LNG FPSO : TURBOEXPANDER PROCESS ECONOMICS MONETIZING THE "GAS PROBLEM"

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ABSTRACT

Three years ago, here at the GPA, ABB Lummus Global Inc. presented the Turboexpander Dual Refrigeration Cycle Process for LNG onshore/offshore, an ideal technology to capture and provide solutions to the "gas problem" of remote associated gas production.

In this paper I propose to present the results of the ABB program of technology development (NicheLNG Offshore^{SM}) aimed at the offshore application of NicheLNG^{SM}. NicheLNG^{SM} is LNG process technology for small scale and mid-scale gas applications, developed by ABB Lummus Global's Randall Gas Technologies Division.

The paper reviews the application of the technology to associated gas offshore the West African coast and the delivery of LNG to markets in Europe and the US.

After a brief review of the technology and processing facilities required, the paper focuses on the marine aspects of the LNG FPSO solution (Storage, Off-Loading, Marine/Cargo Systems, Structural, Hull Definition, Mooring Systems) and the safety aspects.

To conclude, a discussion on delivered LNG economics, highlighting Cost of Service (COS) is presented, which includes analysis of different export scenarios and capital and operating cost sensitivities. The results of the study clearly show that this solution is able to deliver LNG at COS of 3 to 4 $/MMBTU LNG. With the current trends of gas prices, this represents an attractive opportunity to monetize stranded gas.

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Introduction

In March of 2002, Randall Gas Technologies a division of ABB Lummus Global Inc., presented the Turboexpander Dual Refrigeration Cycle process at the GPA. At that time, we announced that ABB was committed to the development of a solution for the capture of stranded gas and gas associated with oil production, especially offshore gas. NicheLNG^{SM} process technology as it is marketed, was developed as a cost effective solution for the monetization of small scale and mid-scale reserves of non-associated and associated gas. This paper reports on the latest developments on the NicheLNG process, and the its application offshore (NicheLNG Offshore^{SM}).

The "gas problem"

As environmental friendly policies are more rigorously applied, gas flaring is progressively being eliminated. What options does the Operator have for an offshore field that produces gas in the order of 75 to 200 MMscfd? His current options include:

- Re-injection of gas to the reservoir,
- LPG and condensate extraction and gas re-injection,
- LPG and condensate extraction and gas export,

The first option, is not always feasible (depending on the reservoir). It incurs capital and operating cost with no revenues. However, it is a necessary step to avoid gas flaring.

The second and third options have the potential to generate revenues from the extraction of condensate (which can normally be commingled with the export oil) and from the recovery of LPG (propane and butanes). This solution is increasingly being used in offshore developments in West Africa, South America, and South East Asia. Unless there is an economical alternative for the pipeline export of gas to shore, the residual gas still remains an issue.

The NicheLNG process technology was conceived as a cost effective solution to the "gas problem".

The NicheLNG process Program

Two ABB Lummus Global divisions, namely Randall Gas Technologies (RGT) and Floating Production Systems (FPS), have participated in a joint technology development program for the NicheLNG Offshore concept.

The technology development program was the outcome of a business strategy decision taken to jointly develop and market enabling technology solutions for the exploitation of offshore stranded gas. The development program would pool together RGT's know-how in turboexpander technologies and FPS' offshore expertise.

The first phase of the technology program included the development of a design package for an LNG FPSO concept, based on the NicheLNG patented process technology. This work included definition of the topside facilities, configuration of storage, offloading and mooring systems, and the development of safety systems and processes. Based on the technology developed, cost estimates and project schedules were generated for a notional deployment of the facility offshore West Africa. An economic model was also developed covering the production, processing and supply chain from the gas field to the market.

Emerging Developments in the LNG Business

Historically, LNG has been a “utility” business involving long-term contracts between producer, plant operator, transporter, storage terminal operator, and pipeline operator. Project economics have been driven by the “denominator effect” whereby a larger plant can generate a lower unit price for LNG, and very large plants, in the range of 500 to 1,000 MMSCFD, have typically been the norm.

The biggest challenges facing LNG projects have been issues relating to current structure of project financing. Proven processes, developed for application to large land based LNG facilities, pose minimum financial risk to stakeholders and have thus been the processes of choice.

More recently, transactions on an opportunistic basis have taken place, with spot market trading of LNG on a much smaller scale. This trend is expected to continue and accelerate, as government regulations prohibit flaring and resource owners increasingly seek ways to monetize stranded reserves.

The NicheLNG process concept is intended to capitalize on this emerging LNG business paradigm shift.

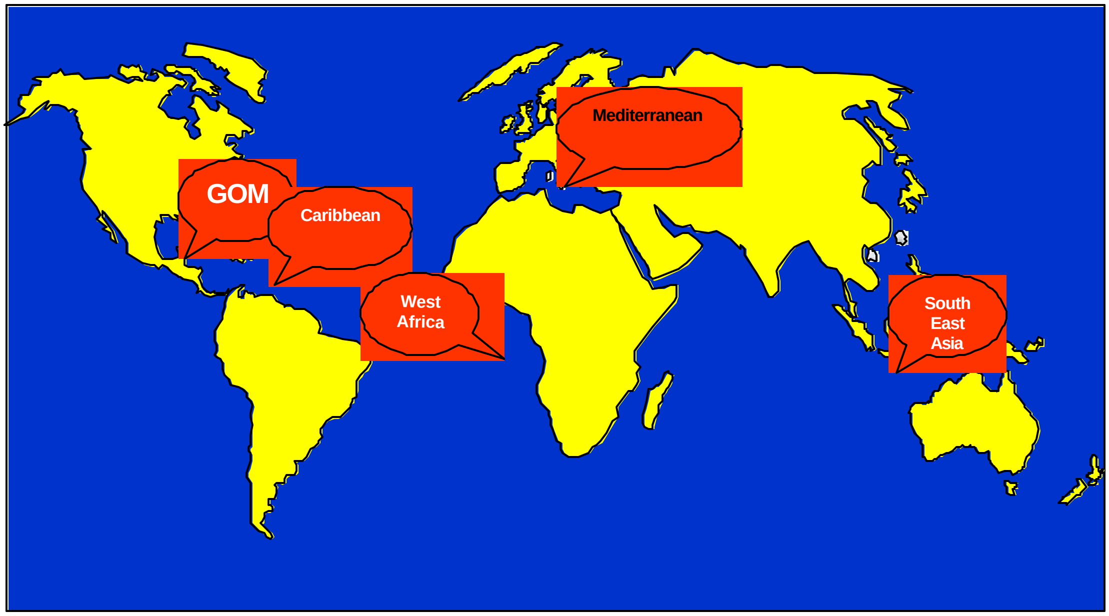
The continuous growth in plant and train size, is indirectly contributing to the conditions that will justify the application of the NicheLNG process technology. NicheLNG process, with capacity modules of 0.5 Mmtpa allow small increments of production to be implemented in response to supply-demand imbalances, without incurring the capital cost of the large -scale plants.

The preferred project applications for NicheLNG are adjacent to oil producing FPSOs, where the process will eliminate flaring, or alternatively the need for re-injection facilities, or for the pipeline export of gas.

Figure 1 shows the potential sites that favor the use of NicheLNG process technology.

NicheLNG process could typically be considered for associated or non-associated gas reserves of 0. 5 to 3 TCF.

Figure 1-Regional Opportunities for NicheLNG



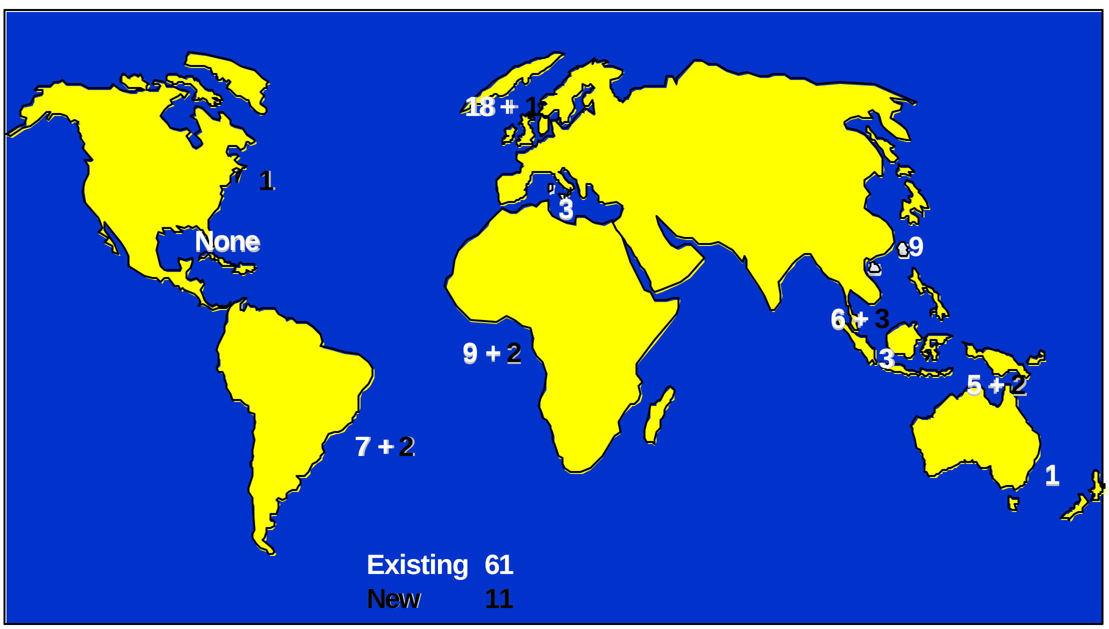


Figure 2
Worldwide FPSO Distribution

Figure 2 shows the distribution of FPSO's around the world (circa 2003)

Brief review of LNG Turboexpander Technology

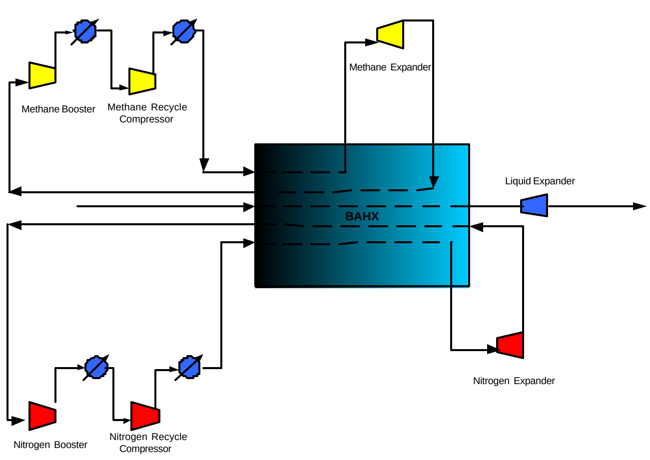
ABB Randall Gas Technologies developed the LNG Dual Turboexpander Cycle for LNG production, and it was granted U.S Patent 6,412,302B1.

The process is very simple and liquefies gas with the use of two independent cycles, one that uses methane, while the other uses nitrogen as refrigerants. A key operational characteristic of this process is that the refrigerants are always in gas phase, introducing relevant simplifications to the process with the elimination of refrigerant receivers, drums, separators and others, very common in classical refrigeration systems. In contrast, most other liquefaction processes involve a large liquid volume of hydrocarbon refrigerant, which represents a significant fire/explosion risk. This is of particular concern in offshore environments. The NicheLNG process is inherently one of lower risk.

The use of these two gases simultaneously artificially creates a binary system that could be considered as a pseudo mix-refrigerant. The methane cycle contributes refrigeration in the region of -100^{o} F to –150^{o} F, while the nitrogen cycle is key in the low temperature region –200^{o} F to –265^{o} F.

Each cycle operates as follows: gas at around 1000 psig and 100^{o} F enters a brazed aluminum heat exchanger, LNG exchanger, where it is cooled before being expanded to about 200 psig, with the use of a turboexpander. Due to the isoentropic

Figure 3
LNG Dual Expander Cycle



expansion the temperature of the gas descends and work is extracted from this process. The cold gas is now reintroduced to the LNG exchanger, where part of the refrigeration gained is absorbed by the gas being liquefied, and by the refrigerant gas. The warmed gas is sent to a booster compressor that is driven by the turboexpander, where its pressure is raised to about 250 – 300 psig. The refrigerant gases are then cooled and sent to final compression to raise their pressure to about 1000 psig to reinitiate the cycle.

The process employs independent methane and nitrogen refrigeration cycles. Turboexpanders, rather than J-T expansion valves, are used in both refrigeration cycles, with energy of expansion recovered in expander-driven booster compressors. The energy recovered represents a process efficiency credit relative to J-T expansion LNG processes. Standard frame-sized turboexpanders, typical of the gas industry, are utilized.

As described, this process is very simple in its configuration as one brazed aluminum exchanger, two expanders and one compressor train-driven either by a gas turbine or an electric driver are the components of the liquefaction step. All these components have had extensive and demonstrated experience in gas processing facilities in similar conditions.

Figure 3 shows a conceptual depiction of the LNG Dual Expander Process.

The flow diagram (Figure 4) describes the NicheLNG process. All major equipment items are depicted on the diagram, illustrating the simplicity and compactness of the process.

Net refrigeration horsepower is provided by driven compression. For the present application a GE LM 2500 gas turbine is tentatively selected to drive both the methane and nitrogen refrigeration compressors needed for each train of 75 MMSCFD. The selection of this tandem arrangement results in a favorable CAPEX, and in a compact plot layout.

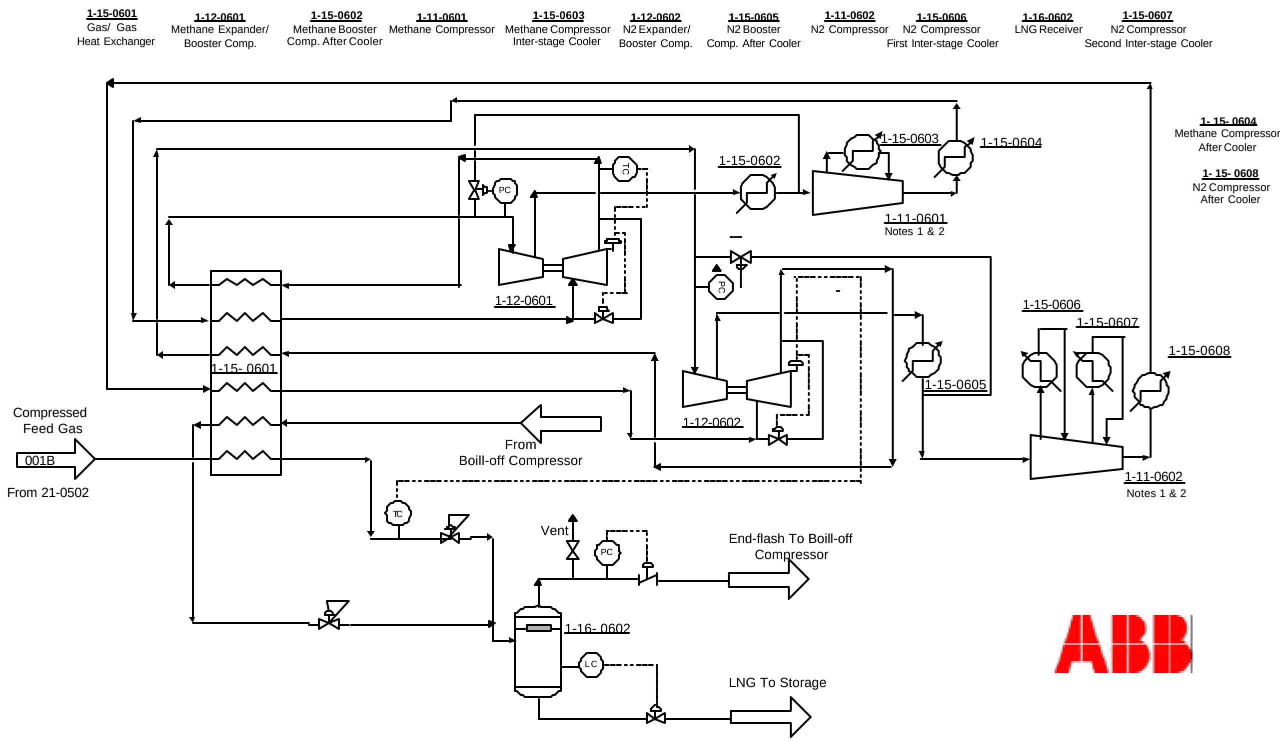
Inlet gas is cooled and condensed against refrigerant in plate-fin exchangers, housed in a cold box. This type of exchanger is compact, requiring a relatively small plot area. Plate-fin exchangers economically achieve close approach temperatures needed for attainment of high thermodynamic efficiency. The exchangers/cold boxes are typical of plate-fin exchangers and cold boxes commonly used in the gas industry.

For the present application, refrigeration heat of compression is rejected via a once-through sea water system. Titanium-tube shell and tube exchangers are employed. On a project-specific basis, a circulating cooling water system or air fin exchangers could be used instead.

Two 100% boil-off compressors are provided, which are sized to service both the process and LNG storage needs. The units are reciprocating “labyrinth type” machines with a proven LNG service history.

Utility/support facilities, include instrument air, cooling water, fire water system, HP flare/vent system, nitrogen generator, LP flare/vent system, fuel gas system, power generation, and LNG storage.

Figure 4-Liquefaction Scheme



Benefits of the NicheLNG Process Concept

By avoiding capital costs associated with gas compression, transportation pipelines, land site preparation, harbor development, and dock construction, deployment of the LNG plant on an FPSO can reduce investment by 20 to 30% relative to a land based plant. At the end of field life, the LNG FPSO can be redeployed for use at another location.

Suitable opportunities for application of NicheLNG Offshore include:

• In an existing offshore production area where oil production facilities are already present, but no local gas market exists. Examples include offshore West Africa, where gas production is growing rapidly. The Brazilian, US, and European gas market are all potentially within economic transport distance for LNG from West Africa.
This was the target location established for the study.

• Non-associated gas field with reserves in the range 0.5 to 3 TCF, which are > 150-200kms offshore. The export of gas by pipeline to shore over such distances imposes a investment burden that renders the exploitation of such gas reserves uneconomic.

• Gas fields too small to support a base load "utility" project, but which, can be economically exploited by serial redeployment of the NicheLNG Offshore.

The proposed concept utilizes a purpose-built double hull steel vessel with an LNG containment system based on a GTT membrane or IHI SPB type storage tanks. These containment systems provide deck configurations suitable for topside installation. The LNG storage capacity is the key driver for the vessel dimensions. The storage capacity is site-specific but will typically be in the range of 138,000 to170,000 m^3.

The FPSO vessel design will be similar to LNG carriers using proven LNG storage systems and technology. The cost of LNG carriers has fallen dramatically from around $ 250 million average in 1998 to $ 160-170 million in 2002.

The generic concept is based on a turret-moored hull with the external turret located at the bow of the vessel. Tandem offloading is performed from the stern with the use of an integrated structural mooring and fluid transfer arrangement.

Basis for Study

The Basis of Study assumes that the feedstock for the LNG FPSO liquefaction plant will have undergone front-end processing, condensate and NGL removal, and acid gas removal.

Field Description

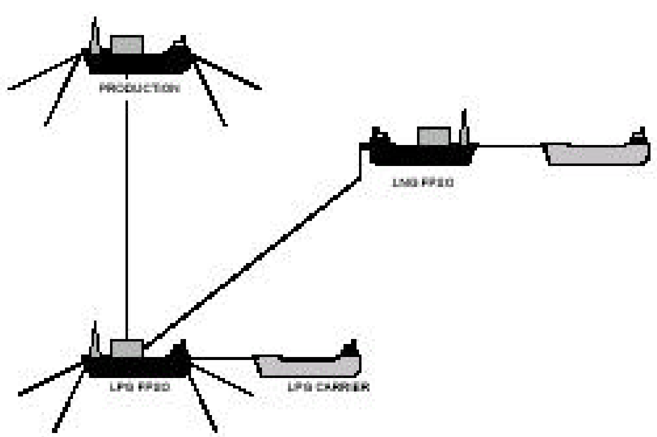
A possible field configuration may consist of the following three units (see **Figure 7**):

1. An oil/gas production facility, e.g. a production FPSO.

2. An LPG FPSO separating condensate/LPG from the gas routed from the oil production facility and pre-treating the residue gas feeding the LNG FPSO.

3. The LNG FPSO liquefying the pre-treated residue gas received from the LPG FPSO

Figure 7
Field Layout



Eventually, the oil production FPSO and the LPG FPSO can be an integrated unit. Alternatively the LPG and LNG FPSO can be integrated into one vessel. It should be noted that the products including crude oil, LPG and LNG should be offloaded from the individual FPSOs to separate product carriers.

Facility Description

The plant will be designed to process 225 MMscfd of feed gas in three identical trains of 75 MMscfd each. This would be equivalent of an LNG production rate of 1.5 million

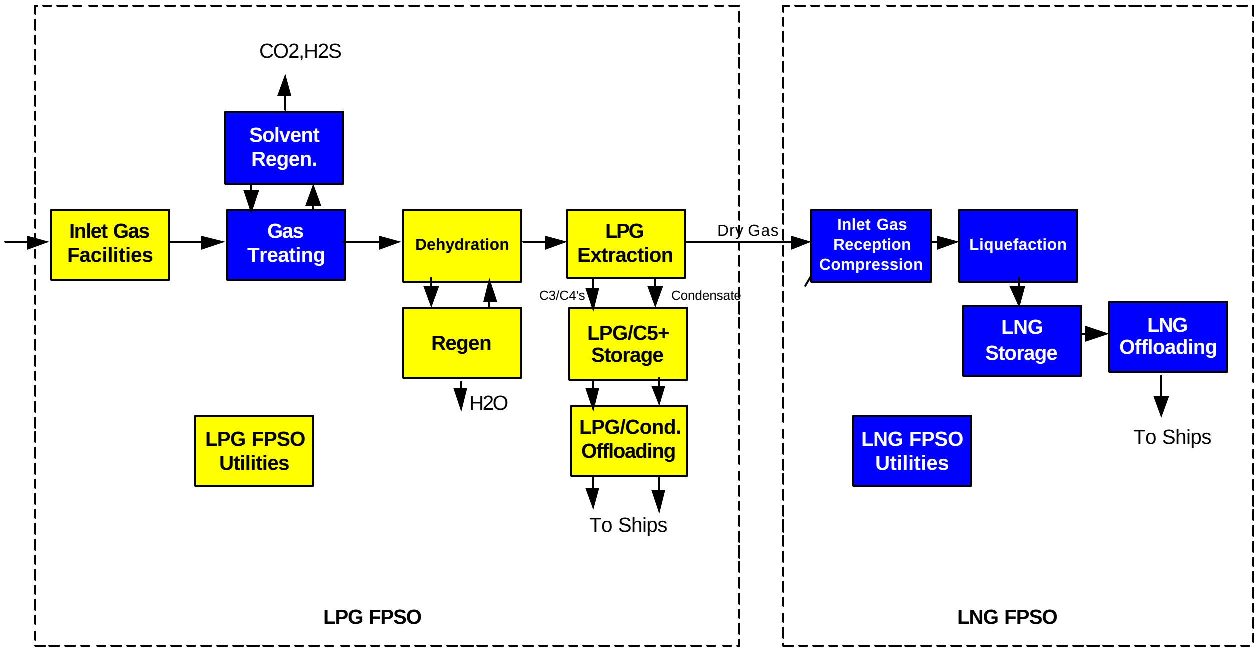


Figure 5 Overall Project Block Diagram

Metric tons per year based on 350 days/ year of operation. Selected plant life is 20 years, which accounts for a production profile that includes a ramp-up, stabilization and decline.

It is assumed that the LNG FPSO, located offshore West Africa, will take residue gas from an "existing LPG FPSO" as feed gas. The core facilities at the LPG FPSO include the inlet gas system module, gas treating, gas dehydration, and LPG cryogenic extraction module.

Feed Composition

The liquefaction plant will be designed to have the flexibility of processing the feed gas as specified below, as well as accommodating other typical compositions which can satisfy feed gas specification for LNG production.
The gas liquefaction facilities take feed gas from a location downstream of booster compressor after-cooler of a typical LPG extraction module. The feed is a residue gas available from an LPG extraction unit after propane and heavier components are

removed. Feed gas will meet the specifications required by the LNG plant regarding acid gas components and mercury content.

The composition and characteristics of the feed gas as adopted from the LPG FPSO are as follows:

Component			
		Mole %	
	Average	**Lean**	**Rich**
Molecular Weight	17.5	16.53	18.72
Water (ppm)	0.1max.	0.1max.	0.1max.
Hydrogen Sulfide (ppm)	4 max.	4 max.	4 max.
Carbon Dioxide (ppm)	50 max.	50 max.	50 max.
Nitrogen	1.48	0.02	4.12
Methane	91.08	96.68	83.67
Ethane	5.79	3.12	8.97
Propane	0.57	0.12	1.81
Iso-Butane	0.01	0.01	0.08
N-Butane	0.01	0.00	0.05
Iso-Pentane Plus	0.00	0.00	0.00
Total	**100.00**	**100.00**	**100.00**
Conditions	Press, psig	T, Deg F	Flow, MMscfd
Normal	435		210
Maximum		100	220
Mech. Design	520	150	225

Contaminants:

- Mercury content should be less than 0.01 microgram per normal cubic meter in the feed gas.
- Carbonyl sulfides, mercaptans, and sulfides are assumed to be not detectable in the feed gas.
- Solids, consisting of sand, dust, oxides, and iron sulfide are assumed to be absent in the feed gas,
- Aromatics are assumed to be not detectable in the feed gas.

Turndown

Liquefaction trains turndown will generally be set by the suppliers of the rotating equipment. Each train is limited to 70 percent in turndown, a value that is dependent on the expander flexibility. However, as there are three trains, the facility could be turndown to less than 33 percent.

LNG FPSO CONCEPT

Proposed Hull Concept

The proposed concept utilizes a purpose-built double hull steel vessel with an LNG containment system that provides a deck suitable for topside installation. Based on this functional requirement, ABB identified the IHI SPB type storage tanks (see **Figure 6),** and membrane type tanks as possible options. The storage capacity is site-specific but will typically be in the range of 138,000 to170,000 m3.

The generic concept is based on a turret-moored hull with the turret located at the bow of the vessel. Tandem off-loading is performed from the stern with the use of an integrated structural mooring and fluid transfer arrangement. Side by side off-loading of LNG is also a possible option.

Figure 6
IHI SPB Type LNG Tanker
(from IHI Internet site)

Main Dimensions, Capacities and Requirements

The LNG vessel will be a new purpose-built steel vessel built according to the marine standards applicable for offshore LNG vessels and production. The complete FPSO will be classified and certified in compliance with Classification Society requirements.
The living quarter will be located at the bow of the ship and the FPSO shall be moored by use of an external turret at the bow.

In general, the hull will be specified similar to an LNG carrier with a typical LNG containment system. The marine systems and equipment are assumed as a part of the hull delivery. The main changes compared to an LNG carrier are envisaged to be:

• No engine and propulsion system shall be included

• The hull shape shall be designed for transport and permanent location only, not ocean going. The hull shape shall be optimized with regard to storage capacity, sea-keeping performance, cost and operation.

• The hull shall provide the required ability to support the topside modules, equipment and offloading system.

• The hull shall be suitable to accept the necessary modifications for the mooring system. Particular attention will be paid to achieving a tank arrangement that can withstand sloshing due to FPSO motions.

Vessel Classification, Rules, Regulations and Guidelines

The FPSO is to be built according to the marine standards applicable for offshore LNG vessels, and production ships. The complete FPSO shall be classified and certified in compliance with their requirements. The vessel and production facilities will be designed in order to meet the requirements for "Approval in Principle" by both ABS and DNV.

Design Environmental Conditions

The design environmental conditions to determine the most severe loading conditions for West Africa are:

• 100 year wind and waves with associated 10 year current
• 100 year current with associated 10 year wind and waves

Storage

The produced LNG will be stored in special storage tanks located within the hull and off-loaded to standard LNG carriers. The LNG FPSO storage capacity will be between 138,000 and 170,000 m3. This capacity shall provide:

• Containment of a typical cargo of minimum 138,000 m3 and sufficient buffer storage to cover probable shuttle tanker or off-loading delays.

• Containment sufficient to retain some spare LNG volume sufficient to maintain the low temperature at any time; i.e. a certain LNG content must remain after offloading is complete.

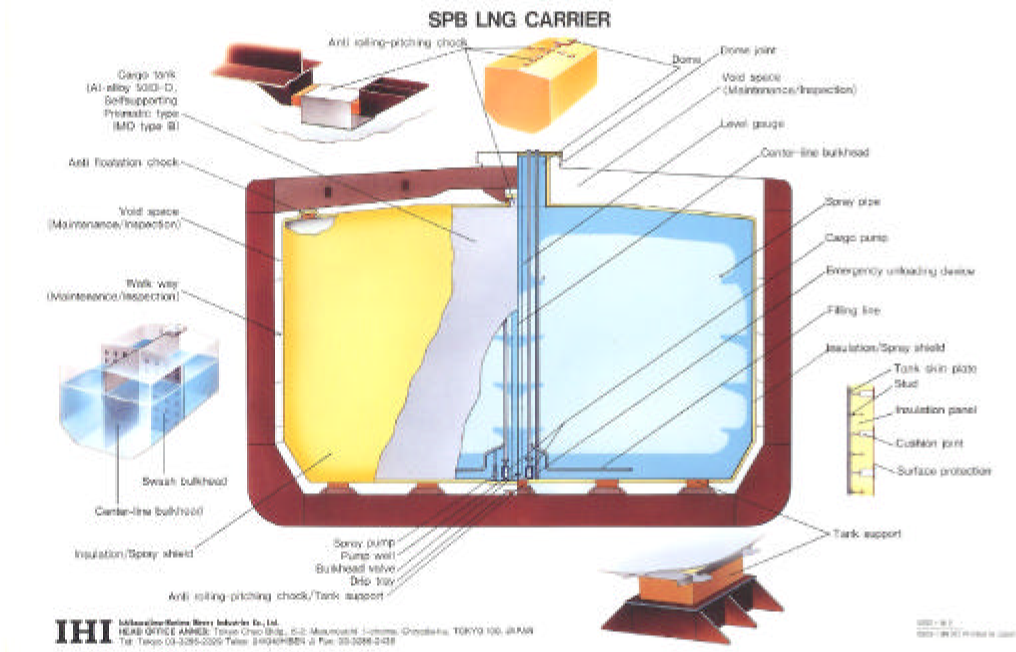
Sloshing

Due to partial tank fillings, liquid movement inside the cargo tanks is an important issue. Traditionally, LNG carriers sail with either full or empty tanks (with a small heel that provides continuous cooling of the cargo tanks). Sloshing is normally not a problem under such conditions. However, the LNG FPSO tanks will need to operate with partial fill. Sloshing can occur when liquid inside the tanks moves at its resonant periods, thus inducing impact pressure on the tank walls.

Recommended Type of Containment System

Although it is subject to final review during Phase II of ABB's technology program, the Phase I study has considered the use of IHI SPB Containment System as a possible option due to the flat upper deck and superior sloshing abilities (see Figure 8).

Figure 8
IHI SPB Type Tank
(from IHI Internet site)



Off-loading

The off-loading operation is a critical and weather dependent operation, which may impose restrictions on operability and regularity. A high availability is desirable to avoid excessive LNG storage requirements. Two alternative mooring positions may be applied:

- Side-by-side
- Tandem

The side-by-side solution replicates the arrangement seen at existing shore terminals, but a tandem off-loading arrangement is considered a more resilient concept for ship-to-ship transfer offshore.

The offloading systems will be connected, and pre-cooling performed before the off-loading operation is commenced. The offloading duration will be 12-15 hours.

The LNG will be exported to LNG carriers with a typical LNG capacity in the range from 87,000 m3 to 138,000 m3. The offloading manifold is located on the side of the carrier. Most of the offloading/mooring systems should be located on the FPSO, in order to minimize the amount of modifications required on the LNG carriers.

<u>Selection of off-loading concept</u>

A reliable and safe off-loading system is very important for stable revenue stream from the field. The following parameters are considered as the most important aspects regarding off-loading technology selection:

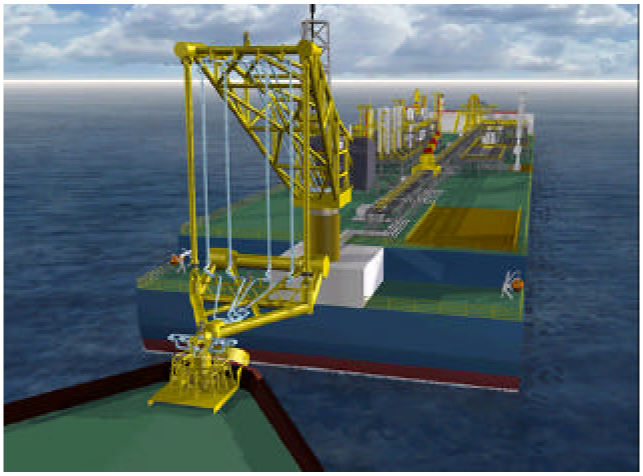
- Safety
- Reliability
- Cost/Weight
- Technology qualification status.
- Client preference

Ship to ship LNG offloading has not been performed to date, and most technologies are still in the development phase.

The main offloading technology vendors are listed below.

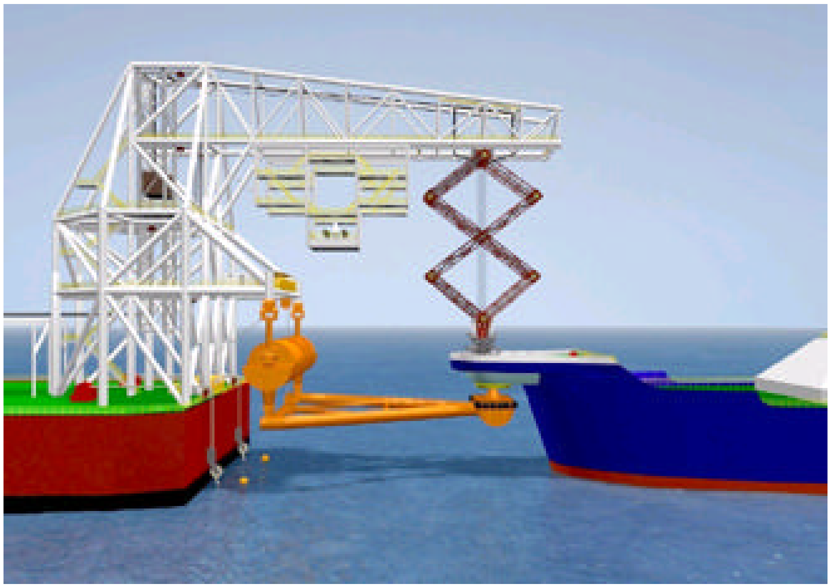
• SBM Imodco – The SYMO concept (see **Figure 9**) consist of an integrated mechanical mooring and LNG transfer system for tandem off-loading.

Figure 9
SBM Imodco System *(Courtesy SBM)*



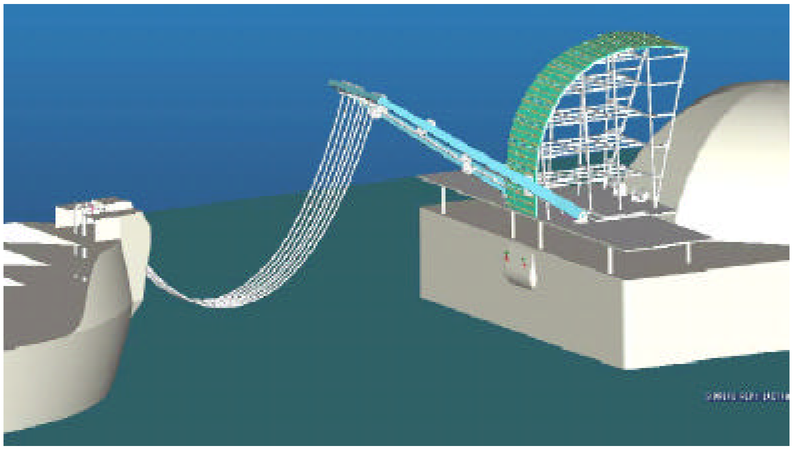
• FMC Sofec (see **Figure 10**) - An integrated mechanical mooring and LNG transfer system for tandem off-loading. FMC Sofec also provides traditional side-by-side off-loading technology.

Figure 10
FMC Sofec System *(Courtesy FMC)*



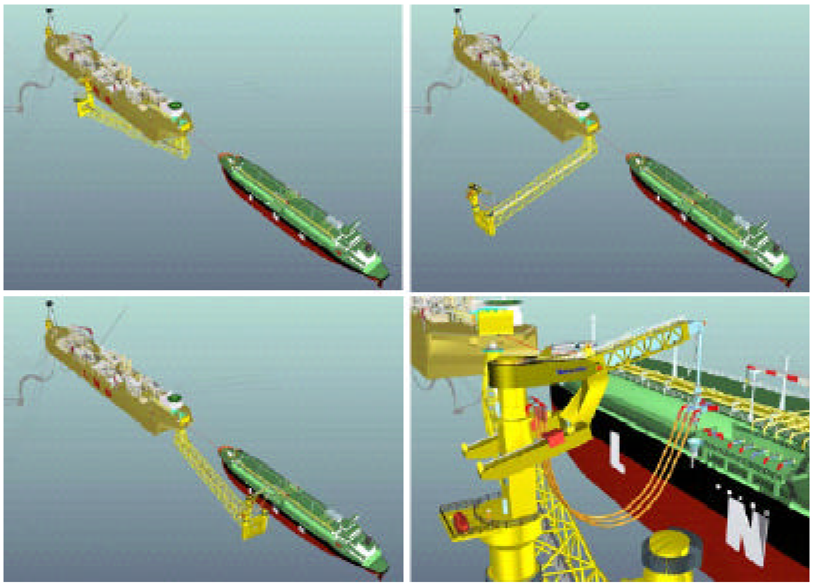
• The OCL Group (see **Figure 11**) – consists of a crane, flexible pipe, and traditional hawser mooring system for tandem offloading.

Figure 11
OCL System *(Courtesy OCL)*



• Bluewater – The Big Sweep (see **Figure 12**); consists of a self-positioning unit for tandem off-loading. Provides also a side-by-side concept.

Figure 12
Bluewater System *(Courtesy Bluewater)*



• Connex, Remora, Eurodim – Side-by-side, tandem and pipe-based concepts.
These off-loading technologies are all characterized as being in the development phase. The selection of the off-loading concept is very dependent on the metocean conditions, reliability requirements, marine procedures/requirements and hull/mooring design.

Marine/Cargo Systems

The marine/cargo systems will be similar to marine systems installed on LNG carriers. These systems are not evaluated in detail as part of this study, and should be further evaluated in a future phase.

The marine/cargo systems will be subject to the marine regulations and codes. It is anticipated that a major part of these systems will be located within the hull. The main marine systems required are listed below:

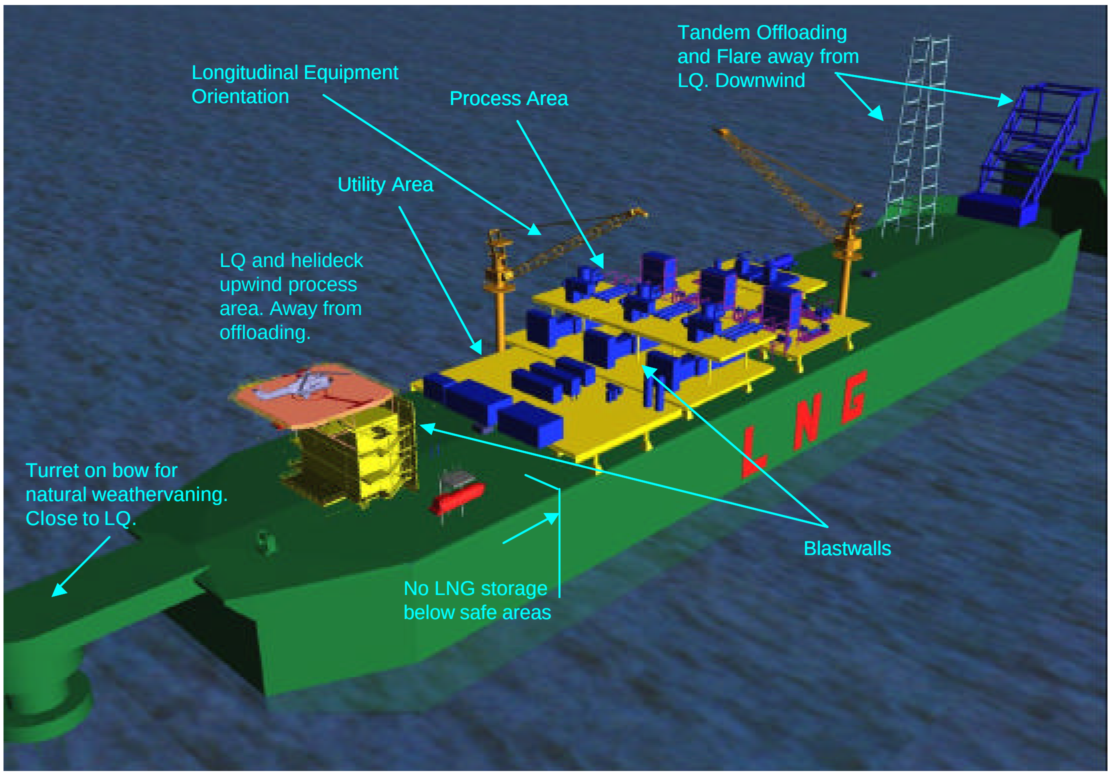
• Ballast system
• Cargo system
• Inert gas system
• Nitrogen system
• Spray system
• Auxiliary and utility systems

Deck Layouts

Overall layout

The design concept is a steel hull with an external turret and tandem off-loading. The design can be easily adjusted for spread mooring and/or side-by-side off-loading . (see **Figure 13**)

Figure 13



Turret

The external turret is located on the bow and this provides natural weather-vaning. The alternative of an internal turret would most likely increase the overall dimensions of the ship since the hull will need to accommodate the turret in addition to the tanks.

Living Quarters

The accommodation is located on the bow side of the vessel, hence, the accommodation is upwind of the process area.

Off-loading

The off-loading equipment is located on the stern in order to provide a stern to bow off-loading arrangement with the moored trade carrier.

Flare/Vent

The flare stack is located on the stern, downwind of the process modules, which provides sufficient separation distance from the living quarters. However, the stack will be relatively close to the off-loading equipment. Flare radiation calculations will verify the radiation levels in the off-loading and process areas, and possible radiation and plume effects on the LNG carrier.

Effect of motions

Compared to typical base load LNG plants, the Niche LNG Offshore facility consists of minimum motion sensitive equipment. The motions are not considered critical for the LNG plate fin heat exchangers.

FPSO Mooring System

The concept is based on a turret-moored solution in order to provide a weathervaning FPSO during operation/off-loading. This is based on the following main considerations:

- Highly recommended by the off-loading technology vendors
- Ease of berthing of a LNG carrier of similar size as the FPSO (no mooring lines)
- A conservative solution flexible for most water depths and weather conditions.
- The benign conditions and minimal number of risers (one) will result in a small turret requiring limited structural support and acceptable riser accelerations. An external turret will provide the following advantages compared to an internal turret:
    - Increased storage capacity for a given hull size
    - Reduced investment cost and modification on the hull

CONCEPTUAL SAFETY EVALUATION

Safety is a primary objective in the development of a floating LNG production solution. Valuable knowledge of safety has been gathered through the existing LNG shipping business, onshore LNG terminals and operation of oil production FPSOs.

Safety Hazard Identification

A safety evaluation has been performed to identify the significant hazards and the potential major accident scenarios that could have an effect on the integrity of the FPSO and the crew. The design and layout of the facilities has incorporated features to maximize the intrinsic safety of the facilities, and to reduce risks to As Low As Reasonably Practicable (ALARP).The key issues in design in order to meet the required safety level are:

• Ensure reliable operation
• Offer adequate protection of personnel
• Minimize the risk of LNG release from the storage tanks, which can develop catastrophic scenarios resulting in total loss.

In addition, floating liquefaction, storage and off-loading will introduce innovative application of technology and technology marinization. Special consideration has been applied to these issues during all phases of technology development.

Economic Evaluation – Cost of Service (COS)

To provide insight into the economic viability of the NicheLNG FPSO described in this study, an economic analysis algorithm has been developed.

Project Cost of Service (COS), according to the definition given by Merlin Associates and Poten & Partners (*LNG Cost and Competition Report)*, is the real price per unit output ($/MMBtu) of LNG/gas that the chain segment must receive (net of condensate and LPG credits) to cover: forward capital and operating costs, sovereign take, and recovery of capital employed at start-up including a required after-tax rate of return. In other words, it is the real price of gas/LNG output at key transfer points that sets the segment or chain net present value (NPV) equal to zero at the required rate of return.

Economic modeling was used in a parametric study to investigate sensitivities of COS to plant size, project capital cost, shipping distance, and other variables of significance. In addition, two example case studies of liquefying gas on an FPSO moored off Nigeria, West Africa, are investigated; one delivering LNG to Barcelona, Spain, and the other to Elba Island, Georgia, on the US east coast.

Figure 16

A result of the parametric study is a plot of COS as a function of plant size and shipping distance, with other variables being held constant. This is shown in **Figure 16.**

The COS plots indicate that the Niche LNG Offshore concept can produce LNG at a price competitive with delivered LNG prices today, and with current and projected US gas prices.

The TABLE I summarizes COS values and their sensitivity to key inputs/variables. This is shown for two case studies, namely, exporting LNG from Nigeria to Barcelona, and to Elba Island (U.S.)respectively. The COS results demonstrate the economic viability of the concept.

TABLE I

From Nigeria	Barcelona, Spain	Elba Island, Georgia
Shipping miles Plant size,MMSCFD LNG Number of LNG Transport	4400 225 2	6150 250 3
COS,	3.25	3.41
Sensitivities COS @ +25% Plant COS @ +50% FPSO Annual O&M COS @ +25% LNG Tanker Lease COS @-10% Plant	 3.59 3.37 3.44 3.51	 3.73 3.52 3.68 3.69

Basis of COS Calculations

- COS is calculated at the delivery point into an existing gas transmission pipeline.
- The COS is taken as constant throughout the life of the project.
- Investment outlay is an FPSO which is single point moored, with a 135,000 cubic meter LNG tank, and with a NicheLNG liquefaction plant installed on the top deck. Leased tankers are used to deliver LNG to market from the FPSO.
- Transfer of LNG from the FPSO storage tank to the LNG tankers is via a tandem loading arm.
- The costs for inlet feed gas, LNG product shipping , and regassification toll, are included as operating costs. Provisions for each of these costs are discussed below.

Project Financing Considerations

The COS described in **Figure 16**, above, reflects a 15% discounted cash flow internal rate of return (DCFIRR) on the FPSO. Note that, for the present analysis, no investment is assumed and no return is required for LNG ships needed to deliver product to market. This is accounted for as an operating cost, as described later.

Other factors reflected in **Figure 16** include a 10 year double declining balance depreciation schedule, as allowed by US income tax regulations, and the assumption of a 38% income tax rate. The COS is based on a 15 year plant life, with zero salvage value. A two-year construction window is assumed, with 50% of the investment committed each year. Working capital is taken as 10% of investment and is returned in the last year of operation.

There is no provision for royalty payments or infrastructure development in the host country.

CAPEX Costs

Total capital cost for the base case facilities was estimated using quotations from equipment suppliers and data from ABB's database. Base case facilities include three trains of processing facilities, sized to liquefy 75 MMSCFD each, located on an FPSO with storage capacity for 135,000 cubic meters of LNG.

To establish costs of the two train (150 MMSCFD) and four train (300 MMSCFD) plants illustrated in **Figure 16**, the allocation to hull related costs was held constant. The process facilities cost was further allocated between train dependent and non-train dependent components. The cost of the revised plant capacity was extrapolated and arrived at on this basis.

OPEX Costs

The costs include all labor, travel, and maintenance materials for the plant, LNG storage, and hull facilities.

An algorithm developed for this purpose determines the number of LNG ships required. This is a function of FPSO storage capacity, LNG ship size and capability, plant LNG make, distance to market, loading/unloading capabilities, etc.

The following values apply for these LNG shipping parameters:

- 135,000 cubic meter LNG storage within the FPSO.
- 135,000 cubic meter LNG tankers capable of 18 knots ship speed.
- Total of 5 days port delay for each round trip.
- A "utilization factor" of 86%.

The utilization factor is intended to compensate for shipment coordination shortcomings where, for example, plant production would otherwise have to be reduced while waiting for a ship to return. For purposes of the analysis, cost of feed gas to the FPSO and cost to store, and re-gasify LNG delivered to a terminal into a pipeline system, are treated as operating costs. The values reflected in the **Figure 16** above, are $0.30/MMBtu feed cost and $0.50/MMBtu storage and regas cost.

Material Balance Considerations

For purposes of the study, plant size reflects LNG production into the LNG storage tank. Additional feed to the plant is required, and purchased, as necessary, to supply plant fuel and to offset storage tank weathering losses.

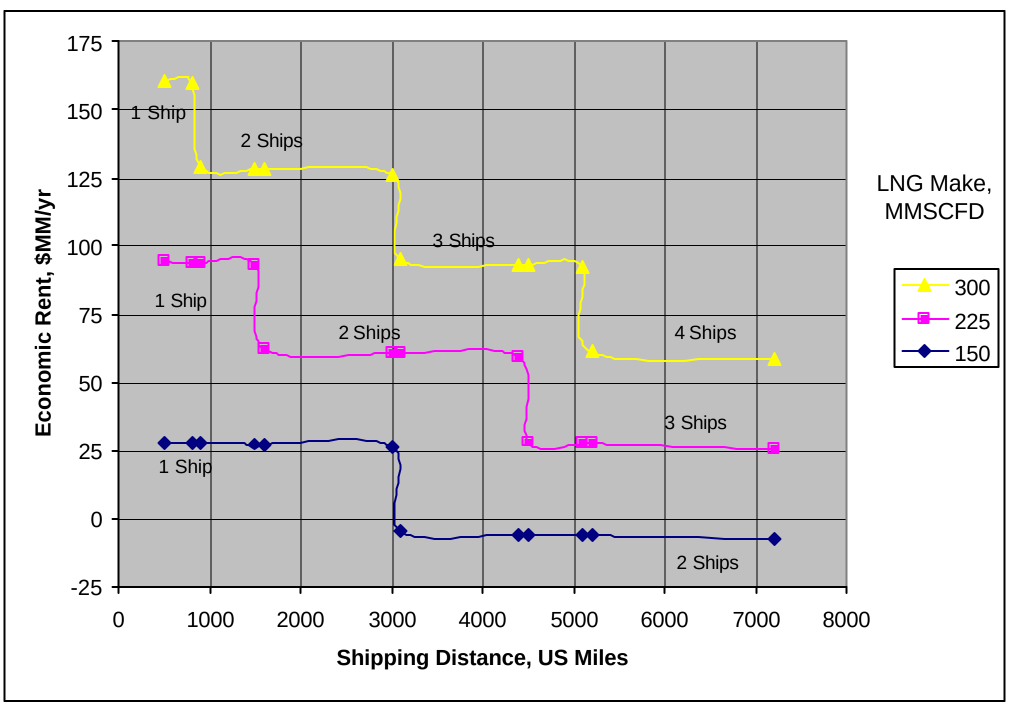
Losses also occur during shipment to market and during re-gasification into the ultimate pipeline consumer. The COS calculation reflects the Btu's delivered into the pipeline, not the plant make.

LNG tanker fuel cost is assumed to be included in the lease rate, and no LNG shrinkage is allocated to tanker fuel.

Economic Criteria

- Economic Rent
  Economic rent is the annual cash flow generated by a market price for LNG in excess of the COS. For a market value of $4.00/MMBtu, the economic rent corresponding to the COS values depicted in **Figure 16** above, are shown on the following **Figure 17**:

Figure 17



Alternate Depreciation Schedules

Two alternate depreciation/plant life/income tax schedules were also investigated to determine their effect on project economics. One assumes a twenty-year plant life with straight-line depreciation over the life of the plant, and a 38% income tax rate. The other assumes a twenty-year plant life with a seven-year straight line depreciation, but with a ten year tax holiday before a 38% income tax is levied. (Such an arrangement reportedly underlies one of the Nigerian LNG contracts.)

Economic Criteria Results

TABLES II and III, below, summarize the values of economic indicators resulting from the alternative depreciation schedules described above, and also assuming LNG price of $4.00/MMBtu into the receiving pipeline. TABLE II is for shipment of LNG from Nigeria to Barcelona, and TABLE III is for the shipments from Nigeria to Elba Island .

TABLE II

Nigeria to Barcelona, Spain, Base Case 225 MMSCFD = 1.6 Met/year, 4400 miles, 2 ships			
Project Life, yrs	15	20	20
Depreciation, yrs	10	20	7
Depreciation Schedule	DDB/SL	SL	SL
Tax Rate	38%	38%	38% after 10 yr tax holiday
COS, $/MMBtu	3.25	3.28	2.93
Economic Rent @ $4.00/MMBtu, $MM/yr	59	56	84

TABLE III

Nigeria to Elba Island, USA, Base Case 250 MMSCFD = 1.75 Met/year, 6150 miles, 3 ships			
Project Life, yrs	15	20	20
Depreciation, yrs	10	20	7
Depreciation Schedule	DDB/SL	SL	SL
Tax Rate	38%	38%	38% after 10 yr tax holiday
COS, $/MMBtu	3.41	3.45	3.12
Economic Rent @ $4.00/MMBtu, $MM/yr	51	48	76

Variable Production Schedule

All results discussed above are based upon a plant production rate fixed for the life of the project at the value of the designated plant capacity. The algorithm described above has

the flexibility to input a non-constant production schedule. This can be used to investigate the effect on project economics of a production build-up during initial years of operation and/or production decline during latter years. For non-constant annual LNG make, economic rent will vary annually as does the plant throughput.
As would be expected, due to the effect of discounting, production of LNG at less than ultimate plant capacity in the early years has a larger effect upon economic criteria than fall-off of production in later years.

Further Work

The following section summarizes the main conclusions from the study. This section also includes recommendations on resolution of critical technical issues.

Study Conclusions

The main conclusion of the study is that the NicheLNG process concept is feasible from safety, technical, and economical points of view. Cost of service for LNG delivered from the West Africa coast to Spain or the US Gulf coast is competitive with natural gas priced at $4.00/MMBtu.

The safety evaluations performed as part of this study conclude that offshore liquefaction, storage and offloading are feasible from a safety point of view by proper design and operation. Extensive safety evaluations and risk assessments performed by others support this conclusion. Offshore LNG production has intrinsic safety over traditional plants located onshore, and potentially close to populated areas.

The existing LNG shipping industry, onshore LNG terminals and FPSOs have developed valuable experience and regulations for safe operation. Compared to competitive LNG concepts, the NicheLNG offshore concept should provide improved safety. This is secured in part by eliminating use of liquid phase refrigerants, low hydrocarbon inventories and through plant simplicity.

When considering the technical and commercial issues that remain to be addressed, some of these will only be resolved when a site specific project and location is established, while others are being addressed in the ongoing Phase II stage of this program.

Recommendations

Phase II of ABB's technology program is designed to address all critical residual technical issues that were identified in the execution of the Phase I program.

Demonstration of offloading facilities for ship-to-ship transfer of LNG has yet to be commercialized but is predicted to be available in the 2005/2006 timeframe. The interdependency between mooring system selection/configuration and the off-loading system must be carefully considered. The operational window for off-loading of LNG in the open sea is a critical issue and its dependence on the mooring and off-loading system parameters must be well documented. Concerns regarding the ability to perform the off-loading operation in the open sea also need to be addressed.

Definition of the LNG containment system requires further investigation. The Prismatic Type B tanks need to be further compared with the membrane design to further delineate their merits and drawbacks for an FPSO application.

Finally, Phase II Technology studies will set the basis to secure an “Approval in Principle” from one of the classification authorities.

The combined LPG and LNG concept must be advanced and similar deliverables prepared as for the LNG FPSO Study.

Will it ever happen?

The idea of an LNG floater is not new for the LNG community. It has been discussed since the early 70s. But it did not gain acceptance because of the same technological limitations that it is facing today. Over and over the concept re-surfaced and came back on the table of discussion.

In the last 5 years, it seems that the convergence of several factors is renewing the interest for this proposition. Other concepts to monetize gas have also emerged to offer alternative paths. Major players, who play the rules of economy of scale, dominate the current LNG market: the bigger the better. As a consequence, the justification of LNG small projects on a “traditional” basis is becoming marginal. This has contributed to the belief that LNG FPSO has to follow the same rules of justification as any LNG project. That’s not what the NicheLNG concept is about. As we said, this is a technology to enable the solution of the “gas problem” in remote offshore locations.

Why will an operator choose to build a NicheLNG Offshore FPSO? It transforms a cost into revenue. It does not just have to do with producing LNG! It is the vehicle to make the operation profitable. This is key to understanding the NicheLNG process value proposition.

The ability to deliver that LNG to market is an important step in this concept. Penetration of the LNG market is not easy. The long term LNG contracting structure for LNG supplies evident today is a barrier to accommodating potential incremental parcels of LNG in the market.

A new set of rules and understanding is needed to develop this opportunity. NicheLNG process and the NicheLNG Offshore concept are promoted with that vision: bring gas value to markets.

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