To Increase The Efficiency Of Supply Chain Of LNG

PROJECT DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT

FOR

MASTER DEGREE IN BUSINESS ADMINISTRATION

OIL AND GAS

BY

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UNDER THE GUIDANCE OF

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<u>CERTIFICATE From The Mentor</u>

This is to certify that the report entitled as "<u>**To Increase The Efficiency Of Supply Chain Of LNG**</u>"

is being submitted by **Mr. RAHUL DWIVEDI** as a part of their Dissertation project. This is a record of candidate's own work carried out under my supervision and guidance.

To the best of my knowledge, they have made sincere and dedicated efforts to accomplish this project.

I wish them all the best for their future endeavors.

(Mr. LUVRAJ TAKRU)

ACKNOWLEDGEMENT

This is to acknowledge the help, guidance and support that I have received during the project work.

I would like to express my heartfelt gratitude to **MR. LUVRAJ TAKRU** for his able guidance and support for making this project report a successful one.

I am also thankful to "THE UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, DEHRADUN", for providing me with an opportunity to pursue my Dissertation project and for providing me with the sufficient help whenever required.

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Research Objectives

1) To identify the risks & challenges associated with the LNG supply chain so that they can be worked upon.

2) To identify the opportunities lying in the LNG sector.

3) To brief how simulation modeling improves the efficiency of LNG supply chain.

4) To brief why Carbon Capture Storage is important for the LNG industry.

5) To find out other means through which the efficiency of the LNG supply chain can be improved. For ex:- Use of small carriers, LNG as a gas fuel, etc.

Methodology of Research

The study involved qualitative analysis for arriving at conclusions.

Primary Data

No primary data was used for this project.

Secondary Data

The study required that secondary data can be collected from sources like-websites, magazines, journals, & industry presentations by the experts. .

Literature Survey

- Internet
- Magazines
- Newspapers
- Online Journals & Articles
- Books on SCM

ABBREVIATIONS

LNG- Liquefied Natural Gas

CNG- Compressed Natural Gas

PNG- Piped Natural Gas

GTL- Gas To Liquid

GOR- Gas Oil Ratio

LDO- Light Diesel Oil

BCM-Billion Cubic Meter

MCM-Million Cubic Meter

MMSCMD- Million Metric Standard Cubic Meter Per Day

MMBTU- Million Metric British Thermal Unit

CEA-Central Electricity Unit

MOPNG-Ministry Of Petroleum & Natural Gas

NELP-New Exploration & Licensing Policy

GSPL-Gujarat State Petroleum Corporation Limited

ONGC-Oil & Natural Gas Corporation Limited

OIL-Oil India Limited

HVJ-Hazira Vijaipur Jagdishpura

MOU-Memorandum Of Understanding

TCNC-Technical Commercial Working Committee

OGL-Open General License

PLL-Petronet LNG Limited

PSC- Production Sharing Contract

FDI-Foreign Direct Investment

ROU-Right Of User

DFD-Data Flow Diagram

VLCC- Very Large Condensate Carrier

RVT-Round Voyage Time

ADP-Annual Delivery Program

ETA-Estimated Time Of Arrival

ETD- Estimated Time Of Departure

SPA- Sales Purchase Agreement

GSA-Gas Sales Agreement

CCS-Carbon Capture Storage

MSC- Marine Safety Committee

EFG-End Flash Gas

BOG-Boil Off Gas

MEA-Mono Ethanol Amine

WHRU-Waste Heat Recovery Unit

HRSG-Heat Recovery Steam Generate

EXECUTIVE SUMMARY

The share of natural gas in India's overall primary energy basket stands at 11%, as against the global share of 24%, primarily on account of supply side constraints.

By 2025, natural gas will comprise 20% of the Indian primary energy basket. Natural gas will substitute crude oil for a host of applications due to its non-polluting and economic nature.

Natural gas is used in a variety of applications, such as feedstock in fertilizer and petrochemical industry and as fuel in the power generation, manufacturing of steel, textile, ceramic, glass and other industrial products.

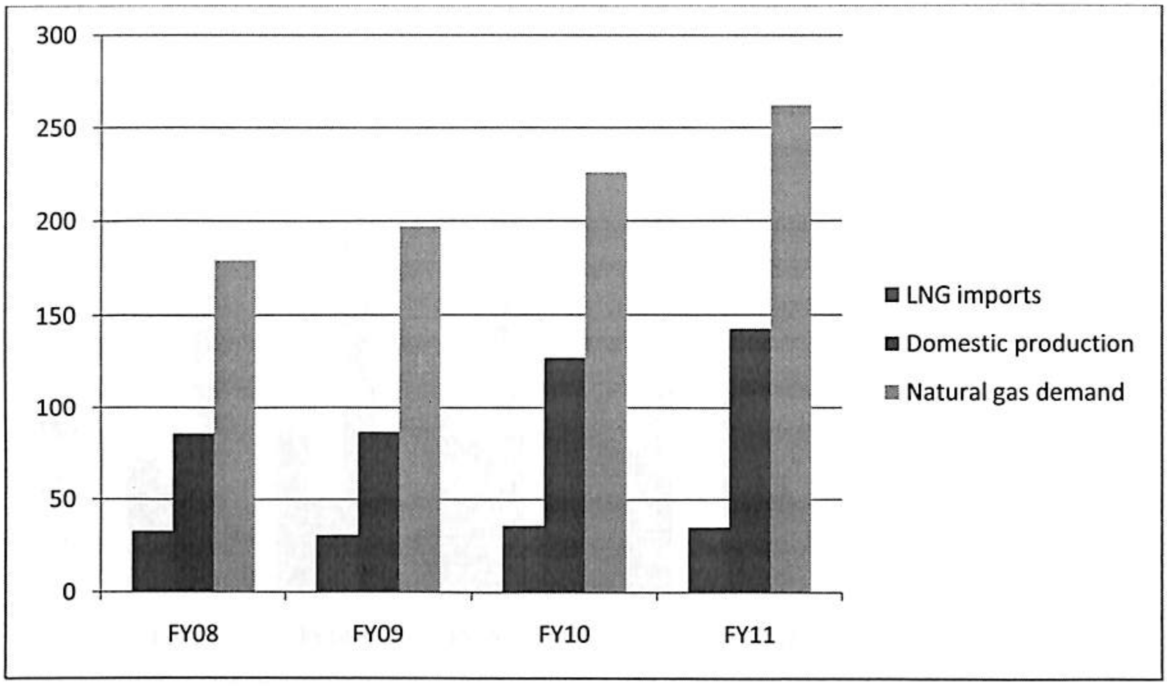
Natural Gas is a major source of CNG (transportation fuel) and is an essential raw material for production of electricity, fertilizers and plastics.

Natural gas and LNG should also be included in the 'Declared Goods' list as natural gas is the source of CNG and PNG. Declared goods status will make imported LNG cheaper too.

It is unlikely that any of the demands of the Natural gas industry would be met.

Why LNG

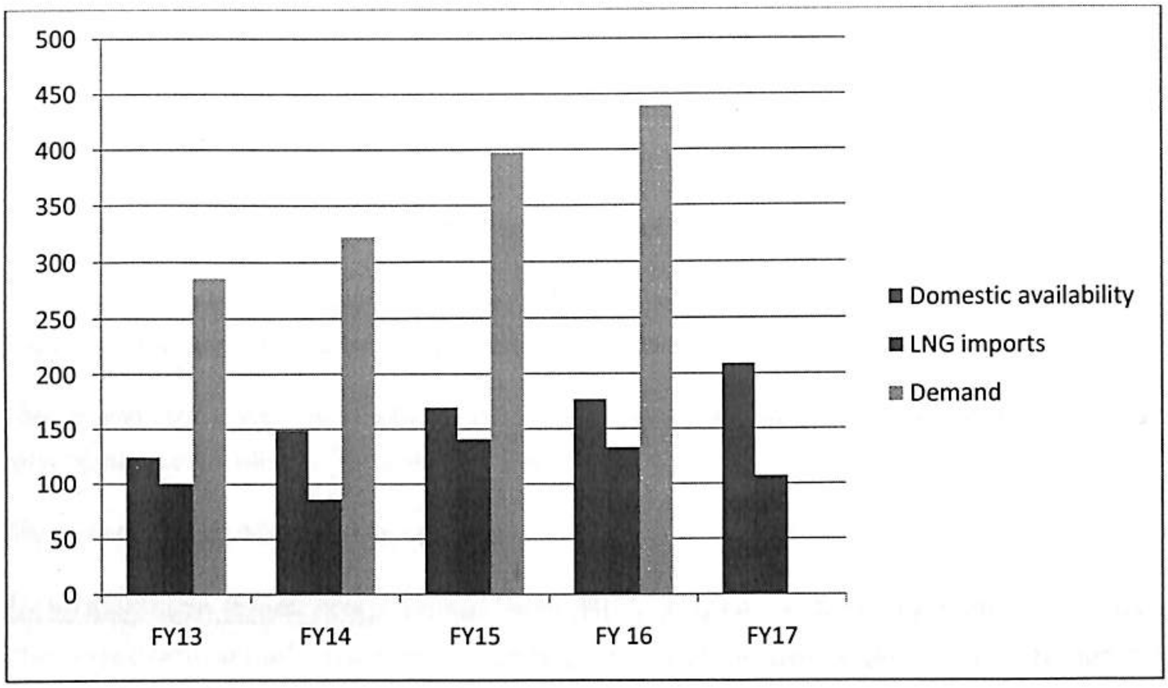
India's natural gas market is characterized by a supply deficit, primarily due to low domestic production and inadequate transmission and distribution. The domestic demand for natural gas far exceeds domestic supply, resulting in a deficit and increased reliance on LNG. The domestic production has remained stagnant through FY09. Later in FY10, domestic production received impetus with commencement of production from KG-D6 field, located in east coast. However due to technical difficulties, production from KG-D6 has declined, which has resulted in a reduction in domestic supplies .



Source : Petroleum Planning and Analysis Cell, MOP&NG

Impact of decline in the domestic natural gas output:-

In a worrying development for gas-based power plants, India's natural gas deficit is expected to continue as the demand will be way ahead of supplies. The gas shortage is likely to reach its peak in FY15, with around 36% of unmet demand.



The power producers' woes may worsen across the country as some of the plants are ready but sitting idle due to non-availability of gas.

A recent communication by the Central Electricity Authority (CEA) to States suggested that developers should not take up new power projects until 2015-16.

A Power Ministry official, who confirmed the letter to States, said the embargo may not have any impact on the 12th Five-Year Plan (2012-17) capacity additions as it was only little above 1000 mw that was targeted for gas-based power..

It is evident from the above that no additional domestic gas is likely to be available until 2015-16. Hence developers are advised not to plan projects based on domestic gas till 2015-16. When MoP&NG indicates availability of gas, developers will be intimated.

A senior official of GVK Power earlier said the Government had asked them to put off their expansion plans until a clear picture emerges on gas availability.

Thus, it is clear that LNG will play a crucial role in the future in fulfilling the demand of various sectors like power plants, steel, cement, etc. Due to the shortage of the domestic gas , GOI(Government Of India) has already decided to provide natural gas on the preference basis giving first preference to core sector-power, fertilizer, LPG and CGD.

Non-core sector like steel, cement, refineries, etc. will have to look for other option like LNG. Power plants are usually located in the coastal areas so it would be easy for them to have an access to LNG and fulfill their requirement of energy.

It is thus very important to increase the efficiency of LNG supply chain to reduce the cost associated with it and make complete utilization of each portion of supply chain.

On the other hand, it is equally important to decrease the amount of carbon released during the process and make the process environment friendly.

This report deals with challenges in the supply chain and risks associated with it and how to overcome those risks & challenges as well.

My report stands on two main pillars-

A) Simulation modeling:- To maximize LNG supply chain efficiency, companies must ensure they meet contractual obligations, seize opportunities for spot cargoes, minimize operational costs and use all assets as effectively as possible.

Simulation modeling helps in achieving above listed factors

B) Carbon Capture Storage:- To capture carbon released during the supply chain and store it so that it can be used for other purposes.

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INTRODUCTION

NATURAL GAS IN INDIA:-

AVAILABILITY & UTILISATION OF NATURAL GAS

Availability of Natural Gas:-

1. Natural gas has emerged as the most favored fuel due to its inherent environmentally benign nature, better efficiency and cost effectiveness. The demand of natural gas has piercingly increased in the last two decades at the global level. In India too, the natural gas sector has gain importance, mostly over the last decade, and is being termed as the Fuel of the 21st Century.

2. Production of natural gas, which was almost slight at the time of independence, is at there at the level of around 87 million standard cubic meters per day (MMSCMD). The major producers of natural gas are Oil & Natural Gas Corporation Ltd. (ONGC), Oil India Limited (OIL) & JVs of Tapti, Panna-Mukta and Ravva. Under the Production Sharing Contracts, confidential parties from some of the fields are also producing gas. Government have also obtainable blocks under New Exploration Licensing Policy (NELP) to private and public sector companies with the correct to market gas at market resolute prices.

3. Out of the total production of around 87 MMSCMD, following internal consumption, extraction of LPG and unavoidable flare, around 74 MMSCMD is available for sale to a variety of consumers.

4. Most of the production of gas come from the Western offshore area. The on-shore fields in Assam, Andhra Pradesh and Gujarat States are additional main producers of gas. Smaller quantities of gas are also produced in Tripura, Tamil Nadu and Rajasthan States. OIL is in service in Assam and Rajasthan States, whereas ONGC is in service in the Western offshore fields and in additional states. The gas produced by ONGC and a part of gas produced by the JV consortiums is market by the GAIL (India) Ltd. The gas produced by OIL is marketed by OIL itself apart from in Rajasthan where GAIL is advertising its gas. Gas produced by Cairn Energy from Lakshmi fields & Gujarat State Petroleum Corporation Ltd. (GSPCL) from Hazira fields is being sold in a straight line by them at market determined prices.

5. Natural gas has been utilised in Assam and Gujarat because the sixties. There was a main increase in the production & utilisation of natural gas in the late seventies with the expansion of the Bombay High fields and again in the late eighties when the South Bassein field in Western Offshore was bring to production.

Utilisation of Natural Gas:-

6. The gas produced in western offshore fields is brought to Uran in Maharashtra and partly in Gujarat. The gas brought to Uran is used in and around Mumbai. The gas brought to Hazira is sour gas which had to be sweet by removing the sulphur present in the gas. After sweetening, the gas is partly used at Hazira and the rest is fed into the Hazira-Bijaipur-Jagdhishpur(HBJ) pipeline which pass through Gujarat, MadhyaPradesh, Rajasthan, U.P., Delhi & Haryana. The gas produced in Gujarat,Assam, etc; is utilised in the respective states.

7. Natural Gas is at present the source of half of the LPG produced in the country. LPG is now being extract from gas at Duliajan in Assam, Bijaipur in M.P., Hazira and Vaghodia in Gujarat, Uran in Maharashtra, Pata in UP and Nagapattinam in Tamil Nadu. 2 new plants have also been set up at Lakwa in Assam & at Ussar in Maharastra in 1998-99. One more plant is being set up at Gandhar in Gujarat. Natural gas which contain C2/C3, which is a feedstock for the Petrochemical industry, is now being used at Uran for Maharashtra Gas Cracker Complex at Nagothane. GAIL has set up a 3 lakh TPA of Ethylene gas base petrochemical complex at Auraiya in 1998-99.

Natural Gas Allocation & Supply Scenario

8. As next to the total allocation of around 118 MMSCMD, the gas supplies by GAIL is of the order of 63 MMSCMD extend over about 300 major consumers. approximately 32% is supplied to the fertiliser sector, 41% to power, 4% to sponge iron & the balance 23% (including shrinkage) goes to different sectors.

All India Region-Wise & Sector-Wise Gas Supply By GAIL

Region/Sector	Power	Fertilizer	S. Iron	Others	Total
HVJ & Ex-Hazira	12.61	13.63	1.24	9.81	37.29
Onshore Gujarat	1.66	1.04		2.08	4.78
Uran	3.57	3.53	1.33	1.41	9.85
K.G. Basin	4.96	1.91		0.38	7.25
Cauvery Basin	1.07			0.25	1.32
Assam	0.41	0.04		0.29	0.74
Tripura	1.37			0.01	1.38
Grand Total	**25.65**	**20.15**	**2.58**	**14.23**	**62.61**

(MMSCMD)

OIL is also supplying approximately 3 MMSCMD in Assam against allocations made by the Govt.

9) Around 8.5 MMSCMD of gas is being in a straight line supplied by the JVs/private companies at market prices to different consumers. This gas is outside the purview of the Government allocation.

IMPORT OF NATURAL GAS TO INDIA THROUGH TRANSNATIONAL GAS PIPELINES.

(a) Iran-Pakistan-India (IPI) Pipeline Project

1. In pursuance of Government decision on February 2005, Minister (P&NG) led a delegation to Pakistan during 4-8 June 2005. Throughout the talks, the 2 Ministers reviewed the Iran-Pakistan-India gas pipeline proposal. They agreed that the project, which envisages supply of gas to Pakistan and India through a transnational pipeline, would go a long way in meeting the energy security requirements of the 2 countries,

and thus should be seen as a significant project for the assistance of the people of these countries.

2. The Indian and Pakistani delegations decided to swap information in regard to the financial structuring, technical, commercial, legal & related issues to realize a safe and secure world class project. To this end, it was decided that the momentum pertaining to the project should be accelerate by constitute a Joint Working Group at the Secretary level at the earliest, which will meet frequently and report the progress to the Ministers to make possible definitive decisions by them.

   - 10.1 An Indian delegation too visited Iran from 11-14 June 2005 and discuss the issue of import of natural gas from Iran through on-land pipeline transiting through Pakistan. Both sides noted with satisfaction that as a result of regular deliberations on technical issues pertaining to the project, a Heads of Agreement amid NIGEC and the Indian companies concerned has been finalized. With a view to undertaking further studies and discussions with regard to relevant issues so that the project can take off by early next year, it was decided to establish a special JWG on the Iran-Pakistan-India gas pipeline project.

   - 10.2 A Pakistani delegation led by Secretary, Ministry of Petroleum and Natural Resources, Govt. of Pakistan visit New Delhi on July 12-13, 2005 for the 1st meeting of India-Pakistan JWG. The second meeting of the JWG took place in Islamabad on 8-9 September, 2005. The 1st meeting of the Special JWG on Iran-Pakistan-India Pipeline Project held in New Delhi on 3-4 August, 2005. The 2nd meeting of the Special JWG on Iran-Pakistan-India Pipeline Project took place in Tehran on 24th October,2005. The Indian side was led by Secretary (P&NG). Indian side already appointed financial consultants i.e., M/s Ernst & Young and is in the process of finalize appointment of legal & technical consultants for the project. During the 2nd JWG meeting, Pakistan informed that they will soon be appointing their Financial Consultants.

(b) Myanmar-Bangladesh-India Gas Pipeline Project.

3. To follow the matter at the Government level, for bilateral and trilateral discussions with Myanmar & Bangladesh, the Minister (P&NG) visited Yangon during the 11-13th January 2005. A Memorandum of Understanding (MOU) for cooperation in petroleum sector between the 2 Governments was signed. MOU provides for furthering cooperation in the hydrocarbon sector and to establish a cooperative institutional

relationship in the field of petroleum industry on the foundation of equality and mutual advantage, taking into account the potential for cooperation available in every country.

4. The 2 Governments will designate a body of experts comprising three representatives of each party to be familiar with and implement the projects in hydrocarbon sector.

    - 11.1 A meeting between the Petroleum Ministers of India, Myanmar and Bangladesh held on 12.1.2005. After meeting a Joint Press Statement issued by the three Ministers. The three sides agreed to transport natural gas from Myanmar to India by pipeline transiting through Bangladesh. Route of the pipeline will be determined by joint agreements of the three Governments. It was also decided to set up a Techno-Commercial Working Committee (TCWC) comprising duly chosen representatives of the three Governments to prepare a draft MOU prescribe the framework of collaboration among the three Governments, including the Myanmar-Bangladesh-India gas pipeline project. The MOU will be signed at Dhaka at the earliest mutually convenient date.

    - 11.2 In pursuance of MoU, a Techno-Commercial Working Committee has been constituted by the 3 Governments. The First Meeting of the TCWC took place on 24-25 February, 2005. The TCWC finalize draft MoU proposed to be signed by the three oil Ministers.

    - 11.3 However, there are certain joint issues which have to be sorted out with Bangladesh. At the same time, India is also exploring the other alternative of import of natural gas from Myanmar. A high level delegation led by Minister, Energy, of Myanmar lately visited India during July 5-7, 2005. Aspects of Myanmar-Bangladesh-India gas pipeline were talked about. Minister (P&NG) visited Bangladesh during 5-6 September 2005 to follow the matter with Government of Bangladesh. The matter is being followed vigorously and the proposed gas imports from Myanmar will be finalized shortly notwithstanding the reply of Government of Bangladesh. GAIL has been asked for a pre-feasibility study of the onland pipeline route from Myanmar to India via North-Eastern Indian States, bypassing Bangladesh territory. An option of getting Bangladesh on board is also being at the same time pursued. Another official level meeting was held in Yangon on 29-30 August 2005, where 2 sides agree to take specific steps for gas supply from Myanmar.

(c) Turkmenistan-Afghanistan-Pakistan-India (TAPI) pipeline

5. Daulatabad area of Turkmenistan reported to have sufficient gas reserves. The Governments of Turkmenistan-Afghanistan-Pakistan-India (TAPI) planned the transnational gas pipeline to develop the available gas reserves in Turkmenistan. They selected ADB as the lead development partner. ADB carried out the study and approached India for participating in the project. Minister (P&NG) discussed this stuff with Pakistani side during his visit to Pakistan 4th to 8th June 2005. This was discussed by Secretary (P&NG) with President ADB during the latter's visit to New Delhi on 1.9.2005. even though, India is not yet formally involved in TAP project, Minister (P&NG) has been invited to the next Steering Committee Meeting to take place in Ashgabat in December, 2005.

Liquefied Natural Gas (LNG)

6. Natural gas at -161 degree C transforms into liquid. This is done for easy storage and transportation since it decreases the volume occupied by gas by a factor of 600. LNG is transported in particularly built ships with cryogenic tanks. It is received at the LNG receiving terminals & is regassified to be supplied as natural gas to the consumers. LNG projects are extremely capital rigorous in nature. The whole process consists of five elements:-

1. Dedicated gas field development& production.
2. Liquefaction plant.
3. Transportation in particular vessels.
4. Regassification Plant.
5. Transportation & distribution to the consumer.

LNG supply contracts are normally of long term nature and the prices are linked to the international crude oil prices. Though the LNG importing countries in recent times have started asking for medium/short term contracts with different linkages.

LNG Imports to India

The LNG trade began in mid 60's and has increased rapidly. In 1992 it was around 80 Billion Cubic Metres (BCM) per annum & crossed the 100 BCM mark in 1996. World trade in LNG is currently in the range of 150 BCM. The main exporting countries of LNG are as follows- Algeria, Qatar, Indonesia, Malaysia, Australia, while, the major importers are Japan, South Korea, Taiwan and Western Europe.

Geographically, India is very strategically located and is flanked by huge gas reserves on both the east and west. India is comparatively close to four of the world's top 5 countries in terms of proven gas reserves, viz. Iran, Qatar, Saudi Arabia and Abu Dhabi. The large natural gas market of India is a main attraction to the LNG exporting countries. In order to support gas imports, the Government of India has kept import of LNG under Open General License (OGL) group and has permitted 100% FDI.

LNG Projects

Petronet LNG Limited (PLL), promoted by GAIL, IOCL, BPCL and ONGC was formed for import of LNG to meet the increasing demand of natural gas. PLL has built a 5 MMTPA capacity LNG terminal at Dahej in Gujarat. The terminal was specially made in February 2004 and commercial supplies commenced from March 2004. PLL is planning to enlarge this terminal to 10 MMTPA capacity by 2008-09 to meet the rising demand of LNG.

Shell's 2.5 MMTPA capacity LNG terminal at Hazira has been made to order. Dabhol LNG terminal (total 5 MMTPA capacity, of about 2.9 MMTPA available for merchant sales) may become operational by 2006 subject to availability of LNG for the project. Upcoming LNG terminals at Kochi in Kerala, Mangalore in Karnataka & Krishnapatnam/Ennore in Tamil Nadu are also under consideration and may start in next 4-5 years time.

Terminal	Re-gasification capacity(mmscmd)	Estimated completion date
Dabhol	19	2013-14
Kochi	19	2012-13(commissioned)
Ennore	19	2015-16
Mundra	19	2015-16
Other east coast	19	2016-17

GAS PRICING

Preceding to 1987, gas prices were fixed by ONGC/OIL. The price is being fixed by Government on 30.1.1987. The price of APM gas of ONGC &OIL was last revised effective 1.7.2005. The most important features of the revised pricing order effective 1.7.2005 are:-

- ONGC and OIL produced about 55 MMSCMD APM gas from chosen fields. The purpose of producer price for this gas will be referred to the Tariff Commission. Till the Commission submits its recommendation & a decision is taken , the consumer price of APM gas will be increased from Rs.2850/MCM to a fixed price of Rs. 3200/MCM.

i. It has been decided that all available APM gas will be supplied to only the power and fertilizer sector consumers against their current allocations along with the specific end users committed under Court orders & small scale consumers having allocations of 0.05 MMSCMD at the revised price of Rs. 3200/MCM. This price is linked to a calorific value of 10,000 K.cal/cubic metre. On the other hand, the gas price for transport sector (CNG), Agra-Ferozabad industries and other small scale consumers having allocations upto 0.05 MMSCMD will be progressively greater than before over the next 3 to 5 years to reflect the market price.

ii. Gas supplies through GAIL network to non-APM consumers will be at the price at which GAIL buys from JV producers, subject to a ceiling of ex-Dahej RLNG price of US$3.86/MMBTU for the current year 2005-06. For the North-East region, Rs.3200/MCM will be measured as the market price during 2005-06.

iii. Price of gas for the North-Eastern region will be pegged at 60% of the revised price for general consumers. Thus, the consumer price for the North-East region will increase from the existing price of Rs.1700 to Rs.1920/MCM.

iv. Subject to the purpose of producer price, based on the recommendations of the Tariff Commission, any extra gas as well as future production of gas from new fields to be developed in future by ONGC/OIL would be sold at market-related price in the context of NELP.

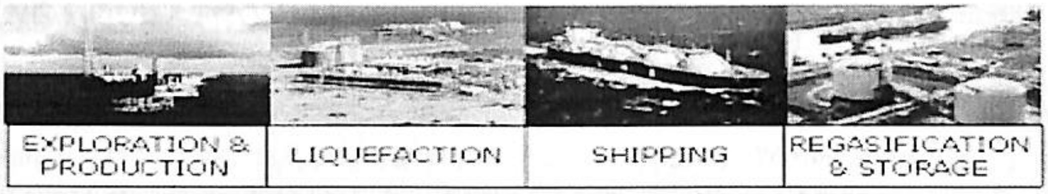
REGULATORY FRAMEWORK FOR THE GAS INDUSTRY

The Ministry of Petroleum & Natural Gas has been regulating the allocation and pricing of gas produced by ONGC and OIL by issuing managerial orders from time to time. The gas produced by the JVs & by NELP operators is governed by the respective production sharing contracts (PSC) amid the Government and the producers. Also,the setting up of a Petroleum & Natural Gas Regulatory Board is under the consideration of the Government & the bill is being drafted.

Under the existing policy, 100% (FDI) is allowed through the FIPB route for both LNG projects & natural gas pipeline projects. Import of LNG and natural gas is on OGL. If a body requires the acquisition of Right of User (ROU) in land, it will approach MOP&NG for the acquisition under the Petroleum & Mineral Pipelines (Acquisition of Right of User in Land) Act, 1962. The draft natural gas pipeline policy covering transmission pipelines and city gas distribution networks is under formulation, with proposed stipulation in line with those under the draft regulatory panel bill.

LNG VALUE CHAIN

The LNG "value" or "supply" chain consists of four highly linked, interdependent segments - exploration and production (or E&P); liquefaction; shipping - from the point of liquefaction to the final destination; and receiving, storage and regasification at the final destination. We use the term "value" because at each stage investments are made to take natural gas from an unusable state to one in which optimal use of natural gas as a critical energy fuel and feedstock for materials can be achieved.



The Global LNG Supply (Value) Chain

EXPLORATION & PRODUCTION:-

The first segment in the LNG value chain is exploration and production. E&P activity ranges from the development of ideas about where natural gas resources might occur (prospect generation), to the mobilization of financial capital to support drilling and field development, to ultimate production. The E&P segment incorporates geologic risk - the chance that natural gas resources in a "play" (an area of interest) either do not exist or exist in quantities or subsurface conditions that do not favor commercially successful exploitation.

U.S. natural gas reserves increased by more than 11 percent, from 183.5 to 204.4 Tcf, between 2001 and 2005.[19] To a large extent, this increase in reserves reflects the impact of higher natural gas prices since 1999; higher natural gas prices both spur drilling and increase the amount of natural gas resource that can be recovered (higher prices facilitate production from higher cost fields that might otherwise not be economic). The U.S., and North America, remains rich in natural gas resources. Natural gas trade - via pipelines and LNG - helps to provide a diverse portfolio of supply options that can offset tight domestic supplies and soften impacts of higher prices during periods when the U.S. demand for natural gas exceeds deliverable supply.

For the year 2005, worldwide proved reserves of natural gas were 6,348 Tcf, an increase of 25 percent over the year 1995, and more reserves of natural gas continue to be discovered.[20] Much of this natural gas is stranded a long way from market, in countries that do not need large quantities of additional energy. The leading countries producing natural gas and selling it to world markets in the form of LNG are Indonesia, Malaysia, Qatar and Algeria. Trinidad & Tobago is an example of a small country that has benefited hugely from its LNG export strategy. Several countries are growing rapidly as natural gas producers and LNG exporters, such as Nigeria and Australia. Countries like Angola and Venezuela are striving to reach their full potential in the global LNG marketplace, and countries like Saudi Arabia and Iran, that have vast reserves of natural gas, could also participate as LNG exporters

LNG LIQUIFACTION:-

Currently, liquefaction capacity to serve the Atlantic and Pacific basins is about the same; all together, including Middle East facilities, about 170 million tons per year (MTPA) of capacity is in place (as of March 2007). Another 91 MTPA is under construction and 285 MTPA are planned.[21] Egypt joined the club of LNG exporters in May 2005 by shipping a first cargo from newly constructed Idku terminal on the Mediterranean Sea.

In 2006 two liquefaction projects came into operation: Australia started its second LNG project in Timor Sea, and Qalhat terminal in Oman shipped first cargoes to Japan and Spain. Feed gas to the liquefaction plant comes from the production field.

During liquefaction, contaminants found in produced natural gas are removed to avoid freezing up and damaging equipment when the gas is cooled to LNG temperature (-256° F) and to meet pipeline specifications at the delivery point. The liquefaction process can be designed to purify the LNG to almost 100 percent methane.

The liquefaction process entails cooling the clean feed gas by using refrigerants. The liquefaction plant may consist of several parallel units ("trains"). By liquefying the gas, its volume is reduced by a factor of 600, which means that LNG at -256° F uses 1/600th of the space required for a comparable amount of gas at room temperature and atmospheric pressure.

LNG is a cryogenic liquid. The term □cryogenic□ means low temperature, generally below -100° F. LNG is clear liquid, with a density of about 45 percent the density of water.

At both liquefaction and receiving and regasification facilities, the LNG is stored in double-walled tanks at atmospheric pressure. The storage tank is really a tank within a tank. The annular space between the two tank walls is filled with insulation. The inner tank, in contact with the LNG, is made of materials suitable for cryogenic service and structural loading of LNG. These materials include 9 percent nickel steel, aluminum and pre-stressed concrete. The outer tank is generally made of carbon steel or pre-stressed concrete.

LNG SHIPPING

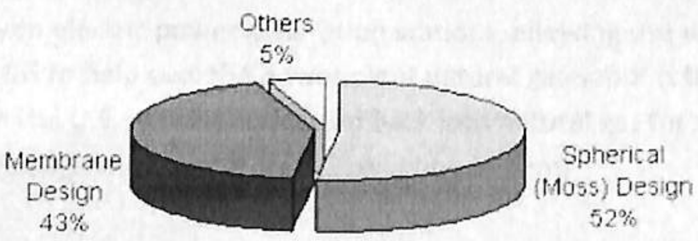
LNG tankers are double-hulled ships specially designed and insulated to prevent leakage or rupture in an accident. The LNG is stored in a special containment system within the inner hull where it is kept at atmospheric pressure and cryogenic temperature (-256ºF).

These are:

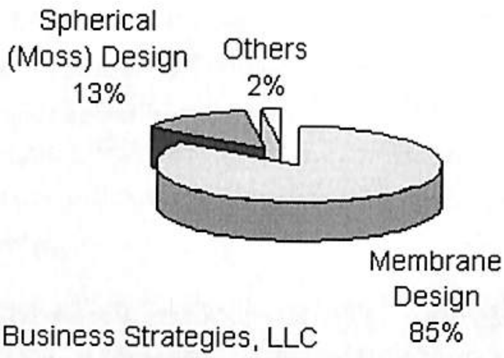
- The spherical (Moss) design (as shown in the photo above);
- The membrane design; and
- The structural prismatic design.

Historically most of the LNG ships used spherical (Moss) tanks. Moss-type ships are easily identifiable as LNG ships because the top half of the tanks are visible above deck. However, the trend is toward membrane design. The figure below shows that 44 percent of LNG ships were spherical design in 2006; this compares to 52 percent of LNG ships in 2002.

LNG Fleet Containment System



LNG Fleet Containment System - Order Book 2005 - 2010
(Number of ships)



Source: Maritime Business Strategies, LLC

The typical LNG carrier can transport about 125,000-138,000 cubic meters of LNG,[23] which will provide about 2.6-2.8 billion standard cubic feet of natural gas. The typical carrier measures some 900 feet in length, about 140 feet in width and 36 feet in water draft and costs about $160 million to build. This ship size is similar to that of an aircraft carrier but significantly smaller than that of a Very Large Crude Carrier (VLCC) used to transport crude oil. LNG tankers are generally less polluting than other ship ping vessels because they burn natural gas in addition to fuel oil for propulsion.

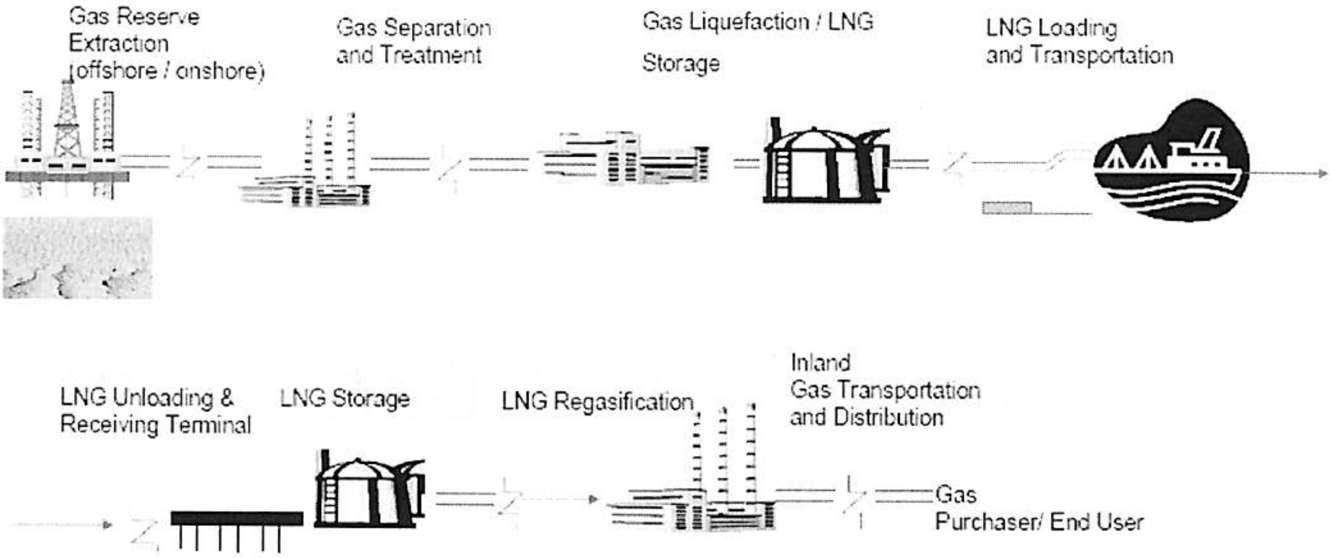
The LNG shipping market has been expanding. According to Maritime Business Strategies, as of March 2007, there were 224 LNG tankers in operation with 145 on order.[24] By comparison, forty two new LNG tankers were ordered in 2005. About 40 percent of the fleet is less than five years old. The LNG tanker fleet size has grown to well over 300 tankers by 2010.

At final destinations, LNG may be used in various ways. For instance, LNG may be used as a transportation fuel for truck and bus fleets; in these cases, LNG import receiving terminals will include facilities to dispense LNG into tanker trucks for distribution to central re-fueling locations. Or, LNG import terminals may be located with electric power generation stations, allowing use of the cryogenic properties of LNG to help cool the power plant natural gas vapor is burned for power production. In the U.S. , LNG is converted back into natural gas for shipment to customers through the U.S. natural gas pipeline system.

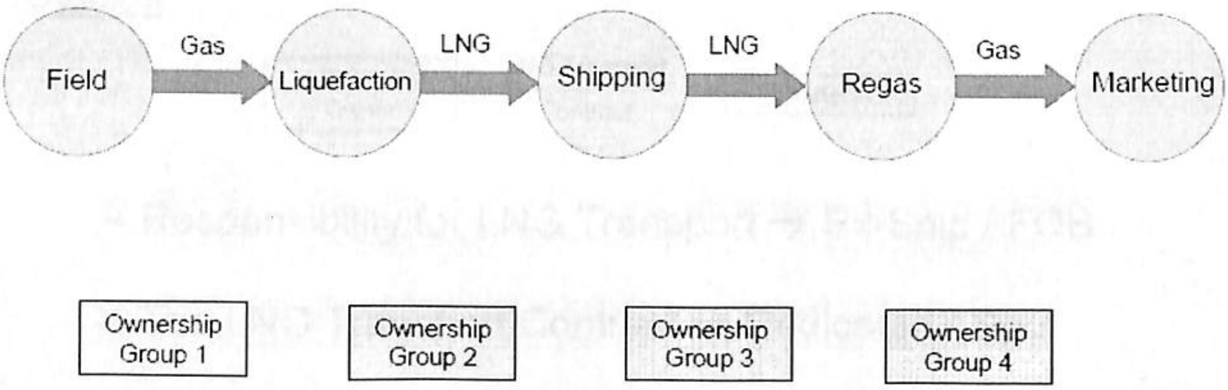
To return LNG to a gaseous state, it is fed into a regasification facility. On arrival at the receiving terminal in its liquid state, LNG is pumped at atmospheric pressure first to a double-walled storage tank, similar to those used in the liquefaction plant where LNG is stored at atmospheric pressure until needed. At that time, LNG is then pumped at higher pressure through various receiving terminal components where it is warmed in a controlled environment. The LNG can be warmed by passage through pipes heated by direct-fired heaters, or pipes warmed by seawater, or through pipes that are in heated water. The revaporized natural gas is then regulated for pressure and enters the U.S. pipeline system as the methane used in homes and businesses. Residential and commercial consumers receive natural gas for daily use from local gas utilities or in the form of electricity.

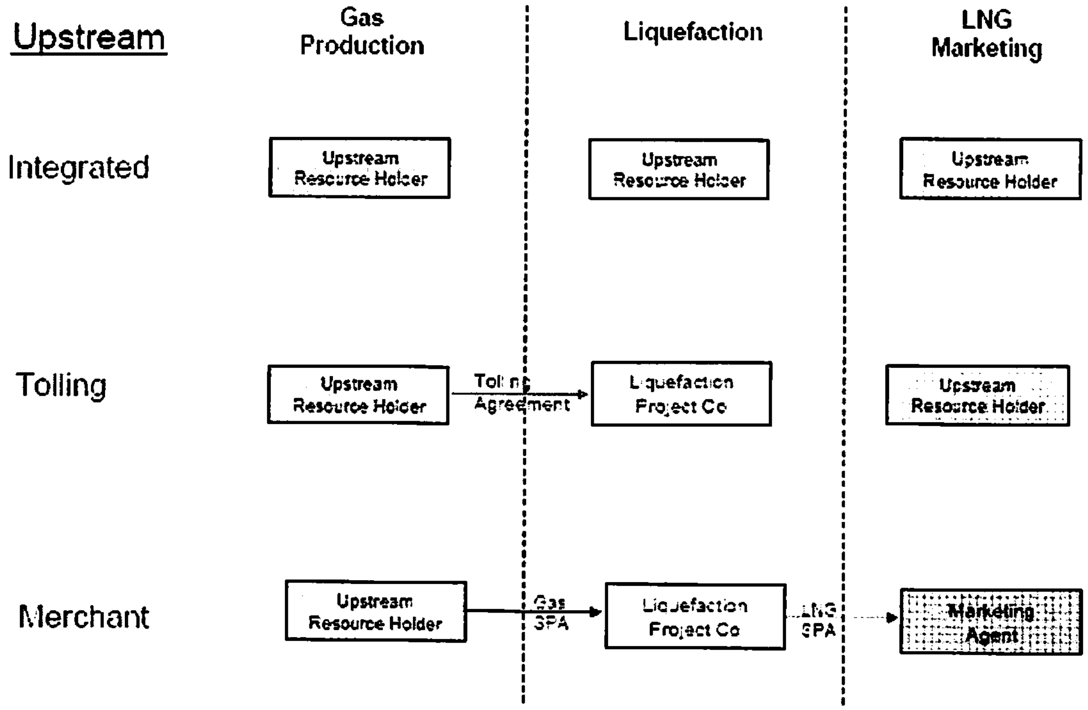
Of great interest is the development of new LNG receiving terminals in the U.S. and North America as well as worldwide. Of all world regions, the U.S. and North America as a whole have been the most active with respect to receiving terminal development. Seven terminals are in operation (four existing, with expansions, and three new facilities, including an offshore LNG ship-based design), six are under construction, 11 have been approved by regulatory bodies (including both onshore and offshore terminal designs), and more than 50 terminal projects are planned or have been proposed. This last figure compares with about 49 planned or proposed receiving terminal projects in the entire remainder of the world. Several factors account for the interest in developing terminals in North America, particularly the U.S. Most important of these is the size and competitiveness of the U.S. natural gas market and expectations that LNG will be an important part of the U.S. supply portfolio in the future. But LNG is also viewed to be an important, strategic part of the supply portfolios for Canada and Mexico as well, even though these countries have large and prolific domestic natural gas resources.

LNG SUPPLY CHAIN

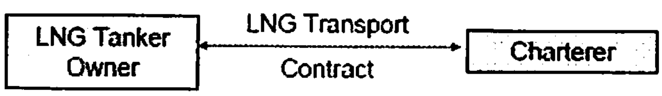


LNG SUPPLY CHAIN STRUCTURING OPTIONS



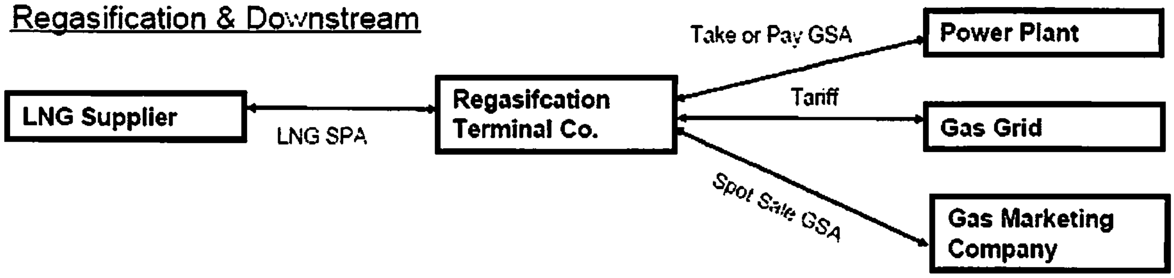


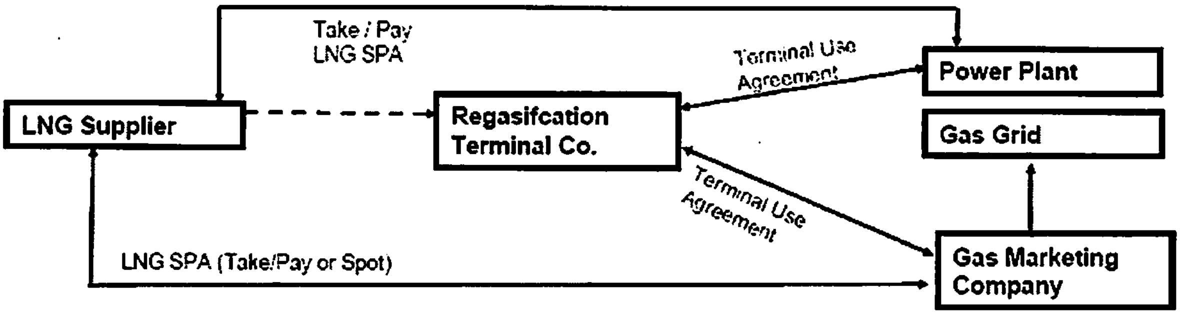
Midstream



- Responsibility for LNG Transport → Ex-Ship / FOB
- The LNG Transport Contract → Dedicated / Spot
- Vessel → Newbuild / Existing
- Tax Lease Structure

Regasification & Downstream





IDENTIFICATION & ALLOCATION OF RISK IN LNG SUPPLY CHAIN

Project-on-Project Risk – "Interdependency"

Construction Risk

- Delay in construction
- Cost-Overrun
- Performance beneath guaranteed parameters
- Materials and Labor Cost and accessibility

Operating Risk

- Operator performance/show
- Equipment failure
- Increased operational cost.
- Labor Availability

Upstream Supply Risk

- Insufficient Reserves
- Failure of Supply/delivery

Downstream Market Risk

- Lack of demand in the market
- Competing Fuels in the market
- Downstream Buyer Risk
- Pricing of Natural Gas

• Regulatory administration

Credit & Payment Risk

• Non-Payment risk

• LNG Creditworthiness

• Creditworthiness of charterer

Liquidity Risk

• Cost-overrun

•Mismatch of Invoice and cash-flow

• Commissioning periods

Force Majeure

• Unforeseeable risk

• God's act

• Inter-dependency of force majeure clause throughout LNG Supply Chain

• Force Majeure Clauses often not back-to-back

Political Risk

• Government support for project

• Permission and Authorizations

Legal Risk

• Breach of contract and non-performance/show

• Contractual silence

• Dispute decree

• Developed vs. Developing authoritarian Environment

General Economic Risk

- LNG and Gas Demand as well as Supply
- LNG Vessel Demand and Supply of State in Supply & Transportation

SUPPLY CHAIN MANAGEMENT IN PETROLEUM INDUSTRY

The supply chain of the petroleum industry is extremely complex as compared to other industries. It Is divided into 2 different, yet directly related, major segments: upstream and the downstream supply chains.

The upstream supply chain involves the attainment of crude oil, which is the area of expertise of the oil companies.

The upstream process consists of the exploration, forecasting, production, and logistics management of delivering crude oil from distantly located oil wells to refineries. The downstream supply chain begins at the refinery, where the crude oil is manufactured into the consumable products that are the area of expertise of refineries & petrochemical companies.

The downstream supply chain includes the process of forecasting, production, and the logistics management of delivering the crude oil derivative to customers around the world.

[Challenges and opportunities exist now in both the upstream and downstream supply chains]

Challenges in the Supply Chain

Logistical Challenges

The logistics network in the petroleum industry is extremely inflexible, which arises from the production capabilities of crude oil suppliers, extensive transportation lead times, and the restrictions of modes of transportation. Every point in the network, thus, represents a major challenge

The oil and petrochemical industries are global in nature. Consequently, these commodities & products are transferred between locations that are continents apart. The long distance between supply chain partners and sluggish modes of transportation encourage not only high transportation costs and in-transit inventory, but also high inventory carrying costs in terms of security stocks at the concluding customer location.

The large distances between supply chain partners present a high variability of transportation times that can damage suppliers in terms of service levels and final customers in terms of safety stock costs. Furthermore the transportation process is carried out either by ships, trucks, pipelines, or railroads. In many cases, a shipment has to develop multiple transportation modes before reaching the final customer's place.

Very few industries deal with that kind of difficulty in shipping. Such constraints on transportation modes in this type of industry persuade long lead times from the shipping point to the final customers' location as compared to other industries. Hence, considering the amount of inflexibility concerned, meeting the expansion prospect of oil demand and its derivates while maintaining high service-levels and efficiency is a main challenge in the petroleum industry.

Other Challenges

The logistics function is only one of many areas that have an effect on supply chain act in the petroleum industry.

Integrated process management, information systems & information sharing, organizational restructuring, and cultural reorientation are equally important. The need for integrated processes from procurement of raw materials to the delivery of the final product is important for a company's success.

Manufacturing efficiency does not ensure a competitive advantage anymore. The industry lags behind in using integrated preparation across the supply chain. This type of breakdown in the supply chain can increase the cost of acquiring crude oil, which will ultimately affect gas prices for consumers.

Due to the globalization of the petroleum industry supply chain, information technology is essential for smooth information flow considering the difficulty of the logistics network in such an industry. Companies' relationships in the supply chain networks are directly related to the efficient use of information technology.

A data flow diagram (DFD) was developed in 2001 to improve the supply chain information flow dependability of the Alaskan North Slope Oil supply chain. The study showed that using the DFD helped to comprehend the importance of the relationship between scheduling and dispatching. By using the DFD to inspect the information flow, overall supply chain efficiency was improved and deformation which is greatly related to supply chain structure, was very much reduced. Besides, the generic DFD developed offers a template for modeling any supply chain activity, whether it is a push, pull, or a hybrid push/pull system.

Complicated information technology is also essential for petroleum industries due to security needs. Petroleum companies ship a huge deal of hazardous products, and supply chain partners (suppliers and customers) must be conscious of the locations of each shipment at any point in time.

As per to Houseman at Accenture, chemical companies are considering wireless technology to track their shipments. A further challenge in the petroleum industry supply chain is the attitude and anxiety regarding association and information sharing between supply chain partners. While association and information sharing represent an important factor for supply chain efficiency

Companies in the petroleum industry are now and then cautious when it comes to sharing their demand/costs information. This type of stinginess regarding collaboration and sharing demand/costs information can squander opportunities for saving the costs.

Improved supply chain efficiency in the petroleum industry, thus, needs a new philosophy in cooperation, even if this means working with competitors. Cooperation information sharing, and asset optimization require the greatest mind change because chemical producers and LSPs will have to work with their competitors, as well as with other operators in the supply chain logistics industry.

The acquisition of complicated information technology, although necessary, can only do so much if it is not supported by a enlightening change.

Opportunities in the Supply Chain and Swap Practices

In an effort to manage their supply chain and decrease costs, oil and petrochemical companies are outsourcing their logistics functions. As the inclination in outsourcing has grown, these companies have become more and more reliant on the services of third-part logistics companies for organization their supply chains .

Companies in the petroleum industry, on the other hand, took the outsourcing idea one step further and originated that one way of outsourcing their logistics functions is to assist and collaborate with competitors. This form of collaboration is known as a ***systematic cooperative reciprocal barter*** (also called "swaps" or "exchanges") of supplies, assets, market share, or the entire business among competitors .

However, despite the noteworthy advantages this practice has generated for companies, a distinct model for making such decisions does not exist. The subject has hardly received any attention in the operations management literature.

At present, no specific method has been adopted to determine when companies should try to make swap decisions. An interview with supply chain directors in two international petrochemical companies that have been concerned in swapping with their competitors for the past few years disclosed that the only methods used are judgmental methods & spreadsheets.

Even though judgmental approaches may improve accuracy in many decision-making problems, they should not be the only methods in use. The use of only such approaches cannot guarantee the best solution.

Project financing of LNG supply chain:-

Issues Particular to Financing Upstream

Development and Liquefaction

- Off taker Risk and Downstream Risk
- Nature of supply Rights
- Terms of construction

Issues Particular to Financing Upstream Development & Liquefaction

• LNG Offtake Agreement

Offtaker Quality

LNG Offtake Agreement terms

Quantity of LNG

Amount- take or pay

Pricing (Maximum or Minimum)

Mechanism for price revision

Upward or Downward Flexibility

Flexibility for destination

LNG Offtake Agreements as Revenue Support for Debt

Issues Particular to Financing Upstream

Development & Liquefaction

- Feedstock Supply of feedstock

Term of production sharing contract

Proven reserves

field development cost

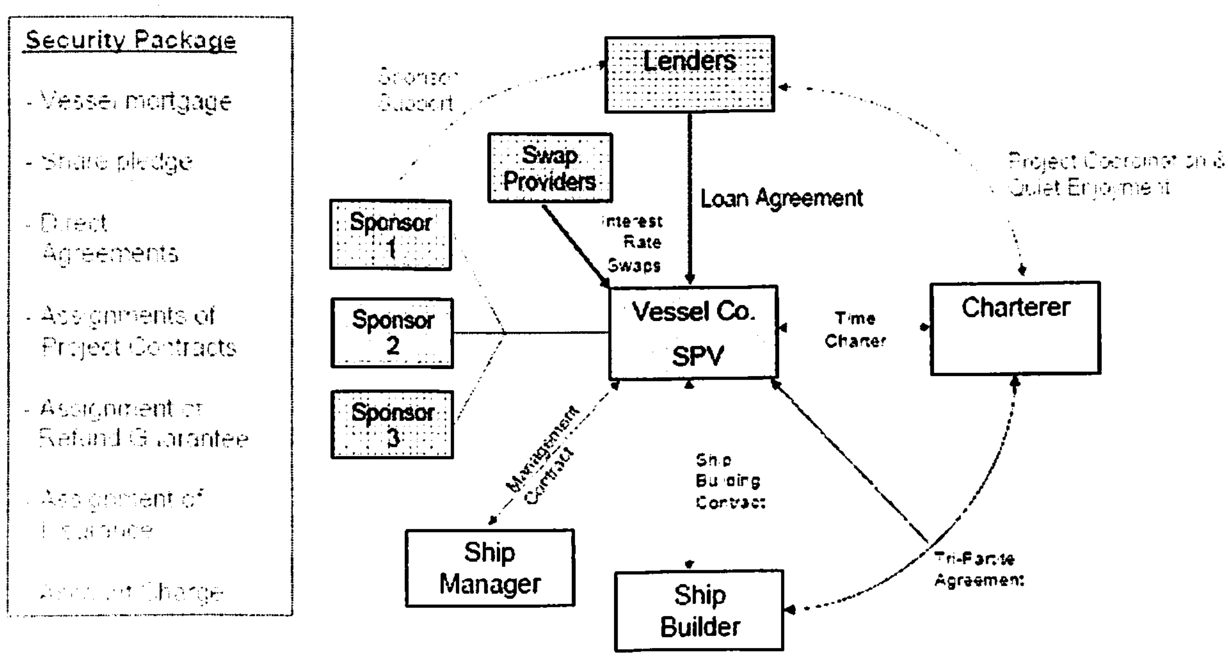
Field development plan

LNG Supply Chain dedication

Issues Particular to Financing Upstream Development & Liquefaction

- Support of sponsors
- Scope of Security
- Political Risk is there
- Health, Safety & Environmental

LNG TRANSPORTATION



Issues Particular to Financing LNG Shipping

- Interdependency of LNG vessels with upstream development & liquefaction as well as regasification in downstream
- Credit risk for charterer
- Party Terms of charterer
- Support of sponsor
- Redeployment of vessel
- Refinancing of vessel
- Guarantee security

Project Coordination & Quiet Enjoyment Agreement among Vessel Company Charterer and Lenders

Charterer consent to finance over vessel and assignment of Charter

Charterer Standstill Period & Lenders Right to treat Default

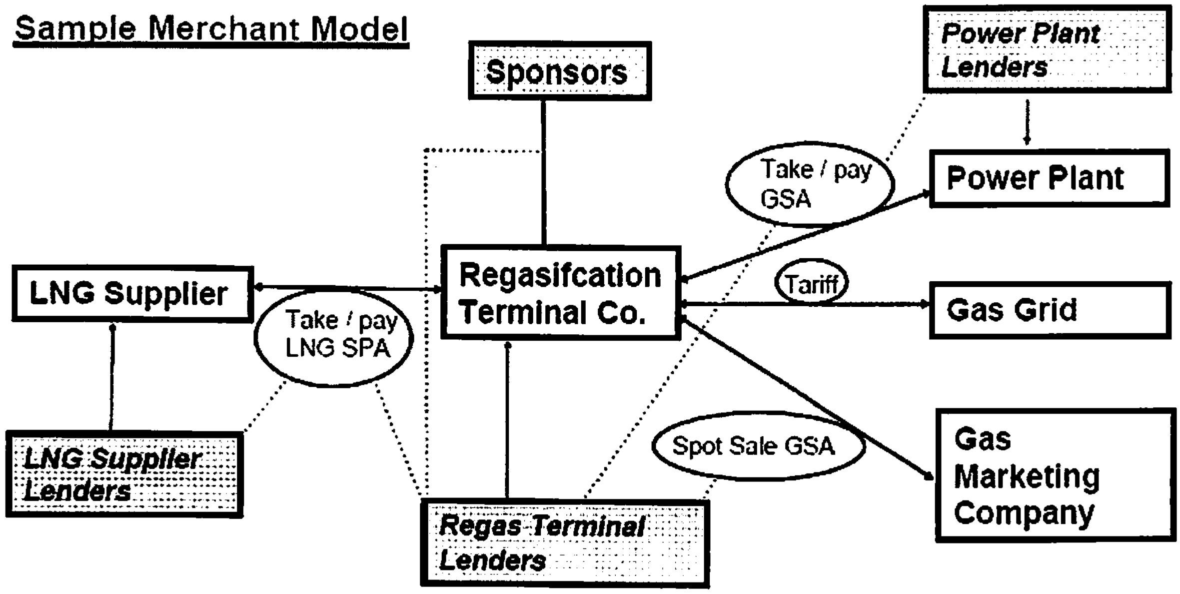
Lender Rights for substitution

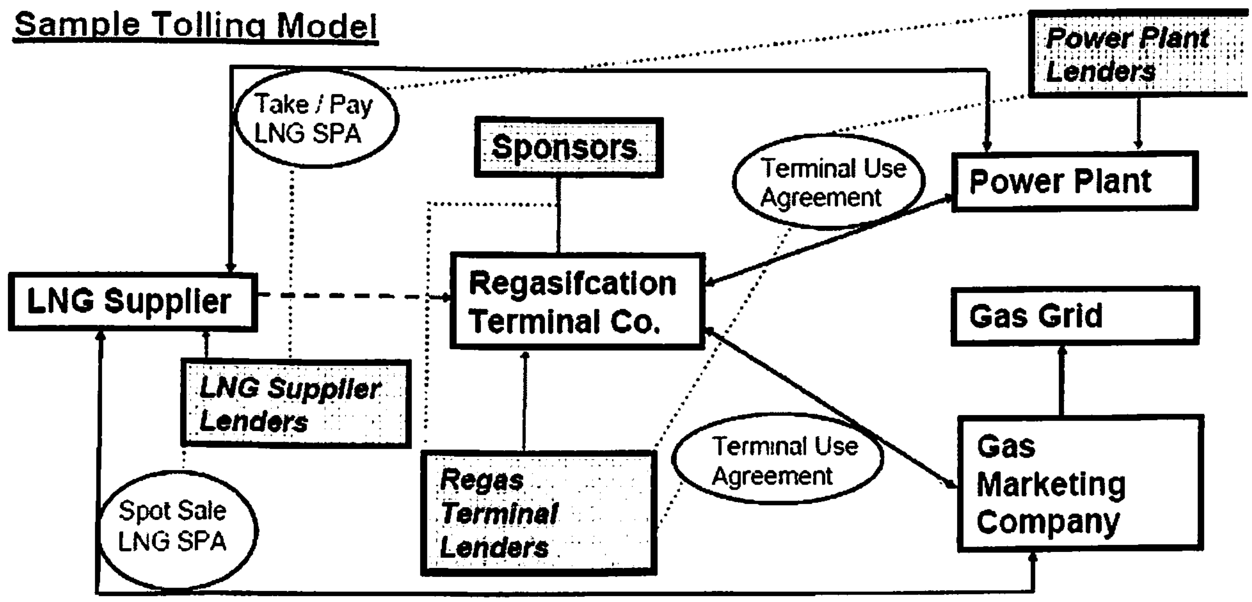
Charterer Right of Quiet Enjoyment

Charter Right of Early Termination of Charter in case Vessel Finance Default

Additional Charterer Covenant

LNG REGASIFICATION:-





Issues in Financing LNG Regasification Terminals

• Regas terminals reliant upon upstream supply

Subject to all upstream risks and delay

Tense supply market has resulted

• Point to point supply model changing & also tolling structure still more common than merchant

• Significant upstream support required from sponsors

• Offtakers mostly invest in Regas Terminals

Issues in Financing LNG Regasification Terminals

• Permitting – "NIMBY"

• Terrorist activities

• Typical construction risks of other large projects

• Severe cashflow management through waterfall

• Direct Agreement between lenders and terminal users

Terminal Use Agreement

• Basic document for regasification terminal tolling structure

• Removes price and volume risk from terminal operation

Terminal Use Agreement Issues

•Counterparty risk

• Force Majeure

• Diversion of cargos

• Legal responsibility

• Numerous users

• Lender rights on Terminal Operator default

DOWNSTREAM

Downstream pricing / economics

• ultimately drive entire project financing structure

Downstream market dynamics

• can be very different from upstream or midstream LNG market

Offtaker strength in target market is very important

Downstream issues in LNG project finance – two examples

• US / UK Grid sales

• GSA along with Independent Power Project (IPP)

MAXIMIZING LNG SUPPLY CHAIN EFFICIENCY WITH SIMULATION MODELLING

To maximize LNG supply chain efficiency, companies must make sure they meet contractual obligations, seize opportunities for spot cargoes, reduce operational costs and use all assets as efficiently as possible. The challenge of achieving these objectives is complicated because they are inextricably related and mostly conflicting.

In addition, when all the factors that can disrupt the supply chain are measured—weather, maintenance, equipment failures, tidal and darkness limitations, seasonal demand patterns, marketing scenario and more—it becomes almost impossible to absorb the overall system. By using simulation modeling to analyze these factors holistically, managers can maximize LNG supply chain efficiency & improve productivity.

Using discrete event simulation software to model the complexity of manufacturing systems has provided top-notch companies with the ability to more precisely envisage the benefits and consequences of change prior to implementing decisions. Illustrative interactive simulation modeling has been used since the early 1980s to measure the true performance of a facility, enabling alternative proposals to be evaluated to determine their true worth. This has enabled, and continues to allow, decision-makers to identify and address unforeseen issues and develop commercial opportunities.

In a marketplace driven by increasing competitive pressures with the current need to reduce capital and operational costs, the capability to "run the plant before it is built" through simulation modeling make sure that the world's leading manufacturers get it right for the first time itself.

There are many case studies that confirms how millions of dollars have been saved through the realization of the benefits as follows

Fully Validated Capital Proposals – the ability to compute the business benefit that will be achieved through the purchase & commissioning of new equipment to either increase efficiency or capacity.

Capital Avoidance – the ability to determine that the resulting performance of a proposed investment will not bring the benefits that were envisioned. This may apply to all of the equipment in the proposal or a section of the equipment. In the latter case, this may be due to over-engineering or the condition of excessive surplus capacity.

Cost Reduction –Its the ability to understand how operational expenditure can be reduced by modifying current practices and operating policies. This normally involves saving labor and material costs through greater suppleness. Similarly improved performance can reduce or eradicate contractual penalties and influence reward when such schemes are in place.

Improved Asset Utilization – the ability to identify how current assets can be used in a more efficient way by changing operating practice. This has led to increased capacity and decreased unit costs.

Until quite recently, simulation modeling was seen as a practice better suitable to manufacturers. Though advances in simulation technology that have improved run speed, ease of use, flexibility as well as the ability to reflect systems where interdependency between interacting aspects coexists in concurrence with complex constraints, has allowed a wider variety of industries to take advantage of this inventive approach to add value through their supply chains.

The world's leading gas companies have now harnessed the power of simulation modeling to improve the quality of their decision making, and as a result realize benefits that are running into hundreds of millions of dollars.

Simulation modeling is serving the world's leading gas companies improve profitability and, simultaneously, provoke some thought on how your organization may also benefit from the application of such pioneering techniques.

Discrete Event Simulation Modeling

The standard definition of simulation is "a self-motivated representation of a real system, by a computer model, that behaves in the similar manner as the system itself." Simulation's unique time-based approach, in combination with the ability to reflect the factors that vary, enable models to imitate accurately the complexity of a real-life system.

As a simulation model advances, an animated exhibit shows resources traveling to equipment that requires intervention; inventory levels drop and rise showing the interaction between production and export systems, etc. Every equipment item is normally represented by an symbol, the color of which changes to show its dynamic position.

The following colors are commonly used:--

Color	Typical Meaning
Yellow	Idle – either spare or waiting for next operation
Green	Busy – operational or in progress
Magenta	Blocked – insufficient downstream capacity to proceed to next stage or downstream storage full
Red	Unplanned stoppage, e.g. broken down
Cyan	Planned stoppage, e.g. changeover / cleaning / maintenance
Blue	No resource available for intervention to service stoppage
White	Outside of operational hours, e.g. off-shift, darkness restrictions

FIG.- Color codes to indicate status of process phases.

Models can use simple block icons to represent equipment; otherwise, a more visually recognizable representation can be developed. This consists of the prospect of importing engineering drawings and even going so far as photorealistic graphics and essential reality representations

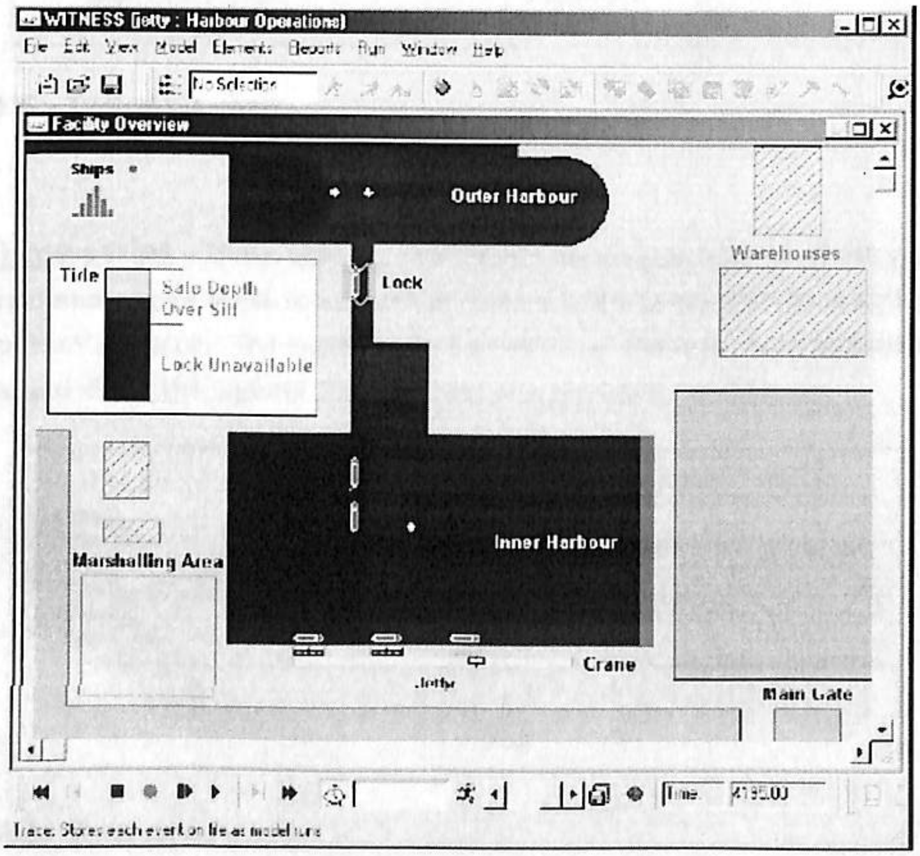


FIG:- Graphical view of simulation.

Similar with the animation, statistics on the performance of the system are automatically collected. **The nature of these important performance indicators are specific to the project, yet, in general they fall into 5 categories:**

<u>Pie Charts</u> – These typically represent the percentage of time that an feature of the system spends in a exact state or the percentage of time that was used to process different categories of product. The subsequent example shows the utilization of a berth in terms of the berth's status and the diverse categories of product that were lifted at that berth or land:-

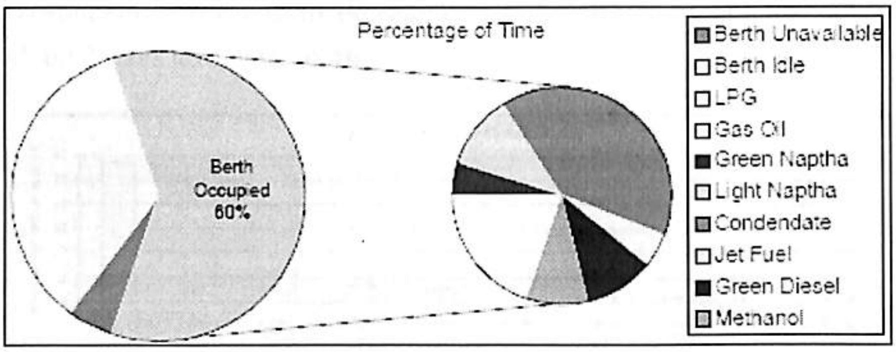


FIG:- Typical pie chart.

<u>Time series</u> – These typically represent how serious aspects of the system vary over time. A common use of these is to check inventory levels to predict when tank tops or stock outs would potentially occur. The example here shows how the maximum and minimum inventory levels in a tank differ throughout the year that was simulated as follows:-

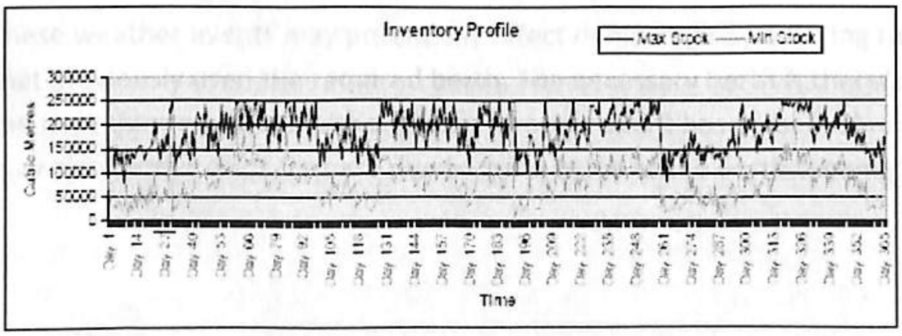


FIG:- Time series graph.

Histograms – These are typically used to show how a meticulous aspect of performance varies and the variety and shape of the variation. Histograms show the number of occurrences of values within defined ranges and are perfect for displaying time aspects of performance that are prejudiced by events which vary in frequency and duration. Examples of histograms used comprises of demurrage, round voyage times, number of days late as compared to ADP and also time spent in a port.

In the example ,a simulation model has been run 50 times, with every individual replication making use of different random numbers. The results of the 50 replications has been aggregated to get a picture on the shape & scale for predicted delay. This shows that over the 50 replications there is an average of 1 ship that will be one day late; an average of 0.4 ships will be 2 days late, and so on.

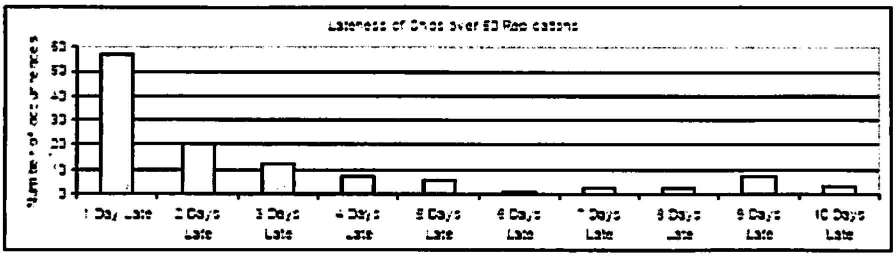


FIG:- Typical histogram graph.

Gantt Charts – These charts are used to know the interactions between events and potential impacts on the system's performance. In the example given here, different colored bars represent different products which are lifted at the berths. Different colored bars within the weather row stand for when different weather events occurring within the simulation.

These weather events may potentially affect demurrage by delaying the departure of the ship that previously used the required berth. The necessary berth is therefore not available when the next ship requires it, although the weather event has passed. Similarly, a ship arriving late may also demur ships that are due to use a berth as the berth tenancy increases.

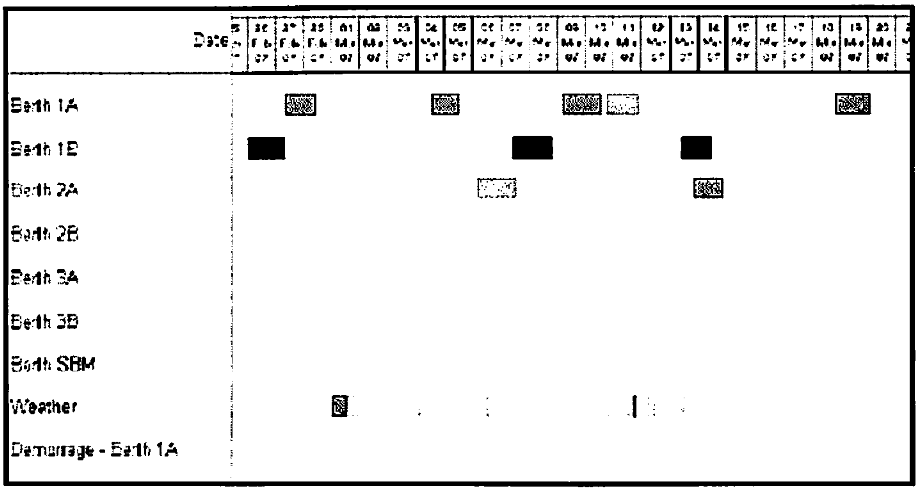


FIG:- Typical Gantt chart.

<u>Other</u> – Finally, any other key performance indicators can be represented in text or table format. Clearly the nature of the KPIs is specific to the project objectives themselves and is designed to allow alternatives to be rapidly compared to facilitate decision support.

<u>Stochastic Events</u>

Simulation modeling also uses the concept of events in order to determine what happens next in a model. For example, there is an event which marks the point when a ship has ended lifting its parcel size. This will then allow the ship to then leave the berth

While some events are fixed intervals, other events need to have variable intervals to reflect the fact that the length of events and times between events are often arbitrary.

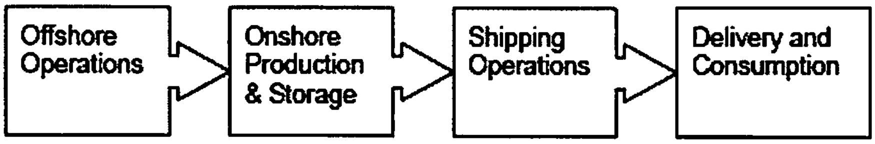
For example, the frequency and perseverance of a storm will not always be the exact same number of hours. Simulation models thus need to reflect this variable behavior using ***stochastic events***. These require the use of random numbers in combination with statistical distributions.

Unlike true random number generators, simulation modeling deploys pseudorandom numbers. These sequences of numbers appear to be random; they are, on the other hand computer generated and fully reproducible for subsequent comparative purposes. These pseudo-random numbers stretch out between 0.0 and 1.0 and are usually mathematically distorted into a sample from the required statistical distribution.

This enables stochastic events to be definite in terms of mean time for their frequency and duration. When modeling with stochastic events, it is significant to ensure that the results from the model are in no way biased as a result of the random numbers that has always been used.

A model is typically run over many replications, each replication deploy different random number sequences. This allows the variation in results to be obtained and thus confidence that the forecast is a balanced view.

Simulation Modeling to Improve LNG Supply Chains



Phase	Summary
Offshore	Gas is extracted from the reservoir and piped to an onshore plant.
Onshore	At the plant, mercury, sulphur and condensate are removed; the gas is dehydrated and liquefied through one or more trains by cooling it to -161°C. It is then stored in tanks to await shipping.
Shipping	The liquefied gas is shipped from the loading terminal to the receiving terminal.
Delivery & Consumption	At the receiving terminal, LNG is pumped from the ship into onshore storage tanks. It is then vaporized and consumed.

FIG:- The LNG supply chain.

Simulation modeling has now been used successfully by oil and gas organizations across each of these phases. Furthermore, several phases have been combined within a project range to provide an understanding of holistic behavior across the supply chain and to define storage requirements to separate out the stages.

Simulating Offshore Operations

Gas companies, whether operating LNG or GTL plants, have an obligation to strike the right balance between in general plant availability (to provide a continuous supply of gas) and the capital costs connected with "redundant equipment." The overall performance of an offshore facility is a intricate interaction between many factors including the following:-

•Gas Oil Ratios

• Drilling schedules

• Well potential

• Water cut

• Teething problems in early years of the field

• Strategies maintenance

• Availability of resources

The connections between these factors are extremely complex and difficult to assimilate without the use of simulation. It is frequently the case that a change can have a counterintuitive outcome. Likewise an improvement in one area can have a incidental effect elsewhere in the system as bottlenecks shift.

Ascertaining the holistic performance of a plant necessitates to quantify the effects of changes across the entire process. These factors are functions of time, and this is where the power of simulation comes into action. **Simulation's time based approach,** along with its skill to **reflect the multitude of factors** that vary, enables models to accurately imitate the **complexities** of offshore facilities.

Simulating a process provides very useful insight into where unforeseen constraints and bottlenecks lie. Once possible issues are identified, simulation models allow numerous ***what-ifs*** to be analyzed to assess how best to improve performance. These are likely to be centered on the cautious philosophy in each section and section block within the plant. This helps in understanding how **equipment can be used more effectively,**thus, resulting in eitheran **improved availability** or the capital avoidance.

In addition, by examining operating policies and practices for flaring, dumping water, intervention resources, etc., it is mostly possible to evaluate how equipment can be used more efficiently to drive up deliverability without extra investment. Note that an important differentiating factor of simulation is that it can be run for the entire length of field. This means that the time-dependent factors will all be logically represented enabling an accurate prediction of performance which is to be made.

This allows decision-makers with the basis to ratify the project or instigate a thorough review of its shortcomings.

Model Data Requirements – Here,the input to a model revolves around a reliability block diagram. In the diagram given, the number of identical assets within a functional module is shown along with the percentage of capacity each block can offer.

For example, a configuration of 3x50% means that each block can provide 50% of the required capacity and 3 identical assets perform these functions. One of the assets serves as a standby whereas the other two assets can meet the capacity requirement all the way through that functional module.

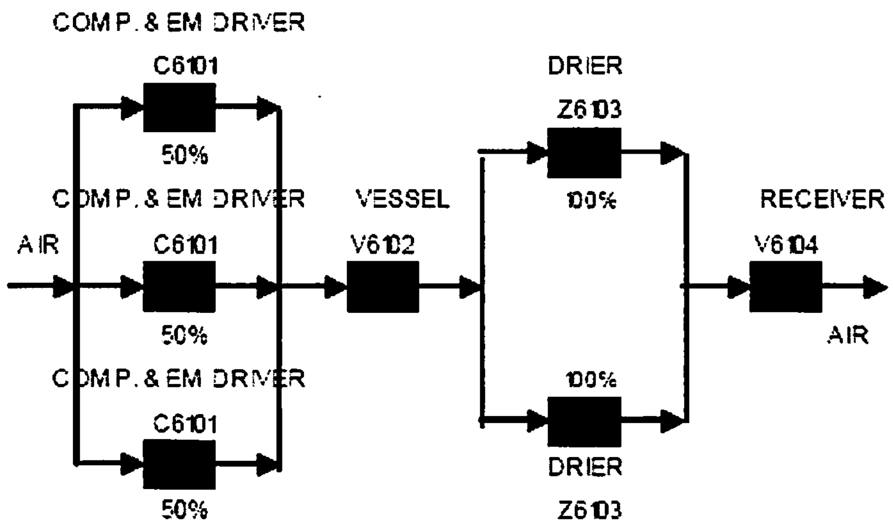


FIG:- Sample reliability block diagram.

The data is frequently held in a spreadsheet in the form of an asset register. An asset list drives the availability model.

For each functional module, the following information is to be required:--

- Capacity of each individual equipment item or a thing as a percentage of the required capacity throughout this functional module
- Number of similar assets in this functional module
- List of stoppages, planned and unplanned,which can occur on this functional module.

- Mean Time Between Failures

- Mean Time To Repair

- The decrease in throughput capacity on failure (as a percentage of the asset's capacity)

- Throughput capacity on repair

- Requirement of repair resource

- Whether to perform preventative maintenance for the other causes of failure in the functional block

One of the important characteristics of graphics-based simulation software is the ability to view an animation of the facility. It helps to understand the interaction between functional blocks stoppages & spare switching, resource availability, and equipment configurations. Furthermore, dynamic graphs of performance can be observed to see when deliverability changes as an active function of the number of wells, product composition as well as resource mobilization.

Results consist of accurate predictions regarding:

• Individual availability figures for each overall area in the process

• The volumes of products produced, injected, flared, etc.

• Environmental impacts like CO2 from flare, power generations, etc.

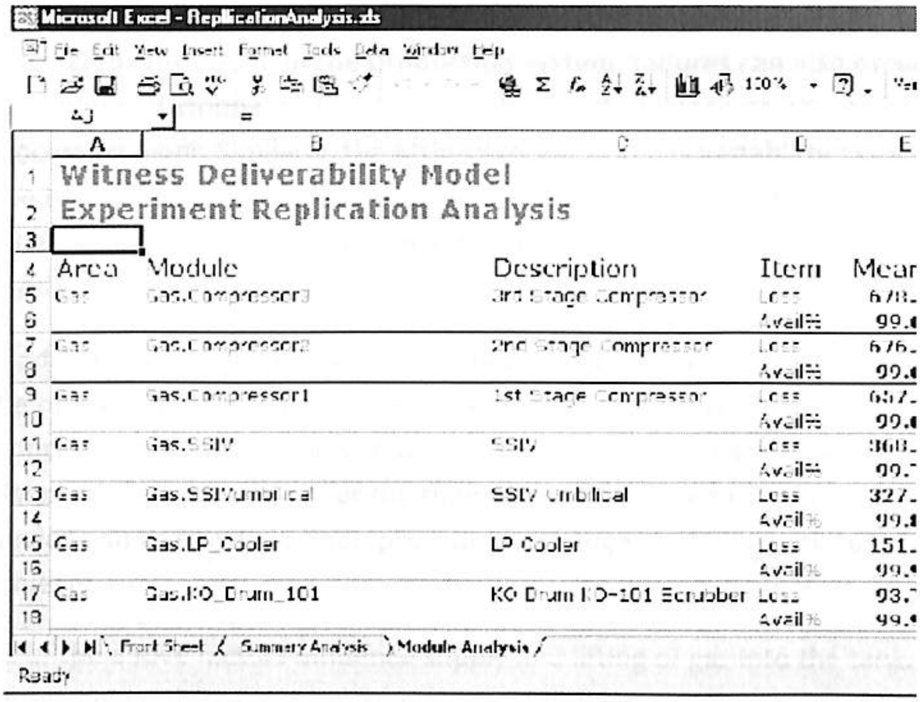
• Volumes of product consumed

• Performance over time as represented by time series graphs

• For each area, a list of equipment ranked according to the loss that was credited to the equipment item.

<u>Ranked List of Losses</u> - This provides a list of all of the losses practiced over the life of field. Every individual piece of equipment is listed with its individual availability and also the volume of production losses apportioned to equipment broken down at that time.

Example of a ranked list of losses is shown:-



Microsoft Excel - ReplicationAnalysis.xls

Area	Module	Description	Item	Mean
Witness Deliverability Model				
Experiment Replication Analysis				
Gas	Gas.Compressor3	3rd Stage Compressor	Loss	678.
			Avail%	99.
Gas	Gas.Compressor2	2nd Stage Compressor	Loss	676.
			Avail%	99.
Gas	Gas.Compressor1	1st Stage Compressor	Loss	657.
			Avail%	99.
Gas	Gas.SSIV	SSIV	Loss	368.
			Avail%	99.7
Gas	Gas.SSIVumbilical	SSIV Umbilical	Loss	327.
			Avail%	99.
Gas	Gas.LP_Cooler	LP Cooler	Loss	151.
			Avail%	99.
Gas	Gas.KO_Drum_101	KO Drum KO-101 Scrubber	Loss	93.7
			Avail%	99.

Front Sheet / Summary Analysis / Module Analysis

Ready

FIG:- Ranked list of losses.

This application is equally applicable to the onshore plant pattern indeed many projects have encompassed both onshore and offshore equipment allowing the complexity of the interactions between these stages to be studied.

Simulating Onshore Production and Storage

Storage Capacity

New gas companies have the need to understand the true interactions between downstream shipping operations and production systems. This can be also summarized at the highest level in the diagram given:

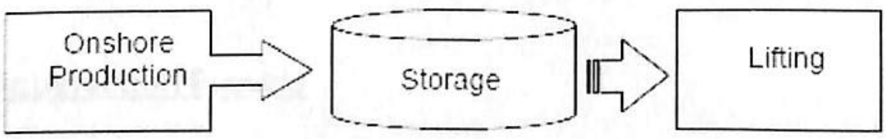


Fig:-Interaction between onshore production and lifting.

Both the onshore production systems as well as lifting operations have stochastic events associated with them. **In the production system, failures can also occur.** These can be caused by unplanned stoppages or may be as the result of knock-on effects from the offshore processing plant. Similarly, the **lifting process** also has **variability** associated with it. This may be due to **unexpected weather, tide or ship failure** events resulting in a ship arriving late; on the other hand, a ship may arrive early due to a smooth passage when contingency were not needed.

In addition to the stochastic events, there are a number of deterministic events that complicate the operation. Tides and darkness events may limit ships from entering the channel; planned stoppages may intentionally reduce production. Other manual interventions may also take place. Production may be for the time being accelerated to try and make up for lost production; similarly ships may have their precedence changed to avoid tank-tops occurring on other projects.

All of the above factors influence supply and lifting of gas into the tank. A delicate balance therefore needs to be struck to make sure that the required level of inventory is available for lifting, in accordance with the schedule; likewise, the tank must have sufficient ullage to deal with any late lifting to avoid shutting the plant & prevent a tank-top.

With capital costs in excess of $50 million dollars for storage tanks and potential for massive production losses if underdeveloped, there is always a need to authenticate the basis for investment in storage capacity and test the robustness of the proposal with tremendous cases of the above mentioned stochastic events.

Berth Capacity

In addition to influential the required capacity for storing inventory, it is equally important to ensure that the berth capacity is correct. If there is inadequate **capacity at the port** then the potential for tank-tops is greatly amplified. Striking the right balance between capital costs (the number of berths and the configuration of loading arms and lines on each berth) and also the potential for ships being delayed is equally critical.

Liquefaction Process

The most common application of simulation within LNG plants is to determine the most appropriate driver selection for refrigeration units. Companies usually need to decide whether gas turbine generators or electric motors offer the finest performance in provisions of overall cost and deliverability. Power generation systems are usually configured as X number of power turbine units (which result in 100% of the power requirements being satisfied) plus Y number of spares which are on standby to replace the loss in the event of one of the x failing. This is given below:

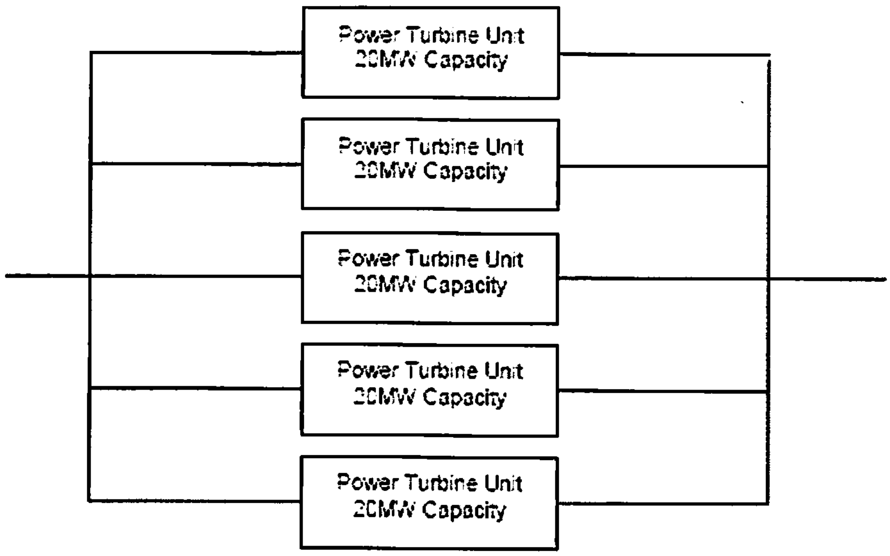


Fig:- Representation of a power generation system.

In the example, if the total power requirement is 60MW then the facility is a 3+2 configuration. The reliability & capacity characteristics of electric motors are essentially different to gas turbines. This means that to satisfy a given power requirement, a different X+Y configuration may be needed. Determining how the power requirement is best met is an important decision and one that is ideally considered with simulation modeling.

In addition to identifying the best configuration, it is mostly necessary to assess the impact of not having enough power turbine units to satisfy the max out demand. It may be that the loss of a power turbine is not disastrous if the loss of power is primarily for auxiliary motors.Knowing the overall system consequences of various power turbine capacity & failure characteristics is critical to maximizing IRR and NPV.

In addition to the capital costs, the cost as well as effect of planned maintenance must be taken into consideration. Gas turbines and electric motors have diverse maintenance characteristics involved.

In addition, if there is more than one strategy in order to perform maintenance, is a complete shutdown preferable to taking units down individually. Simulation modeling provides the means to compare diverse operating policies in order to provide decision-makers with the important information they need to make the correct decisions.

Simulating Shipping Operations

Capacity Planning

Although many areas of the supply chain can realize significant benefits through the use of simulation, the optimization of the configuration and use of the shipping assets is a common need for the main gas companies. With LNG ships costing around $200 million and ship reservation slot costing upwards of $5 million, maximizing ROI while making sure no constraints are added is critical.

The consequences of insufficient ships include the inability to transport cargoes in line with customer demand and the possibility of not being able to avert a tank-top that will result in the LNG plant stoppage.

Both of these situation must be avoided. Beyond the purchase of specific shipping vessels, it is necessary to determine the berth configuration for lifting LNG, propane, butane and condensate. For example, should LPG be situated on the same berth as condensate? Should the berth used for lifting LNG be built-in so that LPG can also be lift?

Similarly the size of the storage for all products must be correctly factored with the shipping assets. For example, if VLCC (very large condensate carriers) are being used, then larger storage vessels may also be required to optimize berth utilization.

Simulation allows proposals to be challenged and validated. In 1 project, the organization concerned had a need to determine whether4 or5 LNG ships were required.

Similarly, the requirements for storage needed to be determined. Simulation modeling allows any parameter to be changed in order to understand the outcome, whether it was beneficial to the overall performance of the system. By fine-tuning the complete system configuration, capital investments can be optimized and money that would have been tied up in superfluous capacity is avoided.

The most suitable combination for storage sizes, number of ships and berth configuration is a function not only of the production capacity; it is strongly influenced by the plant location & the market to which it will serve. For example, if a particular market has a RVT (Round Voyage Time) that is 5 days longer than another market, then additional shipping resources will also be required to serve it. Without simulation, it would be almost impossible to know the requirements to serve the mixture of markets under consideration.

This is because each trip has different patterns for weather, ports have individual constraint for tidal and darkness restrictions and the receiving port may also be served by competing gas companies which may hamper entering the port if their ship arrived late. Many clients have used simulation models to equip them with the knowledge on the result of specific marketing scenarios. This knowledge has then been deployed in commercial debate.

In determining how the shipping system will perform under different scenarios, additional value may be achievable by loading spot ships at the production port. Though determining when these opportunities should be acted upon to minimize the impact on project business is not a straightforward one.

Assessing the Robustness of Annual Delivery Programs

Once the physical aspect of the supply chain is known, understanding how to serve one or more customers in the most well-organized way allows improved asset utilization & increased revenues through working smarter to maximize opportunities for incremental delivery.

LNG companies create annual delivery programs which specify the allocation of individual shipping resources to specific timed deliveries. Example ADP is shown below.

Ship	Receiving Port	Loading Port ETA	Loading Port ETD	Receiving Port ETA	Receiving Port ETD
LNG1	Japan	19/01/03 09:00	20/01/03 04:00	31/01/03 10:00	01/02/03 07:00
LNG2	Korea	25/01/03 12:00	26/01/03 07:00	03/02/03 14:00	04/02/03 11:00
::	::	::	::	::	::
LNG1	Japan	12/06/03 09:00	13/06/03 04:00	24/06/03 10:00	25/06/03 07:00
LNG2	Korea	13/06/03 12:00	14/06/03 07:00	23/06/03 14:00	24/06/03 11:00
::	::	::	::	::	::

Fig:- Sample Annual Delivery Program.

ETA:- Estimated Time of Arrival

ETD:- Estimated Time of Departure

The deterministic aspect of an RVT is calculated by summing:-

- Time to load & unload
- Laden voyage length
- Time to enter receiving port & loading port
- Ballast voyage length
- Bad weather causing delays
- Bad weather prevents port entry
- Breakdown of ships
- Production equipment breakdowns as well
- Unexpected ship stoppages
- Potential for not being able to unload at disport
- Time-critical restrictions such as darkness and tides

For example, 2 days contingency may be added to an 18 day RVT giving a readjusted RVT of 20 days. Though the actual time taken to complete the round trip may be less or more than the twenty days that were used for planning purposes.

The more contingency added, the more robust the schedule; but, this may not make the most efficient use of the holistic assets and thus opportunities to increase business may be missed.

In order to schedule a fleet of ships more aggressively, and to allow incremental opportunities to be proactively seized, there is a need to moderate the risk associated with the various stochastic events that will interrupt production, loading, transit and unloading. The vulnerability of an Annual Delivery Program to the above mentioned factors may be limited to one particular cargo delivery.

On the other hand, when a more aggressive schedule is developed, the consequences of a ship arriving late can wrinkle to the next few cargoes. At that point, there is the potential for many cargoes to be late in succession.

In order to find the most favorable balance point to make the best use of ships, equipment and inventory a series of questions need to be asked. The answers to these what-ifs need to be a series of quantified measures which shows the probability and profile of tardiness, time-dependent inventory levels, production volumes and production losses as well.

Also the underlying cause of lateness needs to be understood; for example, is it the result of production loss, weather events, issue at the receiving terminal or a combination of these factors? Because simulation also aligns processes to time and supports the ability to incorporate variability, it is preferably suited to validate how robust an ADP is.

Furthermore, it will enable any underlying assumptions to be challenged. A simulation-based approach allows LNG producers to understand the implication of different marketing scenarios and the qualities and shortcomings of different ADPs to meet the slight deliveries.

Delivery & Consumption

The consumption of LNG from the storage tank at the receiving terminal is normally subject to various factors that affect the inventory level. This is given in the following diagram:---

Figure 13: Process of LNG delivery and consumption.

The consumption of LNG usually comes from **more than one demand type** and **more than one customer**. Demand could be for either LNG, gas or electricity. The interactions in a receiving port are of concern to both the receiving port operators and LNG suppliers as well.

While the receiving port operator is looking to reduce the storage requirements and the inventory profiles within the port, the supplier also needs to maximize the use of its shipping assets. Understanding the potential for interfering is vital, regardless of whether this is from a supplier part or a receiving port perspective.

Supplier Perspective

If a port has Sales Purchase Agreements in place with more than one LNG supplier, then there is potential for intervention between the competing suppliers' ships. For example, there may be a likelihood of a ship arriving at a receiving port while another supplier's ship is on the berth and also potential for delaying entry into the port, if there isn't sufficient space, the ship will also be delayed until its possible to offload its cargo.

Despite of the cause of the delay for offloading, there may be a knock-on effect in terms of delaying the arrival back at the loading port. This may hamper one or more further deliveries. It is thus important to strike the right balance between contingency and aggressive scheduling to maximize asset utilization.

Simulation modeling allows the impacts of the given conditions to be fully investigated. This enables the risk of following late deliveries to be mitigated.

Receiving Port Perspective

SPAs in place with suppliers need to be coordinated with GSAs (Gas Sales Agreements) with consumers on an annual basis. Analyses can also be performed on the impact of variations from these contracts. When multiple suppliers & multiple consumers are involved, the aggregate quantity then needs to be analyzed.

Such contracts state profiles of demand that will allow port operators to agree shipping schedules with their suppliers to make sure that demand can be met all through the contract period.

As the year progresses, consumers can propose the amount to be taken in a given period subject to an agreed range round about the contracted quantity for that period. The impact of each of these changes then needs to be understood to determine on an aggregate basis whether there will be an extra or shortage of product available. A decision can then be made on whether to cancel a delivery or look to gain an additional delivery from a supplier. The real amount of LNG taken day by day is also subject to deviation from the nominated quantity.

Ships do not always arrive on their agreed day for arrival. This means that sufficient spare inventory must be available In order to continue to fulfill demand when ships arrive late. Simulating this process, thus, allows the determination of whether stock outs or delays in offloading due to inadequate ullage are likely under a given set of contract variations. This allows the capacity of the storage tanks and vaporizers to be determined and stress tested for robustness.

Though striking the right balance between the capital cost of building the tanks along with the working capital held up in inventory and running the risk of a stock-out is not a simple mathematical problem, & that too in light of the flexibility that the gas consumers require now a days.

By simulating a receiving terminal, the equipment pattern is fully stress tested to ensure that capital is not invested in needless capacity while the risks of stocking out are fully mitigated. Furthermore, as a direct result of simulation modeling, a receiving terminal is fully equipped to enter discussions with its LNG suppliers. The terminal is then forearmed with the knowledge on the pattern of deliveries that meets its requirements and the contractual flexibility that will be required to meet its commitments.

Why a simulation is considered essential

Clients in the oil and gas sector have uttered specific needs that must be addressed. An approach, which harness discrete event simulation offers a key number of advantages. They are:-

• Simulation that enables a much more detailed and **accurate representation** to be developed and thus a **better prediction of availability** is produced.

• Without simulation, it would be impossible to accurately determine the size of intermediate & final storage facilities.

• Complex factors such as feedback loops, splitting & joining flows can be modeled precisely.

• All factors that vary over time can be incorporated, e.x:-

- Product composition like condensate, water, etc.

- Well commissioning profiles as well.

- Reliability profiles i.e. equipment less reliable in early years.

- Bottleneck capacities i.e. bottleneck equipment moves over time as ratios of condensate and water vary.

• Many statistical distributions can be deployed to specify the large number of time-based events in order to model all causes of stoppages and delays.

• Simulation is a very credible and proven approach and great confidence has been expressed by the world's leading oil and gas companies.

• Operational policies such as flaring and water dumping can also be modeled precisely.

• Financial implications of different environmental policies can be known.

• The results from a study are not an remote set of figures,instead, results consist of range of numbers allowing standard deviations, percentiles and confidence intervals which are to be generated.

• The results can be recorded dynamically into graphs such as the simulation progresses.

• It is possible to determine the sensitivity to changes in sparing different equipment.

• The model allows the risk to be assessed by challenging project assumptions, e.x. flexing reliability data.

• Because the model is allied to time, it is possible to quantify the NPV and IRR of the project.

Revisiting the benefits of simulation

By simulating an operation, the accurate performance of a terminal, plant, facility or logistics process can be determined. This removes the uncertainty connected with proposals and equips decision-makers with the confidence to authorize change or to enter into contractual commitment. By simulating in advance of decision-making it is then possible to accurately predict the exact outcome of the proposed change or plan.

This allows teams to arrive at a consensus based on facts rather than debating the perceived shortcomings.

True performance metrics are quantified, which can be then exploited to gain commercial advantage. While it is extremely difficult to put a value on the confidence that results from validating a proposal, many organizations seek confidence and risk mitigation as the most important benefit realized from simulation modeling.

Simulation modeling thus allows companies to quantify all aspects of performance. This may include determining some of the factors like:- capacity, lateness, utilization, deferred production, availability, inventory levels & costs. Armed with this information, a variety of combinations of the following **benefits** can be realized:--

- **Capital justification** – the ability to authorize the most appropriate scenario to maximize an organization's company goals

- **Capital optimization** – simulation allows clients to determine which combination of assets meets the requirements at the minimum costs, thus maximizing ROI.

- **Capital avoidance** – the ability to authenticate all business cases and dismiss those which do not warrant investment

- **Increased capacity** – maximizing the prospective of assets so more product can be delivered to market in the most economical way, mostly involving no extra capital costs.

- **Mitigated risk** – the ability to manage risk and make use of assets in the most aggressive way without hampering customer delivery performance

- **Reduced inventory** – the ability to uphold delivery performance while carrying fewer inventories, liberation of working capital that would have otherwise been tied up.

- **Improved asset utilization** – the ability to improve the complete use of key assets and to close the gap between current practice and real potential

- **Reduced unit costs** – derived from improving the utilization of important assets to deliver more product to the market in a manner that incurs no extra costs.

Conclusion

Simulating individual or combinations of stages in the LNG supply chain, clients are able to completely understand the effects, consequences and benefits of proposals for change, marketing scenarios, plant designs, port configurations & combinations of shipping assets. The world's foremost gas companies are insisting on simulating main decisions in order to improve the quality of decision-making and expand competitive advantages.

Simulation allows a complete understanding of the outcome of all proposed scenarios and it provides senior managers with the ability to take decisions quickly with the confidence that they are taking the right decisions.

How Simulation Works:-

Consider the following simple example. Although this is more akin to discrete manufacturing processes, the principal of how simulation works remain the same.

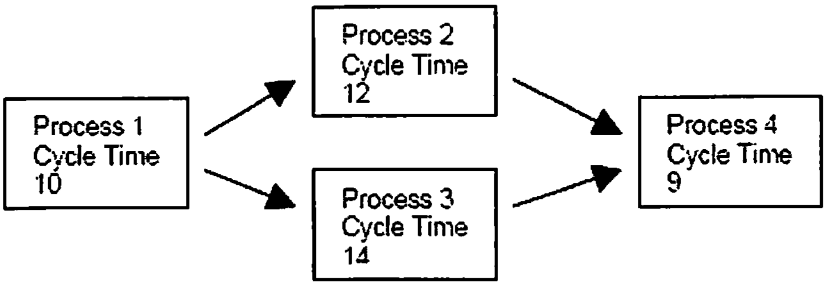


FIG:- Basic simulation example.

At the start of a simulation, the clock starts at0. Assuming an unconstrained supply of materials, then the first operation, process 1, will get a part and finish its cycle at time 10. The part will be output to process 2 which will start its operation at time 10. Process 1 will then pull the next part at time 10. Process 2 is now due to finish its operation at time 22. Process 1 is due to finish its operation at time 20.

At time 20, process 1 finishes its cycle& the part is output to process 3. Another part is obtained by process 1. Process 3 starts it cycle right away and will finish 14 time units later at time 34. Process 1 gets another part and will finish its next operation at time 30.

At time 22, process 2 finishes its cycle and gives its output its part to process 4. This takes 9 time units and will finish at time 31. Process 2 will remain idle until another part is pressed to it.

The process continues & replicating this into a computer model removes the burden of this manual calculation. Furthermore, the performance of each of the equipment items is automatically quantified. Event logs &performance reports are generated automatically:-

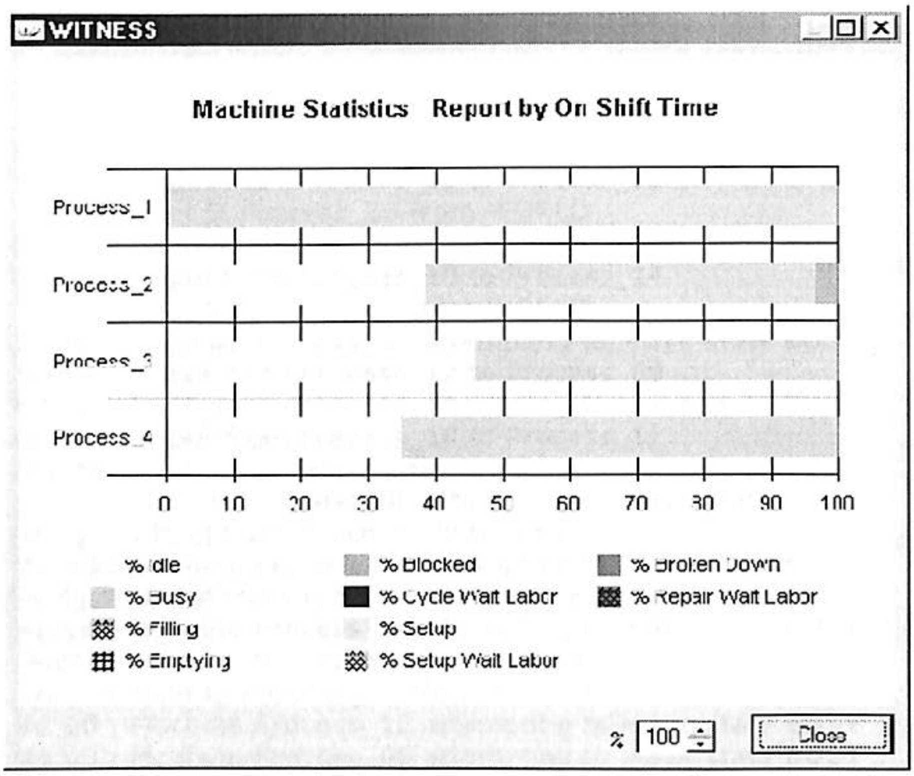


FIG:- Sample machine statistics from simulation run.

```
Interact Box

Widget input to Process_10 from WORLD
10.00 : Machine Process_10 attempting to leave state BUSY
Widget output from Process_10 to Process_12
Widget input to Process_10 from WORLD
20.00 : Machine Process_10 attempting to leave state BUSY
Widget output from Process_10 to Process_14
Widget input to Process_10 from WORLD
22.00 : Machine Process_12 attempting to leave state BUSY
Widget output from Process_12 to Process_09
30.00 : Machine Process_10 attempting to leave state BUSY
Widget output from Process_10 to Process_12
Widget input to Process_10 from WORLD
31.00 : Machine Process_09 attempting to leave state BUSY
Widget output from Process_09 to SHIP
34.00 : Machine Process_14 attempting to leave state BUSY
Widget output from Process_14 to Process_09
40.00 : Machine Process_10 attempting to leave state BUSY
Widget output from Process_10 to Process_14
Widget input to Process_10 from WORLD
42.00 : Machine Process_12 attempting to leave state BUSY
43.00 : Machine Process_09 attempting to leave state BUSY
Widget output from Process_09 to SHIP
Widget output from Process_12 to Process_09
50.00 : Machine Process_10 attempting to leave state BUSY
Widget output from Process_10 to Process_12
Widget input to Process_10 from WORLD
52.00 : Machine Process_09 attempting to leave state BUSY
Widget output from Process_09 to SHIP
54.00 : Machine Process_14 attempting to leave state BUSY
Widget output from Process_14 to Process_09
60.00 : Machine Process_10 attempting to leave state BUSY
Widget output from Process_10 to Process_14
Widget input to Process_10 from WORLD
62.00 : Machine Process_12 attempting to leave state BUSY
63.00 : Machine Process_09 attempting to leave state BUSY
```

FIG:- Sample event log from simulation.

CARBON CAPTURE OPTIONS FOR LNG LIQUEFACTION

The LNG liquefaction process is relatively efficient and is therefore a low emitter of carbon dioxide (CO_2) as compared with other natural gas monetization routes. Carbon capture and storage (CCS) applied to LNG liquefaction services could reduce these CO_2 emissions to near 0.

There 3 main carbon capture technology routes, namely pre-combustion, post-combustion and oxyfuel combustion & the ways in which each of these could be integrated into an LNG liquefaction facility design. An estimation of the capture technologies applied to LNG liquefaction services is reported.

The LNG industry has significantly improved the overall thermal efficiency of the LNG supply chain components with the target of limiting greenhouse gas emissions and the concept for a 0 CO_2 emission LNG chain has been mooted.

To achieve a zero or near zero CO_2 emission LNG chain requires LNG liquefaction facilities with CCS systems integrated into the main plant design.

CCS is the process of reducing the CO_2 content of streams normally released to the atmosphere and transporting the captured CO_2 to a place for permanent storage. CO_2 can be captured from a large range of large single-point sources, such as process streams, heater and boiler exhausts and vents across a variety of industries, like power generation, cement production, refining, chemicals, steel and natural gas treating as well.

Once captured, the CO_2 is then compressed, dried and transported to a suitable storage location such as saline aquifers, exhausted oil reservoirs (where enhanced oil recovery could be employed) or depleted or exhausted gas reservoirs.

SOURCES OF CO2 AND CAPTURE POTENTIAL IN LNG LIQUEFACTION

In the LNG supply chain, the LNG liquefaction plants produce in excess of 75% of the chain CO_2 emissions. The CO_2 emissions within an LNG liquefaction capacity differ depending on the plant configuration.

The plant pattern is dependent on parameters such as feed composition, feed pressure, product specifications, liquefaction technology, cooling media, compressor driver selection and the level of heat power integration. The bulk of the CO_2 emissions from LNG liquefaction plants occur from combustion of fuel and from CO_2 taken out from the natural gas feed stream.

The CO2 emissions for some LNG projects are shown in figure. This provides an indication of the comparative CO2 emissions from fuel combustion and from feed gas; as much as 90% of the LNG liquefaction plants CO2 emissions comes from combustion of fuel.

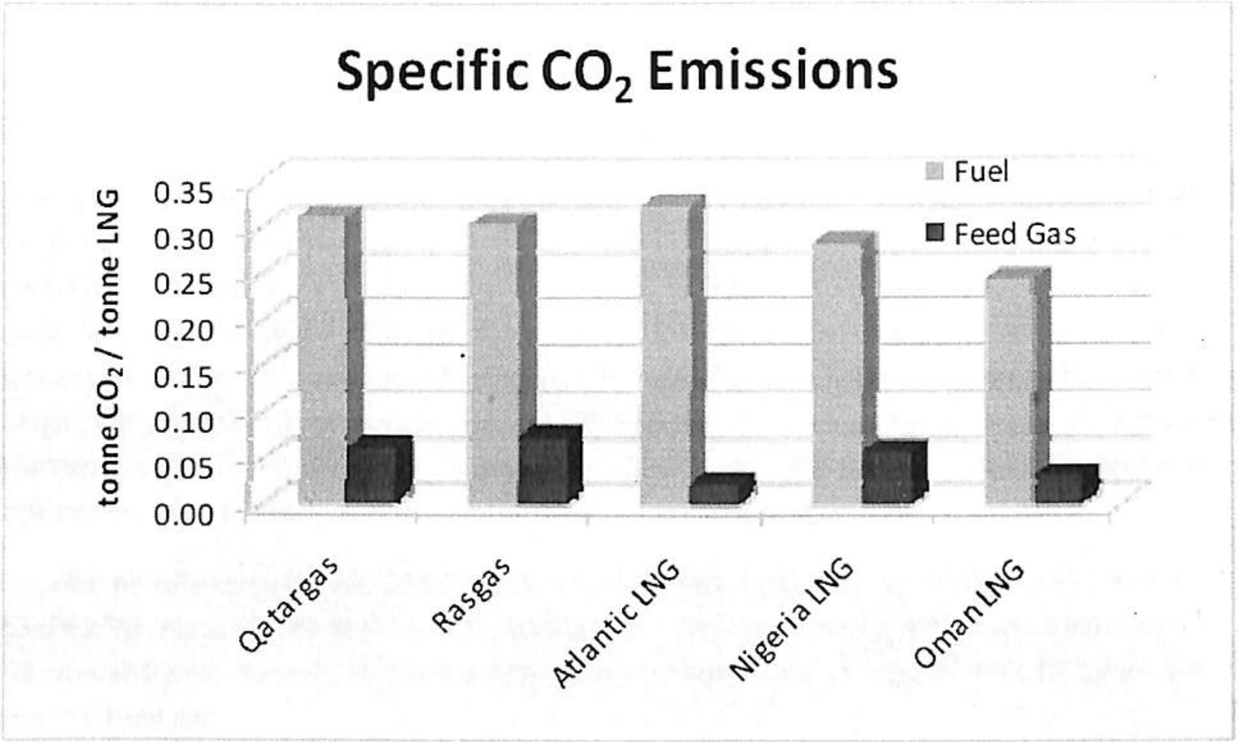


FIG:- Specific CO2 Emissions

<u>CO2 Emissions from Feed Gas</u>

LNG liquefaction plants separate the CO2 from feed gas as it is necessary to achieve the necessary CO2 specification in the feed gas to the liquefaction system to avert freeze out in the liquefaction heat exchanger. The CO2 emissions from feed gas depends mainly on the level of CO2 in the feed gas and secondly on the plant's overall thermal efficiency.

For a fixed product schedule and production rate, improving the facilities overall thermal efficiency reduces the CO2 emissions in 2 ways. Firstly, the CO2 emissions from fuel are decreased, because there is less fuel, and secondly, the CO2 emissions from feed gas are decreased because using less fuel requires less feed gas. Just because the CO2 is readily separated from the feed gas and concentrated in the acid gas removal division as part of the normal LNG gas treatment process, it is not unreasonable to suppose that capture levels of virtually 100% are attainable.

All operational LNG plants, except Snøhvit, currently emit this CO2 to atmosphere either directly or via a thermal incinerator or through sulphur recovery depending on the entire composition of the feed gas. Snøhvit LNG plant at Melkøya near Hammerfest has a CO2 drying and compression system which is installed for export of some 700,000 tonnes per year of CO2 to the Tubåen formation situated 145 km offshore at a depth 2500 m below the sea couch. For LNG liquefaction plants with CO2 content in the feed gas in the range 0.75-2.28 mole% the CO2 emissions are 0.02 to 0.07 tonne CO2 / tonne LNG correspondingly.

Pro-rating these figures it is expected that at CO2 concentrations in feed gas at around 8 mole% the CO2 emissions, from feed gas, reaches the level resulting from fuel combustion, i.e. 0.24 tonne CO2 / tonne LNG. Thus, for an LNG facility where high CO2 feed gases are processed, except CCS of CO2 from the feed gas is provided, the total CO2 emissions will be considerably higher than current LNG industry benchmarks. Both the Gorgon and Browse feed gases consists of high CO2 concentrations. The Gorgon LNG development, which is now in the engineering and construction phase, contains a CO2 reservoir injection system for storage of the CO2 detached from the feed gas in the Dupuy formation 2500 m below Barrow Island.

This scheme will decrease the CO2 emissions by 0.20 tonne CO2 / tonne LNG to 0.35 tonne CO2 / tonne LNG. Plans for the Browse LNG development, that will process a feed gas with a high CO2 concentration consists of investigations into the export and storage of the CO2 taken out from the feed gas.

CO2 Emissions from Fuel

Figure here shows that the CO2 emissions from fuel for LNG liquefaction plants are typically in the range 0.24 to 0.32 tonne CO2 / tonne LNG. With optimization of the heat and power balance the fuel consumption & CO2 emissions from fuel can be decreased by approximately 30% leading to CO2 emissions from fuel in the range of 0.17 to 0.22 tonne CO2 / tonne of LNG.

Taking into account capture and export of 90% of the CO2 from the combustion flue gases, there is potential to decrease the CO2 emissions from fuel to around 0.02 tonne CO2 / tonne LNG.

CO2 GENERATED FROM FUEL GAS COMBUSTION

Carbon Capture Technologies

There are 3process routes that can be considered for CO2 capture, these are:

- **Pre-combustion**
- **Post-combustion**
- **Oxyfuel combustion.**

Pre-Combustion –

Feed (solid or gaseous hydrocarbon feedstock) is routed to a reformer where it is converted to synthesis gas predominantly carbon monoxide and hydrogen. This syngas then undergoes a shift reaction which increases the H2 level of the syngas whilst converting the CO to CO2. The high pressure, high temperature syngas is then cooled, before being washed with a solvent in order to absorb the CO2 leaving a concentrated H2 stream & a CO2-rich solvent stream.

The solvent regeneration process releases the CO2 into a stream which can be dried and compressed for export. The process offers a high degree of integration potential as it generates a concentrated high pressure hydrogen stream & the syngas cooling train can be used to increase significant quantities of high, medium and low pressure level steam. A variety of CO2 solvent removal systems are available consisting of physical and chemical solvent-based systems as well as optional technologies such as membranes and pressure swing absorption.

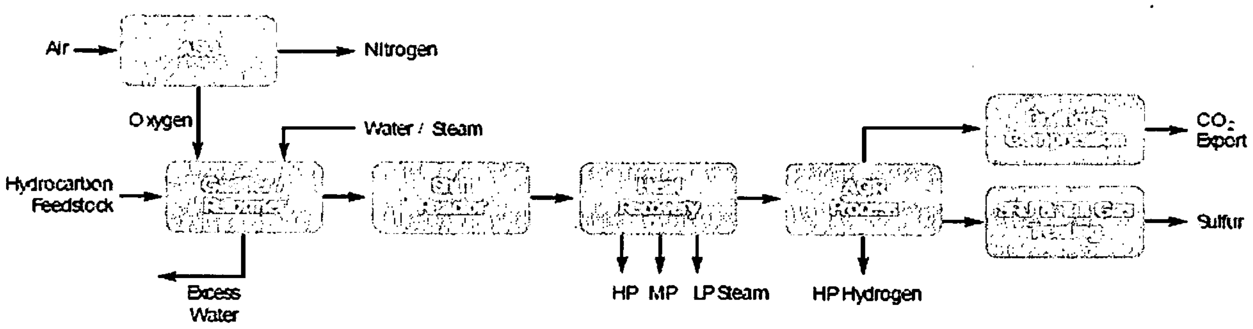


FIG:- Pre-Combustion Flow Scheme

The pre-combustion capture scheme could be integrated into an LNG liquefaction facility which is as follows:

- The high pressure H2 stream can be used as fuel for gas turbine drivers e.g. for the refrigeration compressors. Besides the generated steam could be used to provide process heating, motive power and power generation.

•An LNG plant using electric motors for the refrigeration compressors, the high pressure H2 stream can be used as the fuel for a combined-cycle gas turbine (CCGT) power plant & the generated steam used for similar duties.

The high pressure H2 stream can be used as fuel for boilers and the steam generated (together with steam from the pre-combustion heat recovery process) used for heating, motive power and power generation as well.

For these alternatives the feed supply to the gasifier/reformer can either be a typical LNG plant fuel gas stream, containing LNG plant feed, end-flash gas (EFG) and boil-off gas (BOG) or feed gas. Depending on plant location, coal, petcoke, fuel oils, municipal solid waste or biomass can be used as the gasifier feedstock which will allow more of the natural gas feed to the facility to be converted to LNG and other products like LPG, condensate.

The CO2 captured from flue gases can be then combined with CO2 captured from the natural gas feed, in the acid gas removal unit, and then fed to a common CO2 drying & compression system for export.

Post-Combustion –

Flue gas from fired equipment (e.g. gas turbines, boilers, fired heaters) is at first cooled in either a waste heat recovery unit (WHRU) or in a heat recovery steam generator (HRSG) and then is further cooled by direct water contact before ingoing a blower designed to overcome the absorption system pressure drop.

The flue gas then enters the absorption column, in which it is washed with a solvent such as Mono ethanol amine (MEA). The flue gas is stripped of around 90% of its CO2 content before being released into the atmosphere from the top of the absorber. The CO2 rich solvent is regenerated in a stripping column where CO2 is released and then dried and compressed for export. A range of processes exist utilizing different kind of solvents.

The post-combustion capture scheme can be integrated into an LNG liquefaction facility as follows:

• Capture of CO2 from the flue gases of distributed fired equipment such as gas turbine drivers, gas turbine generators, fired heaters and boilers. Different options, with varying or changing levels of heat integration, are available for configuration of the capture equipment.

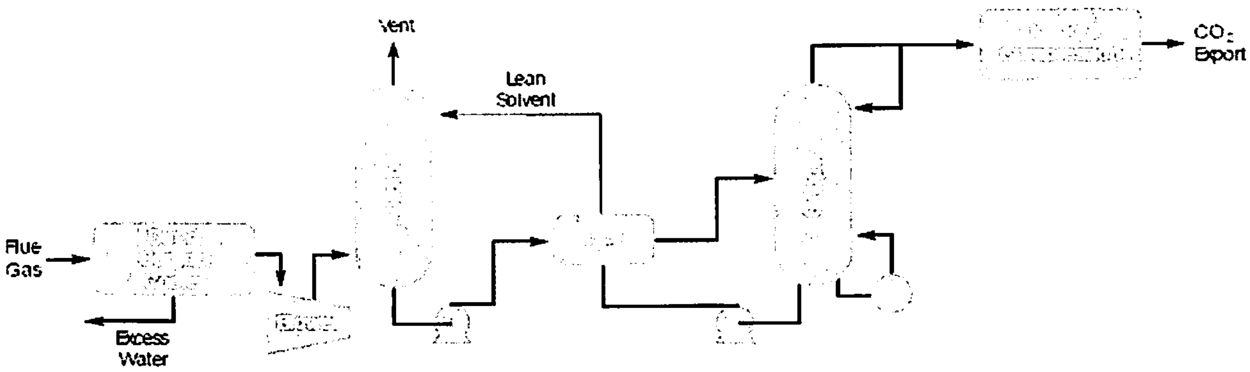


FIG:- Post-Combustion Flow Scheme

a) Flue gases can be moved to a common centralized capture unit serving all CO2 emitters.

b) Solvent can be pumped around the facility from a general stripper to individual absorber placed at each CO2 emitter.

c) Individual capture systems can be provided local to each CO2 emission source.

d) A combination of the above two.

Provide capture of CO2 from the flue gases of a CCGT power plant used to provide power for an all electric motor LNG facility. Process heating duties can be supplied from the power plant steam cycle.

• Provide capture of CO2 from the flue gases of a centralized boiler plant used to generate steam for the LNG services or facilities heating, motive power and power generation necessities.

In all cases, the CO2 captured from flue gases can now be combined with CO2 captured from the natural gas feed and then fed to a common CO2 drying and compression system for export purpose.

Oxyfuel Combustion Process –

The feed is combusted with oxygen, from an air separation unit, into an oxyfuel combustor ex. boiler or gas turbine. The temperature in the combustor is moderated by recycling a part of the flue gas back to the combustion chamber.

Flue gas passes through particle removal, by electrostatic precipitator, sulfur removal by limestone scrubbing & water removal by cooling and condensation. The remaining flue gas is further processed to meet the required CO2 product purity specification before being dried and then compressed for export.

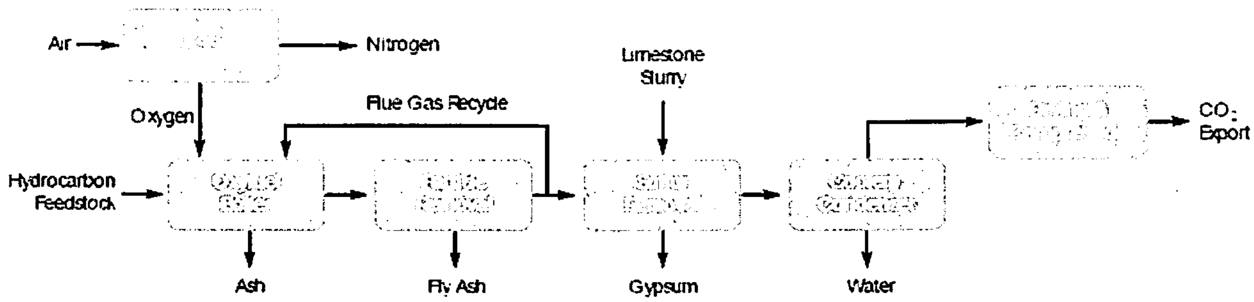


FIG:- Oxyfuel Combustion Flow Scheme

The oxyfuel combustion capture scheme can be integrated into an LNG liquefaction facility in many ways.

• Steam can be generated in oxyfuel boilers and the steam generated used to provide the LNG facilities process heating, motive power & power generation requirements or necessities.

• Oxyfuel gas turbines can be employed:

a) In a CCGT power plant used to provide power to an all electric motor LNG plant with process heating duty supplied from the power plant steam cycle

b) In direct-drive overhaul for the refrigeration compressors with steam generated, using a HRSG on gas-turbine exhaust which is used to provide process heating, motive power and power generation as required

For the pre-combustion options the feed supply to the oxy combustor could be a typical LNG plant fuel gas stream, consisting of LNG plant feed, EFG and BOG, feed gas only or alternative or substitute fuels.

The CO2 flue gas stream can be combined or united with CO2 captured from the natural gas feed and then fed to a common CO2 drying and compression system for export purpose.

Carbon Capture Technology Evaluation

The 3 main capture routes described above could all be applied to LNG liquefaction plants and each of them could achieve equivalent CO2 capture levels. Both pre-combustion and post combustion technologies are now available for natural gas fired systems.

Whilst pre-combustion capture can be applied, via the production of syngas from natural gas and its subsequent use within gas turbines, this would require noteworthy additional complexity and process equipment and associated capital and operating costs over and above that necessary for post combustion.

It is likely that the availability would be decreased with loss of syngas production causing a loss of LNG production. A more favorable application for pre-combustion within an LNG application might now be where there are other adjacent markets for syngas and H2 to be supplied "over the fence" for other applications like ammonia production, Fischer-Tropsch, further power generation.

Use of syngas in addition to the LNG plant would then warrant a larger syngas production facility, with equivalent economies of scale and potential operating flexibility advantages.

Oxyfuel combustion of natural gas in gas turbines is beneath development by gas turbine vendors and not yet available on a commercial scale. Due to the technical risks and uncertainties & doubts in design, oxyfuel gas turbines have not been considered further as a means for carbon capture on LNG plants. Instead Oxyfuel boilers can be applied to generate steam from natural gas and the steam used for power needs. Though, like pre-combustion,this would involve significant additional complexity, process equipment and costs, as compared with that required for post-combustion. In the same way the availability would be reduced with loss of oxyfuel production thus causing a loss of LNG production.

Post-combustion technology, as compared to pre-combustion and oxyfuel combustion, is considered to provide similar capture levels at no greater technical risk, process complexity, capital & operating costs.

Post-combustion technology, on the other hand, is seen to offer the simplest means of integrating flue gas CO2 capture into LNG liquefaction services design at the outset or as a later retrofit to a capture-ready plant. The post-combustion capture and export system can be designed to be bypassed, during planned and unplanned outages in such a way so that there is minimal impact on LNG production availability.

Therefore, of the 3 main capture process routes, post combustion has been considered the most suitable.

Calculation of the specific costs

The basis for calculation of the specific costs is as follows:

- $$\text{Cost of } CO_2 \text{ captured (US\$/tonne)} = \frac{\text{LNG cost}_{capture} - \text{LNG cost}_{no\ capture}\ \text{(US\$/MMBtu)}}{\text{Specific } CO_2 \text{ emissions (tonne/MMBTU LNG HHV)}}$$

- $$\text{Cost of } CO_2 \text{ avoided (US\$/tonne)} = \frac{\text{LNG cost}_{capture} - \text{LNG cost}_{no\ capture}\ \text{(US\$/MMBtu)}}{\text{Specific } CO_2 \text{ emissions}_{capture} - \text{Specific } CO_2 \text{ emissions}_{no\ capture}\ \text{(tonne/MMBTU LNG HHV)}}$$

Carbon capture has the potential to decrease the total CO2 emissions from the liquefaction facility to round about 0.02 tonne CO2 / tonne LNG. However, heat recovery and integration optimisation has the potential to reduce CO2 emissions at a comparatively low specific CO2 avoided cost when compared to capture options.

The cost of post-combustion capture equipment in order to remove CO2 from gas-turbine flue gas sources requires higher investment and consequently higher CO2 emissions charges to provide an economic motivation.

With 90% of the carbon in the feed gas to the liquefaction facility leaving in the products, almost all of which will be producing CO2, greater reductions will be achieved by improving combustion system efficiency and also by capturing CO2 at end users.

Other measures to improve the supply chain of LNG:-

Establishing a New Infrastructure for Energy

The growth in the use of liquid natural gas (LNG) has been extraordinary in the last 10 years. This development underlines the long term tendency in fossil energy carrier use towards energy carriers with lower carbon content. Apart from its character as a commodity, LNG is also seen as an alternative to heavy fuel oil as ship fuel due to its environmental track record.

A) Gas as a Marine Fuel

For a long time, LNG was a fuel which was related to users who needed natural gas but had no or difficult access to pipelines. LNG carriers were driven by steam turbines of low efficiency. Few reasons were the simple handling of boil off under all circumstances, the likelihood to adjust the energy supply to the need by adding fuel oil within the simple process of a steam boiler and also the high system reliability.

Now, an increasing part of LNG carriers is driven by high efficient gas engines. This growth - which happened on a commercial bases after the change of the millennium - allowed the introduction of LNG as ship fuel. But introducing LNG as fuel for shipping also requires the availability of LNG in ports and the aim to protect the environment from emissions from CO2 and NOx emissions. Nonetheless, a growing mankind, the industrial development of mankind and the limitations of fossil fuel resources will drive the inclination towards low carbon content of fuel and also higher efficiencies which are possible through technologies which are being already on the way.

The IGF-Code will include the requirements for use of gas as fuel on liquefied gas tankers and thus open the door for gas as fuel on LPG tankers. With regard to liquefied gas tankers, the IGF-Code will also substitute the regulations.

For vessels apart from gas carriers, the questions arise whether gas as ship fuel has a market and how the supply chain will look like. Furthermore, the questions related to the fuel price and the availability of LNG in ports is of utmost importance. Without an LNG infrastructure, the applications will be inadequate to special routes with possibilities for LNG supply and special ship types with routes like ferries.

Current developments in the Baltic sea indicate that this problem will not exist at least in this area any more in the near future. Though, there are indications that a number of port cities around the Baltic sea like Luebeck, Swenemuende, Goeteborg, Stockholm are too planning to use LNG within their energy supply infrastructure. For the city of Luebeck,the reason to develop a LNG receiving terminal project was the advantage for the gas supply for the city.

The limited number of pipelines available for supply and the rising distances required for gas supply by pipelines are increasing the transport costs. LNG imported from Bergen, Norway, via ship will be competitive to pipeline gas especially regarding the buffering possibilities which allow the gas supplier to avoid peak gas import during the winter. The accessibility of LNG in the port of Luebeck gives the opportunity to use it as ship fuel and to decrease the emissions from ships which contribute to a large extend to the air pollution of the city.

B) New Type of LNG Vessels

Regarding LNG supply, Norway seems the most appropriate partner for small LNG costumers in the Baltic sea area. The LNG infrastructure in Norway is by now existing and new plants (liquefaction) like the LNG plant of Nordic LNG in the Risavika outside of Stavanger are still under construction. Nordic LNG is a joint venture of I.M.Skaugen and Skangass. Whereas Skangass is a joint venture between Lyse and Celsius. **The yearly capacity is round about 300.000,- tpy with a possibility to increase this upto 600.000,- tpy.** The transport of the gas to the costumer would be done by the Multigas LNG carriers of I.M. Skaugen.

A first series are now currently being built with Germanischer Lloyd class in China. These vessels fit in to the new type of **small LNG carriers with Type-C tanks** and will be able to bring the idea of small scale LNG distribution into actuality. The liquefied gas capacity is about **10.000,- and 12.000,- m3.** They will be able to transport aEthylen and LPGs and use a new designed reliquefaction technology to keep the tank pressure.

The first vessels will have a length of 137 m, Type-C tanks with 5.2 bar gauge pressure & a cargo capacity of 10.000,-m3. The 7 MW power of the main engines allows a service speed of 16.5 kn.

This new type of LNG vessels will allow smaller terminals which allow a faster implementation of the projects and the use of LNG in a broad range of applications including LNG as ship fuel. The cost & capital efficient ships are available as of 2009 and the supply chain will need lower infrastructure costs as compared to large scale LNG applications and in many cases be more cost efficient as compared to pipelines.

Small LNG Tankers

The possibility to adjust the infrastructure to the demand quickly is an advantage as compared to the gas supply with pipelines. Depending on the distance one 10.000 cbm carrier can move up to 500.000 tons per year. Further adding additional vessels to the supply chain is easier. In an increasing market for gas the small LNG concept is an option for customers who will never get gas from a pipeline. It is a concept to monetize stranded gas on the production side which allows exploiting gas field too small for traditional large scale LNG.

C) From Coal to Low Carbon LNG Fuel

From the beginning of industrialization more than 200 year ago, the carbon content of energy carriers has been reduced and thus the efficiency has increased. Though the coal period was successful with a fuel carbon content of 100 percent and the first ships fired with coal reached efficiency below 5 percent using low pressure steam engines. The bunker occupied an essential part of the ships' volume as well.

Oil started its career in the 20ies of the last century and has already reduced the carbon content of fuel. The efficiencies of energy conversion for ship propulsion increased to the values for state-of-the-art diesel engines up to 50 or more percent. The introduction of natural gas reduced the carbon content of energy carriers to the lowest value possible. Now only the use of hydrogen which has to be produced artificially will give a further reduction and allow a carbon and thus carbon dioxide free energy conversion as well.

D) Legal Background for LNG as Ship Fuel

According to the current SOLAS convention, fuels with flash points above 60°C are allowed to be used as fuel. This excludes gases as fuels with the exception of LNG tankers which are allowed by the IGC-Code to use LNG as fuel for propulsion.

With permission of the national administration, twenty vessels are currently running on LNG as fuel in Norway. Amongst them, are a number of car ferries and 2 offshore supply vessels. The first RoRo vessels are still under construction in India with a delivery scheduled for the year 2010.

These practical examples reveal that gas as ship fuel is an option for propulsion of vessels apart from liquefied gas tankers. In the past, international agreed safety requirements were missing and thus each national administration had to set their own requirements. This also relates to the operation variety of such vessels to national waters because individual permit from each administration involved are required. This was one reason to suggest the development of an International Code for Gas as Ship Fuel to the Marine Safety Committee (MSC) of IMO in 2004. The work started along with the development of Interim Guidelines for natural gas as ship fuel. The so called IGF-Guidelines are under final review by IMO. The guidelines are limited to natural gas as a fuel & internal combustion engines as energy converters.

They allow the introduction of gas as ship fuel on an international base. They will be the international safety standard in the near future until a general Code would have been developed and set into force or action as part of the SOLAS convention. The IMO time schedule is the next SOLAS revision planned for 2014. This IGF-Code will include requirements for other gases other than LNG and also other energy converters than IC-engines. Thus LPGs will be included and also boilers, turbines and fuel cells will be covered as well.

E) Ship Bunkering:-

The product tanker is the 1st ship with regular fuel oil operation which is converted environmentally friendly propulsion based on natural gas. This allows Skangass with its LNG plant in Risavika, to step into the market for refueling vessels.

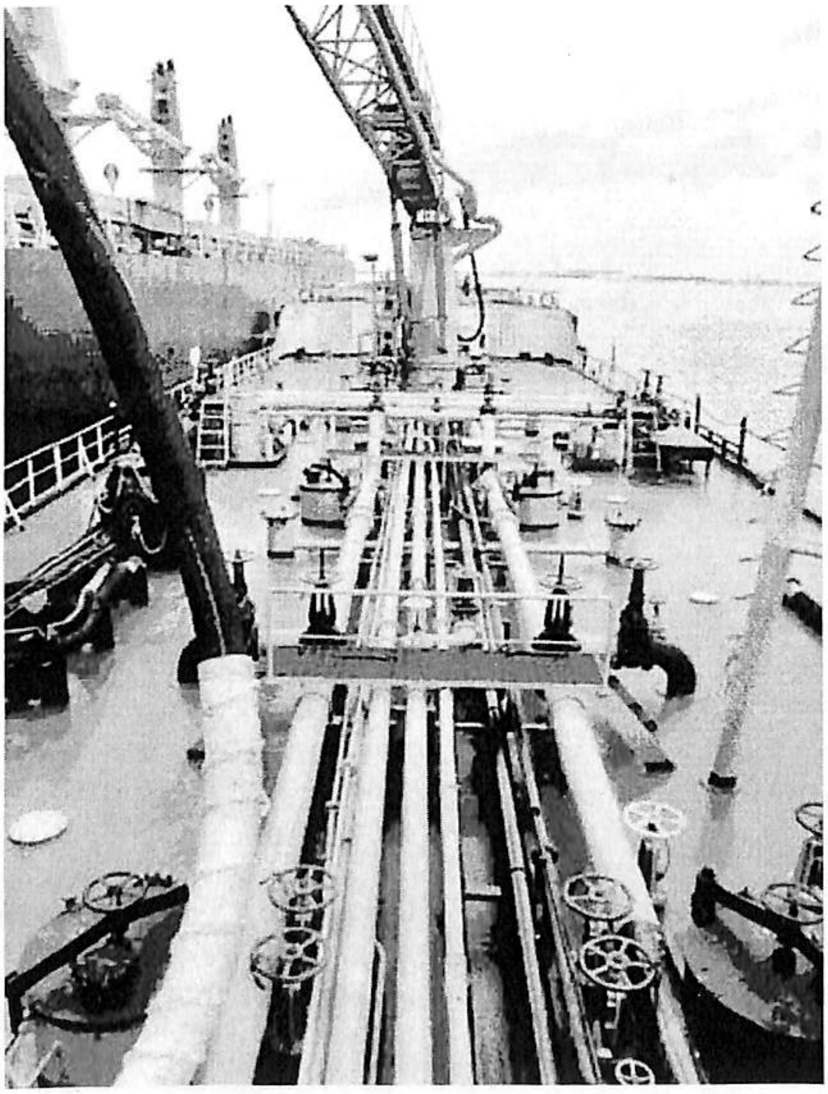
A bunker barge approaching a huge oil tanker for the bunkering operation.

The ship was built in the year 2007 and is owned by the company Tarbit Shipping. Bit Viking sails along the Norwegian coast with petroleum products for Statoil. The alteration of the Swedish-owned ship is supported by NOx.
Through a completely new technique, the ship's engineer were recently accustomed for LNG fuel.

Statoil is extremely pleased with the cooperation with Tarbit Shipping and Skangass, and thus

this opportunity to help reduce emissions along the Norwegian coast.
This is a sole event set in an environmental perspective.

Conversion of Bit Viking`s engines from running on heavy oil to LNG reduces NOx emissions by 85%, sulphur and particle emissions are removed completely and CO_2 by 99%.



Flexible connecting hose used to supply the oil to the ship after connecting it to the suitable bunker manifold.

With bunkering directly from the tank at Skangass, the supply chain is more efficient. It will become common for vessels to use LNG for fuel, as it is a much cleaner and better option as compared to the heavy oil and diesel. In Norway a lot of ferry traffic has switched to LNG. The potential are high also for offshore supply vessels.

For Skangass, the bunkering of ships is a significant priority. **LNG for ships will provide considerable reductions of NOx, sulphur, soot and particle emissions.** In addition to these environmental benefits, LNG will also **provide large economic benefits.**

LNG Economics:-

LNG projects are pretty much capital intensive. The cost of the entire chain from wellhead to the receiving terminal can be US$4 billion. As in the case of pipelines, economies of scale are very important:-

A) Liquefaction plants typically consist of 1 or 2 processing trains. The economic size of each train is about 3 to 3.5 million tonnes per year. With this size of project, the capital cost of the LNG production facility is in the $1-2 billions range. Thus, adding a second train once a plant is built can reduce the overall unit cost of liquefaction by 20-30% which is very significant.

A single-train plant normally costs around $1 billion, even though actual costs vary geographically according to land costs, environmental & safety regulations, labour costs and local market conditions.

B) Technological progress achieved in the past has led to a sharp decrease in investment & operating costs of liquefaction plants. The average unit investment for a liquefaction plant dropped from $550 a ton a year of capacity in the 1960s, to around $350 in the 1970s and 1980s, and to $250 in the late 1990s. For projects starting operation today, the price is slightly under $200 (in current dollars).

C) Transport costs are a function of the distance between the liquefaction and regasification terminals and the size of the vessel as well. Using a larger number of smaller carriers offers more flexibility and decreases storage requirements but increases unit shipping costs. The largest LNG carriers now has a maximum capacity of 135,000-138,000 m^3 and cost around $170 million to build.

Considerable reductions in cost have been achieved over the past decades because of economies of scale. Tanker sizes have now increased from some 40,000 m^3 for the first generation to a range of 130,000 to 140,000 m^3.

D)Regasification plant construction costs depend upon throughput capacity, land development and labour costs (vary according to location), and storage capacity. Economies of scale are most important for storage. These are maximized for storage tank capacities of round about 150,000 m^3 – the largest possible at present.

The last 5 to 10 years have seen some chief reductions in LNG supply costs. These have come from increases in train size, improved fuel efficiency in liquefaction and regasification (from high-efficiency gas turbines), improved equipment design, the removal of gold-plating and better use of available capacity.

Liquefaction costs have decreased typically by 25% to 35% and shipping costs by 20% to 30% from 1990 to 2000. The cost of regasification has decreased less than costs for the other parts of the LNG chain since the 1960s. Technology & productivity gains have been largely make up for by higher storage costs, the largest single cost component.

	Cost estimate Early 1990s	Cost estimate Early 2000s
Upstream development cost	0.5 - 0.8	0.5 - 0.8
Liquefaction	1.3 -1.4	1.0 - 1.1
Shipping (LNG tanker)	1.2 - 1.3	0.9 -1.0
Regasification	0.5 - 0 6	0.4 - 0.5
Total cost	**3.5 - 4.1**	**2.8 - 3.4**

Cost reduction in the LNG chain (Middle East to Far East LNG project) $/million Btu

CONCLUSION

Development of gas-fuelled power stations in India is boosting the demand for gas in the country. BMI states that gas consumption in India has increased by more than 160 per cent since 1995 while average annual demand would grow by 6 per cent over next few years.

Gas production is estimated at 50 BCM in 2011 while total gas consumption is predicted at 81 BCM in 2016 from an estimated 58 BCM in 2011 by BMI.

Thus the future of natural gas is very bright in India and especially that of LNG due to the drastic fall in the domestic gas output.

India is one of the fastest emerging nation and their economy is growing rapidly too which is only next to china as compared to the world. It relies heavily on energy resource such as oil & gas to improve its infrastructure which is why it imports 80% of its crude oil and imports LNG too.

It has some commitments towards the preservation of the environment. Thus, India needs to reduce the carbon content from the LNG supply chain and improve its LNG supply chain through simulation modeling in order to maximize LNG supply chain efficiency, companies must ensure they meet contractual obligations, seize opportunities for spot cargoes, minimize operational costs and use all assets as effectively as possible.

It will improve the decision making of a firm and the process of the firm as well.

RECOMMENDATION

1) Identify the risks and challenges associated with LNG supply chain and work on them.

2) Identify opportunities in the supply chain. For example:- swap practices or outsourcing its work to some other party.

3) Clear the financial issues in order to reduce the cost.

4) Make an effective use of the simulation model to increase the efficiency, reduce the cost, complete asset utilization, etc.

5) To capture carbon dioxide and use it for other purposes through Carbon Capture & Storage option.

6) Make use of LNG gas as a marine fuel to increase the efficiency & decrease the pollution level as well.

7) Make use of small ships(carriers) & ship bunkering.

8) Liquefaction plant must consist of two trains to reduce the overall unit cost.

9) Technological advancement is necessary to reduce the investment & operating cost.

10) Maximize economies of scale as well.

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