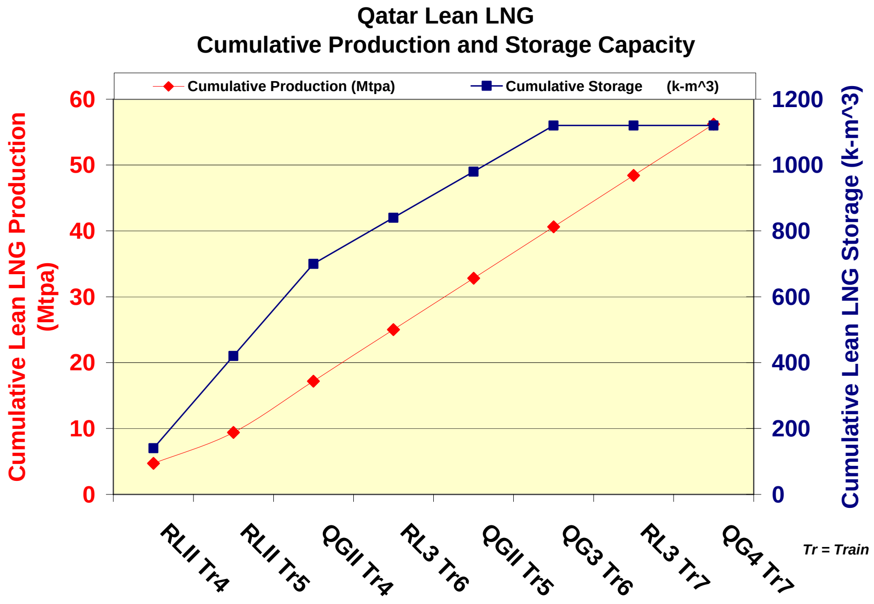

Figure 5. Summary of Production and Storage Capacity Growth for Qatar's Lean LNG Expansion

The third method employed to overcome this challenge was the modular construction associated with the storage tanks and loading berths. As the storage capacity is required, LNG tanks can be installed to match that demand. Correspondingly, the export facilities (i.e., loading lines and marine berths) can be installed as the existing berths reach their export capacity limit. This modular approach combined with the continuous operation tie-in points allow continuous operation and construction to occur safely without any impact on tank filling and tanker loading. Additionally, this modular approach results in an efficient deployment of capital costs.

Lastly, instituting a common lean LNG specification ensured that LNG stored in the tank farms would have a compositional value that was acceptable to all of the JVs. In essence, it becomes a fungible product, allowing JVs to export the lean LNG product from any tank and any berth.

5.2 Commercial Challenge

To exploit the technical benefits of the Qatar Common LNG Facility, certain commercial obstacles had to be overcome. They were (1) establishing a capital cost allocation methodology, (2) agreeing on separate utilization methodologies for tanks and berths, and (3) developing an inventory allotment system.

Establishing a capital cost allocation methodology for the various components of the facility posed a concern from the JVs regarding equitable sharing of costs. Some of the storage facilities were already under construction based on the traditional standalone concept when the Common LNG Facility was conceived. EPC contracts had already been awarded by some JVs that were pursuing a standalone approach. Integrating the capital costs of these already awarded EPC contracts with the yet to be awarded EPC contracts presented an obstacle. It was overcome by establishing a cost allocation methodology for the various components (i.e., tanks and berth facilities) that allowed a JV to take advantage of lower capital costs associated with previously awarded EPCs (specifically in a rising cost market). Their costs were then merged with future EPC contract costs, and the total costs were shared equitably with all participating JVs.

Agreeing on separate utilization methodologies for tanks and berths presented difficulties in instituting rules for JVs access to the various components of the integrated storage and loading facility. There is a tendency to use average rundown rate of the production trains as the primary usage factor. This is appropriate for berth access, but is not for storage access. Just as in a standalone application, a JV's storage requirement is based on the inventory fluctuations expected in its supply chain. These fluctuations are influenced by voyage time volatility, ADP ratability and scheduling requirements, parcel size, throughput, relative fleet capacity and a number of less significant factors. JVs anticipating greater inventory volatility need access to more storage than ones expecting less volatility. A negotiated resolution was required to address this difference in storage capacity needs. This negotiated resolution resulted in JVs who expect to require more inventory and experience greater inventory volatility obtaining a larger fraction of the tank volume.

Lastly, establishing the inventory entitlement system provided another hurdle. Traditionally, each venture would have a specific, integer number of tanks and berth dedicated for its exports. In this integrated system, each JV is entitled to a fraction of the total storage and berth capacity, resulting in a more complex system to manage. Each JV is expected to occasionally require more storage than originally entitled, but each JV is also expected to often use less storage than originally entitled. The participating JVs are establishing a system of usage fees and production curtailment rules to allow high entitlements to occur as necessary while encouraging JVs to operate within their entitlements. Due to continual borrowing and relinquishing of storage capacity, there will be challenges managing the total inventory level and individual inventory allotments for the various JVs. Effective management of the total inventory is critical to ensure the inventories do not reach storage capacity and cause production shut-ins.

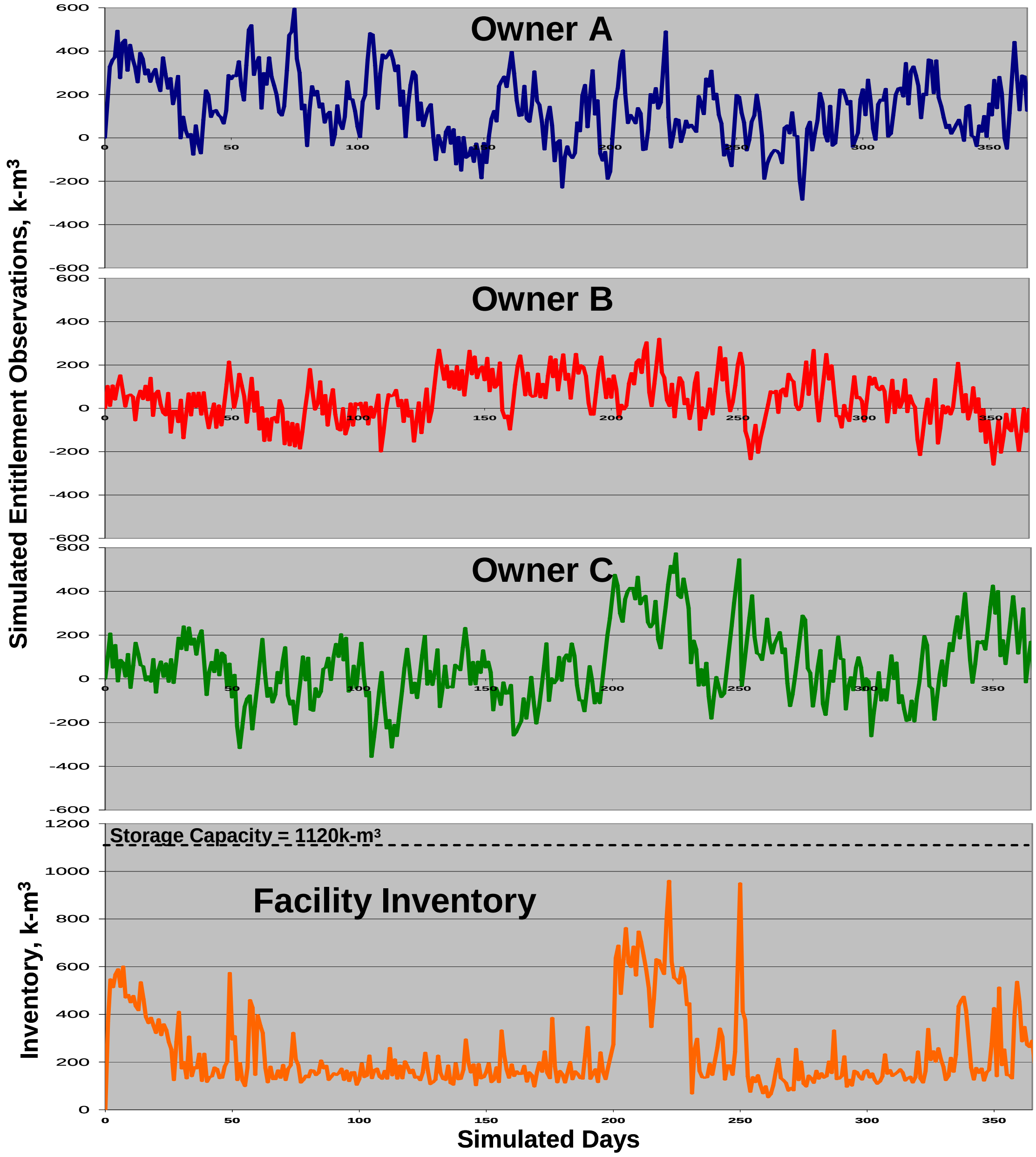

Figure 6. Sample Simulation Observations of Owners' LNG Entitlements & Overall Facility Inventory

As stated in earlier sections, several pipelines from the five JV owners are feeding this storage and loading facility and four berths are acting as outlets. Therefore, "multiple-to-multiple" relationships complicate the effective management of inventory entitlement levels for the individual JVs. Figure 6 depicts the typical inventory entitlement swings that would exist over a multi-month period for this facility and demonstrates complications in managing the total inventory and JV entitlements. For example, *Owner B* has periods where its inventory level swings from about +250 k-m^3 to about -220 k-m^3 for a one-year period and *Owner C*'s inventory swings from about +600 k-m^3 to about -380 k-m^3. This imbalance is managed by establishing equitable rules for inventory allotment, sharing of inventory data, and employing a state of the art software system.

6.0 PRINCIPAL DYNAMICS OF INTEGRATED SYSTEM

6.1 Promoting Low Inventories through an Entitlement System

In a standalone facility it is necessary for the venture to have produced at least the cargo volume prior to a scheduled loading. Therefore, total, cumulative LNG lifted by that venture is always less than the total amount of LNG produced by that venture. However, in the common integrated facility a JV is able to lift more than it has produced. As discussed above, an entitlement system has been established that tracks all production supplied to the facility and all cargoes leaving the facility. An extensive metering system has been included that tracks origin, specification, and volumes of LNG over time. The primary purposes of the entitlement system are as follows:

- Promote efficiencies similar to LNG production sharing across JVs
- Track and allocate costs of inventory stockpiling
- Facilitate assignment of train shut-in responsibility during tank-top and upset events
- Promote low inventories and maximize availability of production to shipping by allowing JVs to experience negative balances (i.e. liftings exceed production).

As noted, JVs are capable of optimizing inventory management practices for tankage needed for “reserve production” and “fluctuation” by implementing an entitlement system. Simulation analysis has helped to demonstrate the benefits of this entitlement system by simulating and tracking over time the expected inventory needs of each JV owner such as shown in Figure 6 above. The analysis suggests that system performance can be improved over 50% by allowing JVs to draw into other JVs’ inventories or to figuratively “go negative.”

Figure 7 below proves this point. The cases where JVs are permitted to draw on negative entitlements beyond -400k-m^3 are indicative of periods where JVs who are temporarily long on shipping haul cargoes produced by JVs who are temporarily short on shipping. The simulation analysis treats these deep dips of entitlement in a simple fashion that is somewhat reflective of a production sharing environment. However, in reality, the situations that require these deep dips may be treated with other commercial arrangements such as planned swaps or FOB sales to the facility’s partner JVs.

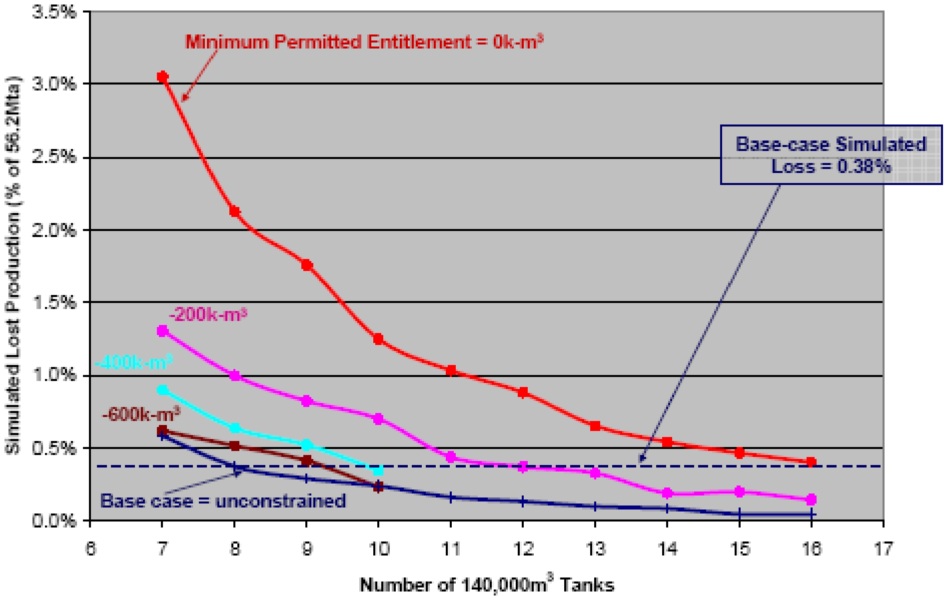

Figure 7. Simulated Lost Production Observations[6] as a Function of Minimum Entitlement Requirements and Number of Tanks Installed

6.2 Relationship between Floating Storage and Inter-arrival period

The relationship between the throughput scale of this facility and the frequency of liftings enables a dynamic phenomenon referred to as “floating storage.” This term is often used to describe systems where “surplus” ship capacity is purposely acquired to act as supplemental storage, but in this application the floating storage effect is more of a by-product of the massive scale. There are two significant factors at work here:

- Low inter-arrival time – Figure 8 shows that as throughput grows to ~56 Mtpa, ships arrive about every 14 hours.
- High fleet utilization - Table 2 below provides sample metrics from a representative trade served by Qatar JVs. This sample suggests fairly high fleet utilization on an idle time basis of 96.1% (90.4% on an ideal voyage basis).

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[6] A key performance indicator in the supporting supply chain analysis is the amount of simulated production shut-in (and subsequent revenue loss) that occurs when inventories reach storage capacity.

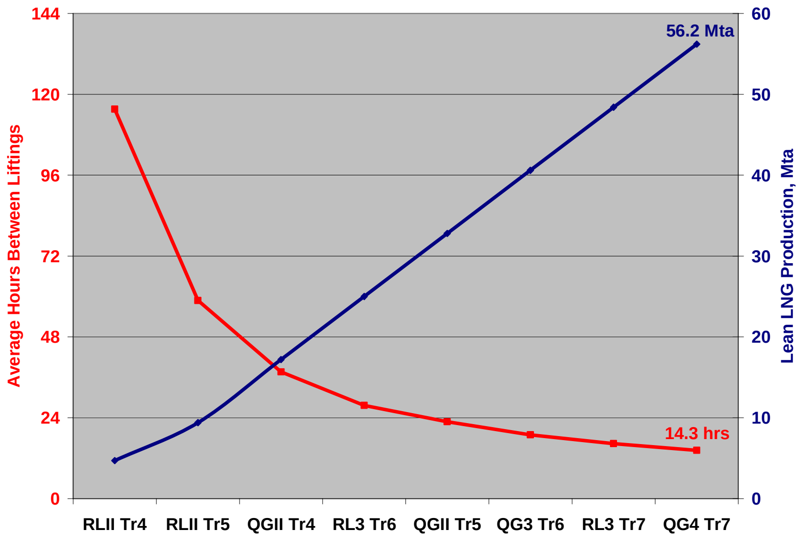

Figure 8. Relationship Between Production Build-up and Average Time Between Liftings

Table 2. Sample Voyage Observations

	Duration	Comments
Average voyage duration	32.7 days	average after all delays
Average ideal voyage duration	29.6 days	best possible; cannot be done in less time without speeding-up ship
Delta	3.1 days	
Average idle time	30.3 hours	includes delays for cargo, berth, and tank ullage availability

The sample above indicates that an average of 30.3 hours of margin is available per voyage to cover the dynamics associated with cargo, berth, and tankage readiness. The sample ship could slow-steam back to the Ras Laffan, Qatar port if a significant part of this margin would be spent otherwise waiting for cargo readiness. However, the system operators may choose not to slow-steam the ship if a ship scheduled for an earlier lifting appears to be significantly delayed. With liftings occurring every 14 hours on average, a ship with 30 hours of “idle” time on hand may be able to “cover” one of two earlier liftings. This concept of floating storage that results as a by-product of scale is estimated to represent about 350,000m^3 of storage capacity ($2^1/_2$ x 140,000m^3 tanks). Since this is a dynamic transportation system, it is important to realize that these opportunities are not always present or actionable. Furthermore, identifying and acting upon these opportunities is sure to be a challenge in itself.

6.3 Multiple Berths Enable Higher Berth Utilization

Practical maximum berth utilization converges toward theoretical maximum berth utilization as service time decreases and the number of berths available increases. *Practical maximum berth utilization* is the design point for maximum utilization of a berth or series of berths. *Theoretical maximum berth utilization* is the maximum possible utilization that a berth can physically load ships. These can also both be stated in terms of capacity or throughput. The theoretical maximum is fairly objective and is typically based on 100% utilization. The practical maximum design point can be quite subjective, but successful criteria must take the following items into account:

i. downtime associated with maintenance and weather
ii. required port time and queuing delays on ships
iii. extended vessel cool down requirements
iv. needs for irregular loading schedules
v. shipping due-date ranges and commercially-required loading windows
vi. downstream impacts on the supply chain
vii. impact on storage sizing

Under most circumstances, it is not feasible to expect a dynamic system to have berth design points where practical maximums are equal to theoretical maximums. The facility design point was chosen to be 70% *berth allocation* based on a combination of numerical and supply chain analyses and experience from terminal operators. A standalone facility, very much based on the items noted above, is likely to have had a maximum berth allocation ranging from the upper 50%'s to lower 60%'s. Berth allocation differs from berth “utilization” or “occupancy” in that it includes time that the berth is physically occupied *and* “dead time” when the berth is not physically occupied but is physically unable to be occupied by another ship. More specifically, this “dead time” includes harbor transit time of the berthing or departing ship and miscellaneous delays[7] while a ready ship is awaiting clearance to start its approach into the harbor. In this application, allocated time does *not* include unoccupied time during due-date ranges, commercially-required loading windows, or weather lock-out periods when no ships are waiting for the berth.

Many view 70% allocation (equivalent to 60-65% utilization in this application) as relatively high, but since the impact of such high throughput is not expected to constrain the supply chain, this design point is viewed as appropriate, if not conservative, for this application. Figure 9 below demonstrates the point. Consider the scenario when two ships from the same JV arrive to the port simultaneously. The red line suggests that when only one berth is installed (such as in a standalone case) a ship can only be loaded and “turned around” every 34 hours. That means the second ship is likely to have a 34 hour delay. The system designer must then make sure that there is either an installed over-capacity of shipping and/or a relatively low design point for the berth capacity in order to minimize the probability or impact of long loading delays. However, when four berths are used in that same scenario, the second ship would only be delayed about 7 hours before a berth was made available. This simple example gets quite complicated when weighing all the possible scenarios. For this reason, dynamic modeling tools were utilized and are recommended to thoroughly evaluate specific applications. The dashed line below shows how the maximum, instantaneous capability of the loading system is, not surprisingly, well above the long-term average system requirement. Prudent planning and operation may prove that the 70% allocation threshold was quite conservative.

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[7] Miscellaneous delays prior to clearance for harbor approach could be attributed to harbor traffic, weather, or tug/pilot availability

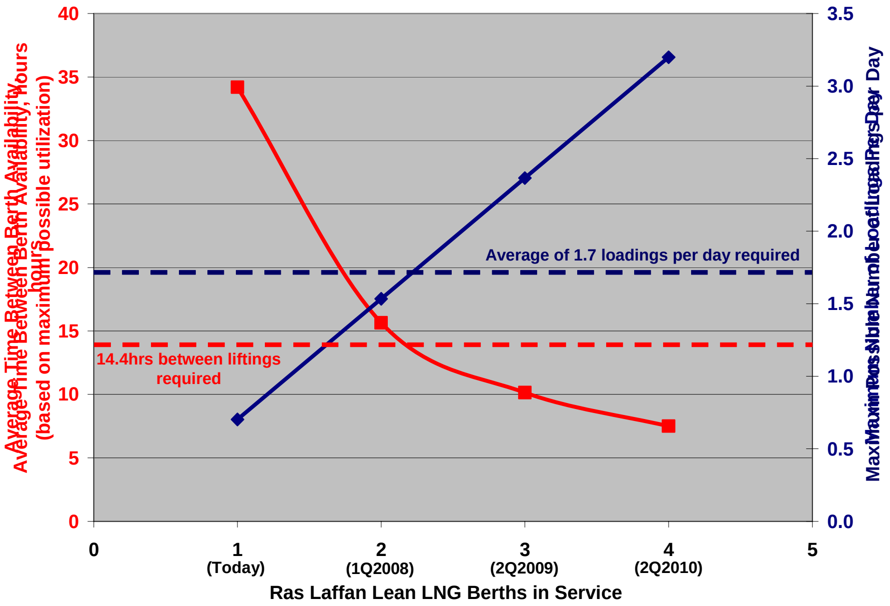

Figure 9. Average Time Between Berths Becoming Available & Maximum Possible Number of Loadings per Day (average parcel used as basis)

6.4 Control of Shipping

In many of Qatar's lean LNG supply contracts, Qatar JVs are responsible for providing shipping and therefore are the controlling charterer. This has great advantage from the perspective of the storage and loading facility. The primary purpose of storage is to provide buffer for fluctuations in production and shipping arrivals. With control of shipping in the same hands as the JVs and operators of the common facility, the primary purposes of storage can be accommodated in the most cost effective manner. Tactically speaking, the following actions can help minimize the impact of temporary storage constraints

- Loading schedule changes
  - Rearrange loading schedules to avoid production shut-in due to tank-top events
  - Delay loading of ships in order to “squeeze in” spot cargoes from opportunity production

- Vessel speed-up
  - Accelerate ships in route to alleviate potential tank-top events
    - Example: Operators can load a ship over 7 hours earlier than planned by accelerating a ship just 1 knot during the generally calm transit from Suez to Ras Laffan, Qatar port. The average parcel size of about 200k-m^3 offers significant floating storage and is significantly larger than the 100+k-m^3 of LNG that is produced during this “saved” time.

7.0 SUMMARY

The five JVs associated with Qatar's 56 Mtpa lean LNG production expansion have chosen to inventory and load their LNG exports through a single integrated facility instead of numerous standalone facilities. Qatar's Common LNG Facility is of unprecedented scale and offers several value-adding benefits. The facility's design and operational synergies offer unitized storage savings of about 50% over traditional, standalone LNG storage and loading facilities. The facility's expandable tank farm design and available berth capacity when coupled with port expansion plans can accommodate significant production increases. The shift away from standalone facilities dedicated to each JV minimizes periods of stranded storage and berth capacity during planned and unplanned train shutdowns. Furthermore, a single producer is not stranded or extremely constrained if a single berth or tank is removed from service. Planning is enhanced because the common specification and storage facility allow all lean LNG production to be treated fungibly. This also improves immediate response and recovery to supply chain upsets. Lastly, the facility contributes to optimization of the Qatar JVs' fleets by providing storage and loading flexibility that minimizes necessary inventory holding time and encourages lifting schedule optimization and reallocation. This reduces potential delays to shipping.

To exploit these benefits, design and commercial hurdles had to be overcome. The primary design challenges were (1) integrating the new facilities with existing facilities and (2) engineering storage and export capacities with uncertainty about future production growth. There were three commercial hurdles that had to be addressed: (1) establishing a capital cost allocation methodology for existing, contracted, and yet to be contracted facility assets, (2) bringing JVs to agree on separate utilization methodologies for tanks and berths, and (3) developing an inventory entitlement tracking and management system.

When compared to the traditional, standalone approach for storage and loading, the overall benefits of the integrated approach far outweigh the challenges that had to be overcome to attain it.

8.0 REFERENCES CITED

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