Chapter 3

Review of Literature

3.1 Introduction

This chapter deals with the a study of present status of existing storages for the companies around the globe, learning from the earlier research work carried by scholars in this field. The current literature is reviewed with an idea to build an overall understanding of the scenario, it becomes vital to build the foundation of existing quantum of knowledge by identifying the research gas that exists. The research gap turns out to be the starting point of this research work.

3.2 Global and Indian scenario of Pipelines and Natural Gas Storage

The available literature on Natural Gas Storage was studied through various means likes books, journals, professional websites, global and national conferences and the newspaper reporting, etc.

The researcher has also presented two papers on Natural Gas Storage for CGD in the ICMI 2016 conference (Dehradun). Details of papers presented are placed as Appendix-E.

The global literature survey carried out has been carried out for following countries/continents:-

- United States
- Europe
- Russia
- Australia
- China
- Middle East
- Japan
- India

3.2.1 United States

In U.S. a wide network of both inter-state and intra-state natural gas pipelines exists. There are more than 210 pipeline systems with a collective length of more than 548,665 Km. Texas having most number of pipelines followed by Louisiana and Oklahoma. In U.S the pipeline regulator is the state government agency for intra state pipeline, and for inter-state pipeline Federal Energy Regulatory Commission (FERC) is the regulator.

In U.S. most of the pipelines have diameter within the range of 6-48 inches.

- **Gas storage in United States**

Before 1994, interstate pipeline companies were the owner of the gas flowing through their systems and also owned the storage facilities of gas. They had complete control over the capacity and utilization of storage facilities. However after the implementation of FERC order 636, the storage facilities owned by the pipeline companies need to be operated on open access basis. Open access has allowed LDCs, intrastate pipelines and other independent operators to use storage not only for backup inventory but also for many other purposes like arbitrage opportunities. Storage can be used in conjunction with various financial instruments so as to make profit from market conditions etc.

There are currently 419 gas storage facilities in U.S. out of which 332 are depleted gas/oil reservoir gas storages, 47 are aquifers and 40 are salt caverns type gas storages. These storage facilities are mainly distributed in the gas producing areas. Approximately 50 percent of the storages are in northeast region. This particular region consumes most of the gas in U.S. Apart from this there are storages in Texas and Louisiana etc. Broadly speaking there are good amount of storage facilities all across the country. The following diagram gives the accurate details of all the storage locations.

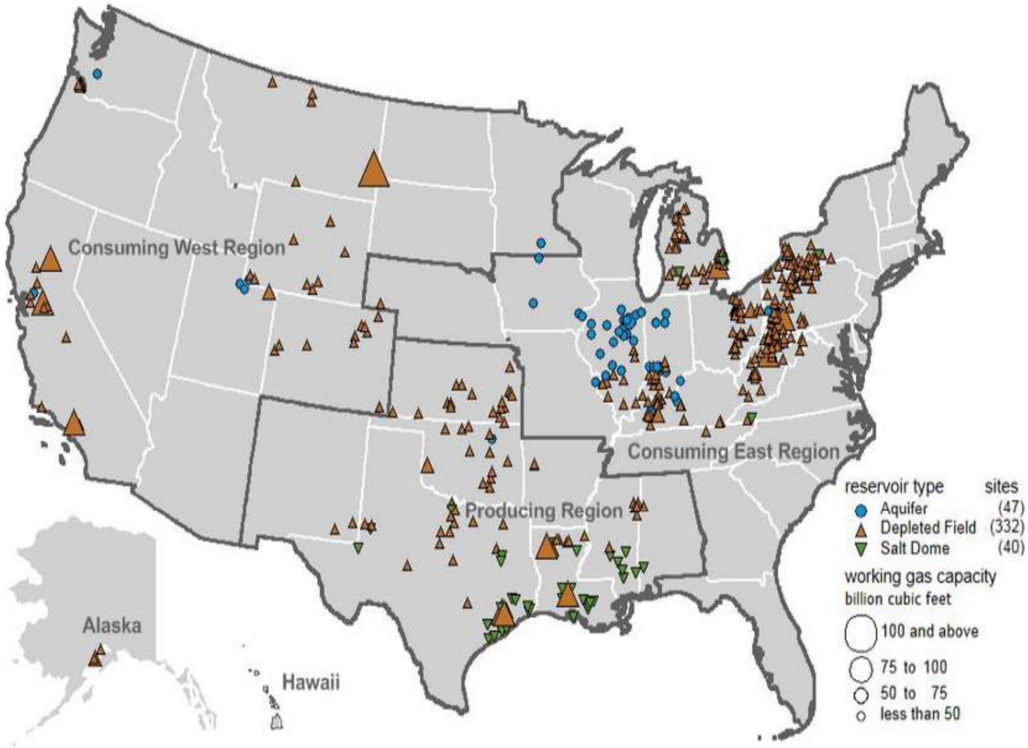

Fig 3.1 Gas storage locations in US map, (Source: EIA)

The total storage capacities and total working gas capacities of the different types of storages are as follows:

Table3.1 Working gas capacities of different types of storages, (Source: EIA)

Total Storage Capacity	**9,172,951 mcf**
Salt caverns	654,266 mcf
Aquifers	1,443,769 mcf
Depleted Reservoirs	7,074,916 mcf
Total Working Gas Capacity	**4,748,636 mcf**
Salt Caverns	455,729 mcf
Aquifers	453,054 mcf
Depleted Reservoirs	3,839,852 mcf

Current geographic distribution of underground storage facilities with their capacities in U.S. are as follows:

Table 3.2Location & capacity of different types of storages, (Source: EIA)

	Number of storages	Total storage capacity	Total working gas capacity.
Alaska	5	83592	67915
Alabama	2	35400	27350
Arkansas	2	21853	12178
California	14	599711	374296
Colorado	10	122086	60582
Illinois	28	1000281	303312
Indiana	22	110749	33024
Iowa	4	288210	90313
Kansas	18	283974	122970
Kentucky	23	221723	107600
Louisiana	19	733939	446713
Maryland	1	64000	18300
Michigan	45	1079424	674967
Minnesota	1	7000	2000
Mississippi	12	303522	180654
Missouri	1	13845	6000
Montana	5	376301	197501
Nebraska	1	34850	14819
New Mexico	2	89100	59738
New York	26	245779	129551
Ohio	24	577944	230828
Oklahoma	13	370535	181055
Oregon	7	29565	15935
Pennsylvania	51	774309	433214

Tennessee	1	NA	NA
Texas	37	842072	541161
Utah	3	124465	54898
Virginia	2	9500	5400
Washington	1	46900	24600
West Virginia	30	524337	258056
Wyoming	9	157985	73705

3.2.2 Europe

Europe imports its natural gas via its vast pipeline network from Russia (Russia accounts for 30% of European imports of natural gas), Asia, Middle East, and Africa. Some of the major trans-national natural gas pipelines are:

- **South Caucasus pipeline (from Azerbaijan and Middle East)**
  Its total length is approximately 700 km it connects the Shah Deniz field to Europe via Georgia and Turkey. The capacity of transporting is 7 BCM per year.
- **Nord Stream (From Russia)**
  It is an offshore natural gas pipeline and it connects Russia with Germany, its length is approximately 1220 km and it has a capacity of transporting 55 BCM of natural gas per year.
- **Blue Stream (From Russia)**
  The length is approximately 1207 km out of this 396 km of the pipeline is under the black sea. It connects Russia and Turkey.

The total length of pipelines in Europe is more than 200,000 km and the diameters of pipeline in Europe ranges from 6 inches to 47 inches. They are planning to expand the pipeline network further in future.

- **Gas storage in Europe**

As per the statistical report published by Euro gas in 2014, the total number of storage facilities in Europe was 150. Germany has 51 storage facilities, being the highest number among all European countries. It followed by France which has 16 storage facilities.

The details of the countries in Europe with storage facilities and its working capacity and peak output are shown in the table below:

Table- 3.3 Storage facilities and working capacity in Europe

Beginning of 2014	**Number of storage facilities**	**Working capacity (in million cubic meters)**	**Peak Output (in million cubic meters per day)**
Austria	8	8166	94.4
Belgium	2	967	57.0
Bulgaria	1	550	4.2
Croatia	1	553	6.0
Cyprus	0	0	0
Czech Republic	8	3497	57.4
Denmark	2	1035	25
Estonia	0	0	0
Finland	0	0	0
France	16	11709	191.0
Germany	51	23821	638.0
Greece	0	0	0
Hungary	5	6330	80.1
Ireland	1	230	2.7
Italy	13	16676	277.8
Latvia	1	2300	30.0

Lithuania	0	0	0
Luxembourg	0	0	0
Malta	0	0	0
Netherlands	5	5378	220.2
Poland	8	2109	41.4
Portugal	5	181	7.2
Romania	8	3100	30.0
Slovakia	2	3160	45.1
Slovenia	0	0	0
Spain	4	2533	13.7
Sweden	1	9	1.0
United Kingdom	8	4680	154.0
EU-28	**150**	**96984**	**1976.2**

(Source: EIA)

Peak output per day in Europe in million cubic meters is 1976.2, so it can be concluded that gas storage plays a significant role in Europe.

Although there are some countries where there is no storage facility, it is because of less demand and supply gap and some of them lack in technological and infrastructural advancement. Out of 150 storage facilities, 72 are depleted reservoir, 26 are aquifer, 50 are salt caverns and 2 are rock caverns. That is 48% of storage facilities present in Europe are depleted reservoirs and remaining 52% are others.

Germany and Czech Republic are the only countries in Europe which uses more than two types of storage facilities. Germany being more reliable of Salt cavern with 33 facilities. Germany has about 20bcm of natural gas stored which corresponds to 75 days of domestic consumption. And France has about 14bcm which corresponds to approximately 90 days of domestic consumption. Rock caverns are only used by Czech Republic and Sweden.

One of the reason for developing more storage is that Europe imports most of its gas from Russia and since there is a volatile relation between Russia and Ukraine, storing natural gas can reduce the dependency on Russia for the short term if there is any disruption in the supply because the main function of storage of natural gas is to maintain the balance between supply and demand.

- **Cost analysis of gas storage in Europe**

The major costs associated with the conversion of onshore depleted gas field to gas storage are dependent upon the size of reservoir, the wells to be drilled for the injection/withdrawal, compression and the processing plant and the pipeline connecting storage facility to gas grid.

For the average injection rate of 5.5 Mm3/day and the withdrawal rate of 8.3 Mm3/day and a peak withdrawal rate of 8.3 Mm3/day and total gas storage volume of 1.0 bcm. The investment cost is 700 euro per meter cube and the annual operating cost is around 3% of capex.. These figures are given by European investment bank, According to EIB the economic rate of return (ERR) of this project will be around 7.5% if the plant will not operate at full capacity. For example, if there is a 10% reduction in working gas capacity then the ERR will reduce to 6.5%. The cost will vary as per the type of storage used, as these numbers will go significantly high if Aquifers are to be developed. Thus the economics of the project is evaluated carefully by the European countries before developing any storage facility.

3.2.3 Russia

Major company operating the pipeline is GAZPROM. GAZPROM in fact has the longest pipeline network in the world, with an approximate length of 168,900 km, Gazprom's pipelines supplies gas to European markets and it has commissioned Nord stream pipeline which is the first natural gas pipeline between Germany and Russia.

The major problem that Russia is facing in transporting gas to European market is the sour relations between Russia and Ukraine, as most of the pipelines to Europe are passing through Ukraine.

As of December 31st, 2013 there were 26 underground storage facilities out which Gazprom operated 22 facilities. There are 17 depleted gas storage facilities, 8 aquifers and 1 salt cavern facility. The working gas capacity of Gazprom's underground storage facilities is 70.4 billion cubic meters. The total number of producing wells at underground storage facilities is 2689. In 2013, 32.7 bcm of gas was withdrawn from underground storage facilities and 38.4 bcm of gas was injected into the underground storage facilities which also included 200 mcf of cushion gas. The maximum daily deliverability during gas withdrawal season was 727.8 MMSCM and average and average daily deliverability during gas withdrawal season was 579.6 MMSCM.

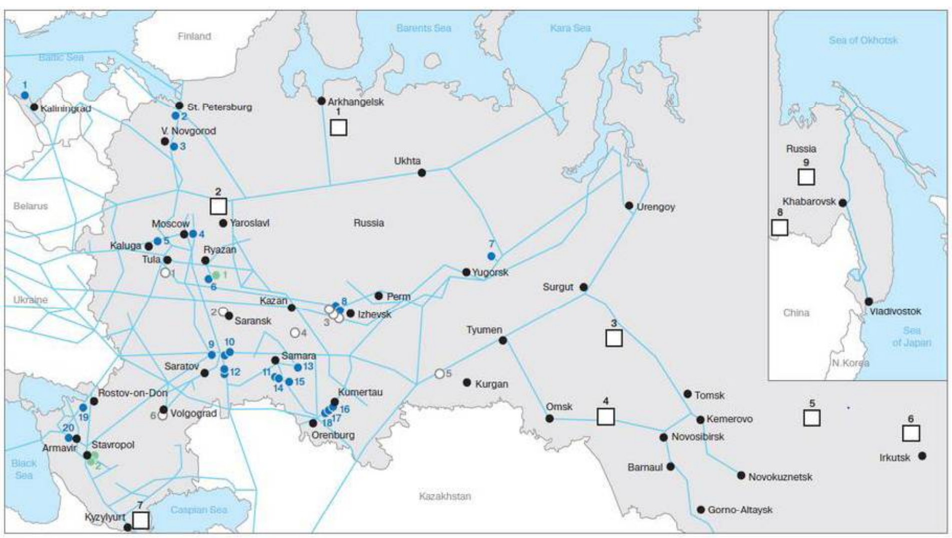

Fig- 3.2 Storage facilities Gazprom

(Source: www.gazprom.com)

Following three underground storage facilities are under construction by Gazprom:

- The Kaliningradskoye underground storage facility (Salt Cavern).
- The Volgogradskoye underground storage facility (Salt cavern).
- The Bednodemyanovskoye underground storage facility (Aquifers).

3.2.4 Australia

There are more than 25000 km network of high pressure natural gas pipelines in Australia, the longest pipeline in Australia is Dampier to Bunbury natural gas pipeline with a length of 1530 km and its diameter is 26 inches. Another major pipeline operating in Australia is Goldfields gas transmission pipeline with length 426 km and diameter of 15.7 inches. Apart from these pipelines, other significant pipelines include, Moomba to Sydney pipeline, Moomba to Adelaide pipeline, SEA Gas pipeline, Parmelia pipeline etc.

Australia has also developed four storage facilities which are as follows:

- Mondarra, Perth Basin
- Moomba, Cooper Basin
- Newstead, Surat Basin
- Iona Field, Otway Basin

All these storage facilities are depleted reservoirs type. The total working gas capacity of these four storages is 1.3 BCM.

3.2.5 China

As per 2013 data, the total length of natural gas pipelines in China is around 49000 km. Each province in China has access to at least one natural gas pipeline. CNPC is the largest natural gas pipeline contractor and operator, as out of 49000 km of total pipeline in China, 40000 km is operated by CNPC. The diameter of the pipeline ranges up to 47 inches with the maximum operating pressure in the range of 120 bar and the maximum capacity is around 30bcm annually.

China, like U.S.A and Russia is also aiming for large diameter, high pressure and high grade steel pipeline. Recently, China has started constructing a 3968 km long natural gas pipeline which will deliver 38 BCM of natural gas from Russia to Shanghai.

Gas storage in China:

The natural gas storage in china is in development stage, and China has the largest gas storage facility in Dagong. This field uses depleted gas reservoirs for storage purposes. This field is used for peak shaving in Beijing city and Tianjin city. The current storage capacity of China is very low with the working gas capacity of approximately 7.3 BCM in the beginning of 2013. China has plans of investing around USD 13 billion to develop 24 storage sites. In future China aims to become one of the world's largest gas storage markets.

Currently SINOPEC and CNPC are planning to construct natural gas storage facilities. Gazprom will also help in promoting the gas storage facilities in China in order to control high level of day to day fluctuations of Russian gas delivery to China.

3.2.6 Middle East

As the reserves of natural gas are high in Middle East (about 36%), thus gas storage facilities are not present in the whole region in large numbers, there are two countries having gas storage facilities with Iran being the pioneer in the region. Iran has two facilities one at Sarajeh and other at Sarakhs. The name of the facility at Sarakhs is Shaurijeh. It has a capacity of storing 4.8bcm of natural gas which can meet the country's demand at peak load. The type of storage is depleted reservoir. Iran is planning to increase the storage facilities by more than a dozen in the coming years.

3.2.7 Japan

In Japan, the high demand season for natural gas is in between December to March and to meet these demand there are 6 underground storage facilities in Japan. The storage capacity in these fields ranges from 213 to 636 MMSCM working gas ranges from 60 MMSCM to 636 MMSCM and the cushion gas ranges from 30 MMSCM to 159 MMSCM. In all the fields, injection is done in summer and gas is withdrawal in winters. In winters the withdrawal from the field and supply to the area around the city of Niigata reaches up to 20mmcf/d.

The major operators for gas storage in Japan are:

- JAPEX (Japan Petroleum Exploration Company Limited), Operating in four fields. Namely- Katakai, Shiunji 1, Shiunji 2, Kumoide
- INPEX, Operating in one field, Sekihara
- JX, Operating in one field, Nakajo

Japan has lot of gas fields and it is expected to have a huge potential for more gas storage in the future. However, there is one challenge for underground storage, i.e. the natural gas produced in Japan is only legitimized as gas for underground storage.

3.2.8 Indian Strategic Petroleum Reserves Limited (ISPRL)

India doesn't have any natural gas storage facility, but it does have strategic storage facilities for crude oil and LPG.

ISPRL is the government agency which manages the construction of strategic storage of crude oil in mainly three locations:

- Visakhapatnam (Vizag)
- Mangalore
- Padur

The storage in these locations will help in providing energy security in case of any disruption in external supply. These crude oil storages are in underground rock caverns and their location is such that they can be easily accessible to the refineries. The cost estimates of strategic crude oil reserves facilities in Visakhapatnam, Mangalore and Padur are Rs. 1178.35 crores, Rs 1227 crores and 1693 crores respectively. The storage capacity, Land requirement and cost requirement of three projects is shown in the table below:

Table- 3.4 ISRPL Storage projects projections,

Project Location	**Storage Capacity (in MMT)**	**Land requirement (In acres)**	**Cost Requirement (In crores)**
Visakhapatnam	1.33	67	1178.35
Mangalore	1.5	104.73	1227
Padur	2.5	179.21	1693

(Source: www.isprlindia.com)

The final completion of the Padur project is dependent on the laying of pipeline from LFP (Land Fall Point) to Padur, and the final completion of the Mangalore project is dependent on the laying of pipeline from LFP near the Mangalore port to the Mangalore cavern.

Where Land fall point (LFP) means the point at which the offshore oil touches the onshore terminal. (i.e. collecting point on onshore)

Fig- 3.3 Padur Crude Storage, (Source: www.isprlindia.com)

3.3 Spot pricing vs. long term pricing

A transaction for any commodity has three components – trading, clearing and settlement.

Trading - Buyer and seller comes together and agree on a particular price is called trading.

Clearing- How much of goods and money buyer and seller exchange

Settlement- It is the actual process of exchanging goods and money.

In spot transactions trading, clearing and settlement happens instantaneously. For example assuming spot R LNG price on 1st July 2015 is $15/ mmbtu and suppose industry ‘A’ needs 100 mmbtu of gas on 1st July 2015 then industry ‘A’ will pay $1500 and will receive 100 mmbtu of R LNG in return. This is spot transaction as all the three components of transactions i.e. trading, clearing and settlement are happening at the same time.

On the other hand, let’s say industry ‘A’ wants R LNG after a year i.e. on 1st July 2016, seller then quotes a price on 1st July 2015 let’s say $16/ mmbtu, both then agrees on the forward price. Trading thus takes place. After a year industry ‘A’ buys 100 mmbtu of LNG at a price of $16/ mmbtu and pays seller an amount of

$1600. Thus clearing and settlement happens on 1st July 2016. Forward transaction is quite risky for both buyer and seller continuing the example, if the spot price on 1st July 2016 is $12/ mmbtu then seller will gain $4/ mmbtu and buyer will lose the same amount as the buyer is bound to pay the amount as agreed in the contract.

On the other hand, it may prove to be beneficial to buyer as if the spot price of RLNG on 1st July 2016 is $20/ mmbtu then buyer will gain $4/ mmbtu and seller will lose $4/mmbtu, as seller is bound to sell the gas at the price mentioned in the contract. Thus it can be concluded that in a forward transaction, gain for buyer is a loss for seller and vice versa.

3.3.1 Henry Hub Natural Gas Spot Price

Natural gas spot price on a monthly average basis is shown in the graph below along with table which clearly illustrates the huge fluctuation in the price of natural gas on spot basis.

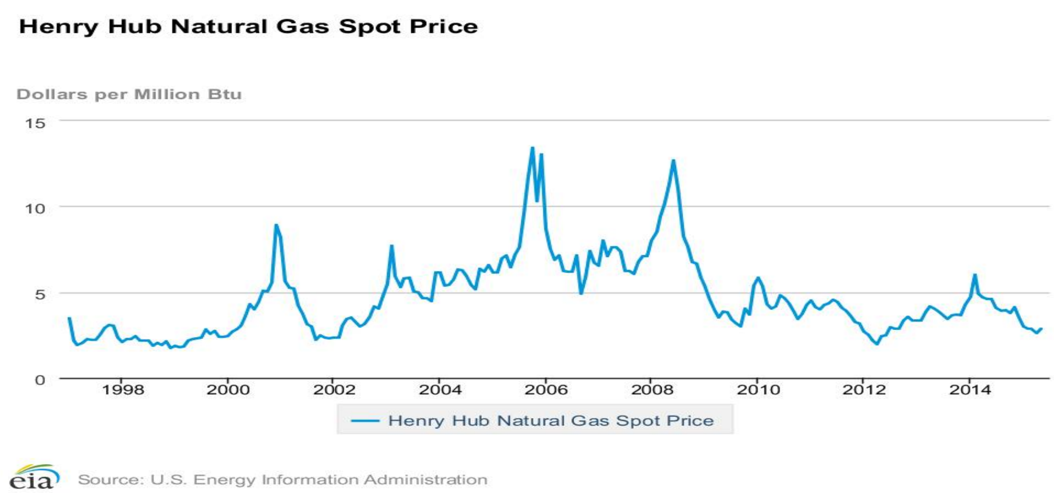

Fig- 3.4 Henry Hub NG Spot price variation, (Source: EIA)

Analyzing the data, it can be seen that from 1997 to 2015, highest monthly spot price reached in October 2005 i.e. $13.42/ mmbtu, and the lowest reached till now is in December 1998. Thus it will be beneficial for the companies to buy natural gas and store it in the period when the natural gas spot price is low, so that they can use the stored gas when there is a high spot price of natural gas.

3.3.2 Future prices of natural gas at Henry Hub

As per the natural gas futures contract 1 (As per the EIA it is a futures contract specifying the earliest delivery date, the delivery month of contract 1 is the calendar month which follows the trade date), the monthly future prices from 1994 to 2013 is shown in the graph below:

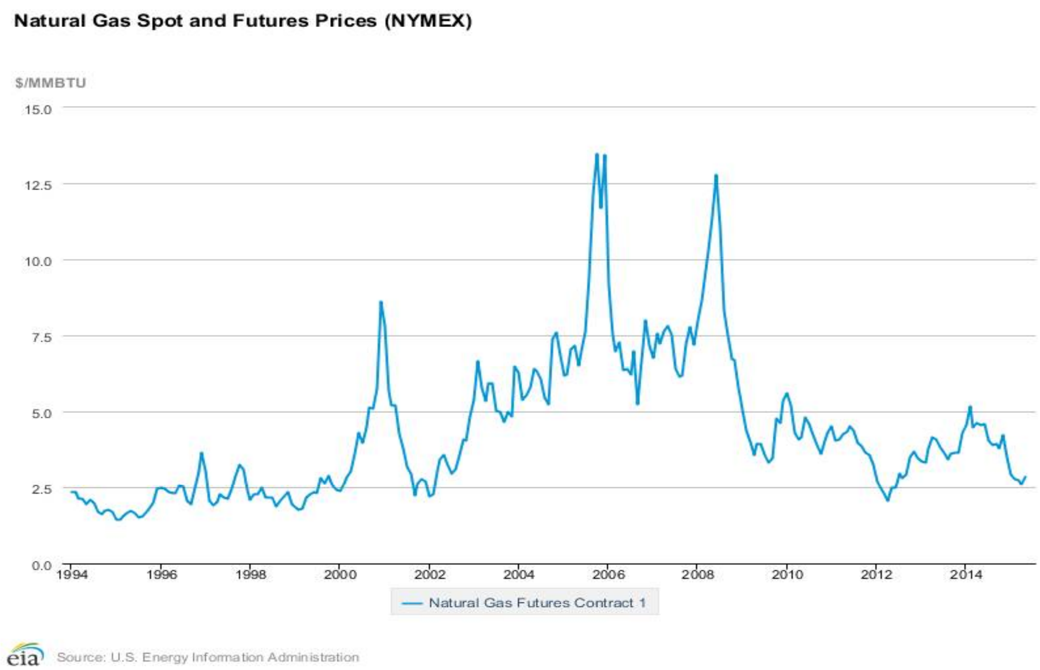

Fig- 3.5 NYMEX NG Spot price variation, (Source: EIA)

The buyer can enter in the long term contract as per the prices at that time. For example in October 2005, it was highest and was trading at \$13.45/ mmbtu, whereas the spot price in October 2005 was \$13.42/ mmbtu,

It was lowest in January 1995, as at that time the natural gas in contract 1 was traded at \$ 1.43/ mmbtu. In May 2015, the future contract of natural gas was at \$2.856/ mmbtu.

Thus, if buyer is anticipating that in future the spot prices might go up, then it would be beneficial for the buyer to enter in the long term contract with the seller, and along with this company should also take the advantage of low price to develop the strategic storage of natural gas.

Example in Indian scenario

India is having a long term LNG import contract with RasGas, Qatar. This accounts for approx. 70% of India's LNG imports. Petronet is the exporter in which GAIL, IOC, BPCL and ONGC have 12.5% stake each. The price as per long term contract of LNG comes close to $13/ mmbtu as compare to the spot price of around $6/ mmbtu, this decline in spot price is due to the slump in the global oil prices, as LNG price is related to crude oil price. As the contract is take or pay India is bound to take the amount of LNG specified in the contract, even if it doesn't take the gas, it is bound to pay the amount as per the contract. Thus RasGas is gaining a lot in this long term contract as they have declined India's request of reconsidering the price of LNG.

Now, as the 7.5 million tons LNG is procured by Petronet from RasGas, GAIL is liable to take 60% of this quantity. GAIL is also suffering, as LNG procured by GAIL is not getting buyer's locally because of low spot prices of LNG. It has no option but to utilize the procured gas in its own petrochemical plant where before it was using cheap domestically produced gas from Reliance's KG-D6 basin. This decline in spot prices is unlikely to change in the coming future thus GAIL's long term growth may face difficulties.

Due to the high price of LNG, industries like power, fertilizers etc. are shifting towards alternative fuel of natural gas like naphtha and fuel oil. In India, if there would have been a storage facility then the advantage of low spot price of LNG could be taken, which is hovering around $6/ mmbtu as compared to the long term contract price of $13/ mmbtu. But there is always a risk involved, as in the past year the spot LNG price was around $20/ mmbtu, and then the spot trading would not have been beneficial. Thus, it is important to deeply analyze the market trend and other relevant factors which might impact the pricing of natural gas and then make appropriate decisions.

3.4 Literature Review of Reports/Articles/Books

Literature survey was carried out by reviewing more than 100 reports, articles, paper published, books as well as companies websites. Summary of some of the report are as given below:-

High efficiency Gas distribution system (Investigation for vertically buried pipe type gas holder)

Authors : Mitsunori Komori, et al

The efficiency of gas distribution companies needs to be increased so as to cope up with rapid increase in natural gas demand. So as to increase the efficiency of the gas distribution companies, gas storage system will play the most prominent role. Gas storage system will allow the storage of gas during low consumption time and discharge the stored gas during the peak time. The paper mainly focuses on building storage facilities in populated areas such as Tokyo, where land space is limited and human safety becomes crucial. Keeping this aspect in mind vertical buried pipeline type gas holder is proposed. Here holes are made inside the ground and then the pipe type gasholder is buried inside the ground. So as to assure safety earthquake resistance analysis and temperature fluctuation analysis has been conducted and whose result has proved the earthquake durability and least influence of temperature fluctuations.

Underground gas Storage in India

Authors: Abhinav Sharma, AbhishekChaudhary.

This paper throws light on the three types of underground gas storages i.e. Salt caverns, Aquifers and Depleted reservoirs of oil and gas and their storage principles. Further as per the analysis of the geology of Indian subcontinent first, ten areas were identified which have good signs of possibility of underground gas storage. Later few sites were retained for further studies. The top four sites estimated are North Gujarat, Bikaner, Kota and Bhubaneswar. There are good signs of depleted reservoirs in North Gujarat with a possible storage capacity of 3BSCM, Salt caverns in Bikaner with a possible storage capacity of 3BSCM and Deep aquifers in Kota and Bhubaneswar with a possible storage capacity of 1250MMSCM. As per the study done by ONGC there are possibilities of Salt caverns in the north western part of Rajasthan (Sri. Ganganagar district, Rajasthan). Apart from the above mentioned areas some areas of Aravalli ranges and some location in Eastern Ghats have good signs of Aquifers formations. Underground gas storage is a new concept in India and not much work is done in this field. Further studies are needed to be carried out in near future since there is great possibility that underground storage facilities will become an integral part of the gas chain.

Natural gas business and market in India

Authors: Subrat Sahu, Varun Singh

This paper analyzes the sector wise consumption of natural gas, PNG and CNG market. India's gas consumption has increased significantly in recent years, and it will continue to grow in future as well, the power and fertilizer sectors are the largest natural gas consuming sectors in India. Further, the authors gave the importance of PNG and its application. As PNG is not only limited to cooking but it has many applications like hot water supply, space heating, CNG dispensing at residence, power generation using micro turbine. It also has industrial and commercial applications like Yarn heat setting (for twisting purposes of clothes, used in textile industries), Cogen (combined heat and power generation), gas fired genset (2.5 -15 KVA), genset for weaving (40 KVA – 125 KVA), gas fired air conditioner / vapor adsorption mechanism (VAM). CNG applications include-road transportation, Indian railways, marine applications. The paper finally concluded by giving the expected energy basket in the year 2025 in which natural gas will have 20 % share. This will be due to the expansion in CGD network, expected commissioning of certain power projects, re opening of some closed fertilizer units. In a nutshell, the future outlook of natural gas is very promising and it will depend on the strong domestic demand, however some policies related to marketing freedom of private gas producers and the long term pricing policies needs to be reconsidered.

Line Pack

Author: E. Shashi Menon,

The concept of line pack is explained vividly by Mr. E Shashi Menon in his book Gas Pipeline hydraulics. Line pack is the quantity of gas contained within the pipeline under pressure measured at standard conditions. The formula to calculate the line pack is given in the book; the variables that are included in the formula are base temperature, base pressure, average of inlet and outlet pressure, compressibility factor, average temperature, inner diameter in mm and length of a pipeline. Large quantity of gas can be stored by increasing the pressure of the gas, usually multistage compressors are used to increase the pressure within the pipeline.

Low Pressure versus High Pressure Dense Phase Natural Gas Pipeline Transportation

Author: J.M Campbell

Link:http://www.jmcampbell.com/tip-of-the-month/2012/09/low-pressure-versus-high-pressure-dense-phase-natural-gas-pipeline-transportation/

Dense phase is a favorable condition in transporting natural gas. In this article author has emphasized on pipeline natural gas transportation in low pressure vs. high pressure. For analyzing this, Mr. Campbell used 1000 miles (1609 km) long pipeline, with a diameter of 42 inches. He has considered three cases in this:

1. High pressure(dense phase)

   The lean gas enters first stage of compressor where its pressure is raised to 97 bar, then it is cooled to 37.8 degree centigrade. It is then compressed further to 222 bar and again it is cooled back to 37.8 degree centigrade.
2. Intermediate pressure

   In this pipeline is divided into three 536.2 km pipeline with one lead compressor station and two intermediate compressor station, in each station the pressure is raised from 42.4 bar to 135.6 bar.
3. Low pressure

   In this pipeline is divided into five 322 km pipeline segments, in each compressor stations pressure is raised from 42.4 bar to 110.3 bar.

After the computer simulation, case 1- 16783.2 SCM/hr

Case 2- 27568 SCM/hr

Case 3- 33440 SCM/hr

Mr. Campbell also mentioned the formula to compute the pipeline wall thickness, here case 1 will require largest wall thickness and case 3 will require least wall thickness. Overall in transportation the composition of gas also plays an important role. It can be inferred from his article that the pipelines can be used for short term storage as well, as pressure can be varied according to the pipeline specifications, and the volume of the gas stored can be increased if the high pressure is maintained within the pipeline, because for line pack purpose pressure is directly proportion to the quantity of gas to be stored.

Gas Balancing Rules Must Take into account the Trade-off between Offering Pipeline Transport and Pipeline Flexibility in Liberalized Gas Markets

Authors- NicoKeyaerts, Michelle Hallack, Jean-Michel Glachant and William D'haeseleer

This paper analyzes the European market and the value and cost of line pack flexibility through the study of characteristics of gas transport pipeline. Line pack can be used to balance the gap between supply and demand. Gas pipelines and compressors can be used to make the gas flow and to store it. The volume of the gas flow can vary according to the pressure differential based on this the transport operator can decide how much gas to supply and how much gas to store based on line pack flexibility (technical limits). Further, the formulas of volumetric flow rate, inlet pressure is given, and the parameters like diameter, length etc. that contribute to the line pack flexibility are explained. The gas flow rate is dependent on the pressure differentials in the inlet and outlet section and by operating within maximum and minimum pressure gas can be stored within the pipeline. As the line pack offers high deliverability rate (but low working volume of gas as compared to other storages) and if the line pack storage is free to shippers, they will not opt for other storage contracts, thus storage market will be affected if the line pack flexibility cost is carried by the transport network and are socialized by the means of transport tariff.

Gas storage in Great Britain

Author: Chris Le Fevre

This paper talks about the complete gas storage in Britain, including the evolution of storage sector in Britain and the role of storage in different seasons, Chris has successfully integrated regulatory framework with the economic dimension. The paper starts with describing the different roles of gas storage, development of storage including the costs, quantity of storage required etc. The regulation and role of a regulator in U.K gas market is touched upon, the operations in the storage facilities are discussed and at the end, the future outlook of storage is discussed. Storage provides the flexibility in gas markets, for the fully liberalized gas market the role of a regulator is huge. Ofgem is the regulator is U.K and it has separated storage from transportation of natural gas. Of all the storage facilities operational in U.K mostly all are UGS facilities, with only 1 LNG storage facility. U.K are emphasizing on large storage capacity from past 15 years, and will continue to do so as storage helps them in meeting peak and base load demand, in future the need of storage in Britain will be propelled by the increment in gas fired power generation and in the condition when there will be a disruption in supply source. Despite the importance of storage facilities and dwindling indigenous gas production in GB, only few projects have been developed so far, the reason behind this is the relative collapse in summer-winter spreads in recent years. The present and future spreads are not sufficient to provide return on gas storage facilities. The main motive of this paper is to address the two questions first, why very few storage facilities (i.e. only 8 till now) have been developed in U.K? Secondly, is there a case for more storage? If this is the case, then how it can be achieved? The answer to the first question is the narrowing of summer-winter spreads. The answer to second question is yes, it's a possibility but it is dependent more on market than on the government. It can be inferred from the report that U.K like many other countries pursue the need for storage base on market conditions and economic viability and regulator plays a huge role in segregating transmission, storage etc. of natural gas.

Prospects for development of Underground Gas Storage system in North East Asia

Authors: Serger Sorokin, A. Goryachev

This paper first focuses on the economic and complex technical problem faced by then northeast countries due to which there are inconsistencies in the modes of supply and construction of natural gas. Then it explains a complex approach to estimate the prospects for underground gas storage in the region. Further the paper focuses on the energy balance, gas consumption, modes of consumption and the gas transportation system in countries like Russia, Eastern Siberia and Far East, China, Japan and South Korea. The modeling methodology focus on various factors like homogeneous factors, investment factors, time factors, geographic factors, infrastructure factors, etc. By the analysis of this paper it can be conclude that there is shortage of underground gas storage facilities in the Northeast Asia. The main deficiency is in China. At present Russia and Japan are providing the facilities for UGS. There is need to focus more on Eastern Siberia and the Fareast for the development of underground storage facilities. The development of underground storage facilities will not only develop the gas market in these regions but will also lead to economic development and energy security of these countries.

Current State of and issues concerning Underground Natural Gas Storage

Federal Energy Regulatory Commission (FERC)'s Staff

This report focuses on the background, history, economics, and possible options for stimulating of underground natural gas storage. The most common among all the three UGS i.e. depleted reservoirs, Aquifers and Salt Caverns is depleted type. All three facilities have different injection rate, withdrawal rate, working gas capacity. The geology is the key issue in determining the type of storage facility to be developed. Under normal conditions storage is most likely to meet the demand of natural gas domestically. It also helps in managing the price of natural gas. In U.S there will be a need of more storage facilities in coming future, currently due to geography, majority of UGS facilities are located in Midwest region. New technologies to improve storage field efficiency are also discussed like to unclog storage wells, sound waves are used. To keep clays from sticking high pressure liquid CO_2 is used instead of water etc. Operators also use Bishop Process in which LNG is unloaded offshore, warmed and then stored as gas vapor in UGS facilities. Some projects have been cancelled, delayed due to rate / environmental issues, thus highlighting the importance of these concerns. FERC also focused upon the economics of developing underground gas storage, a 6-12 cycle salt cavern can cost up to 25 million USD. At last, the gas storage tariff rates by different companies are analyzed with the variables like total capacity, working capacity, load factor, daily deliverability etc. This report has taken into account the importance and description of storage facilities along with the economics involved in the storage business.

The Netherlands: A case of optimization of recovery and opportunities for re-use of natural gas assets

Author- J.N. Breunese

This paper specifically talks about the re use of depleted field for storage purpose especially in Netherlands with the world's picture in the background. The field size constraints, geographical constraints etc.in Netherlands are also discussed. Netherland gives the importance to storage of CO_2 as well, as the Kyoto target for Netherlands is to reduce the CO_2 emission to 162 MT/year. Breunese emphasized that to develop depleted storage facility the gas field does not have to wait to fully deplete, as Norg storage facility was established when the field was 50 % depleted and Grijpskerk field was established even before any depletion. The advantage to develop UGS in early stage is that the time and cost to fill the cushion gas is saved. At last he concluded by stating that Netherlands can manage the natural gas effectively by a master plan.

Construction and Consideration of America's Underground Gas storage (Journal of petroleum science research)

Author: Jianzhang Wu, School of Petroleum Engineering, Longjiang Road number 16, Chengdu city, Sichuan Province China.

Based upon the research done on the underground gas storage facilities in USA, information about the number of underground storage facilities, types of underground storage facilities, characteristics, capacity and reservoir site layout are concluded. Further information regarding natural gas industry in China and the development further required along with problem faced are also discussed. The business scope along with U.S gas storage operating management is also explained. The article has covered the general situation of construction of storage facilities in China along with the counter measures for acceleration of underground gas storage construction. Further the challenges regarding the construction of storage like the resource challenge, technical challenge etc. are also discussed. With the analysis of this article it can be said that in China development of underground gas storage facilities is in starting stage and more emphasis is required on the technical aspect through technical innovation and management creation so as to build the facilities.

Economic viability of underground natural gas storage in depleted oil reservoir in Nigeria

Authors: Anyadiegwn C.I.C, Anyanwu E.E and Obah B.

Department of Petroleum Engineering, Federal University of Technology, Owerri, Nigeria

This article throws light on the economic viability of underground natural gas storage in depleted oil reservoirs (Z-16 T and Z-16RS) located at Southeast, Nigeria. A proper explanation regarding the cost subdivision is given in the paper which includes the acquisition cost, development cost, cost of gas gathering facilities, cost of cushion gas and the annual storage cost. Further subdivision of these above costs is also explained. With the help of this article it is quite clear that the cost of depleted reservoirs can be determined. Z-16T had a higher IRR (26.8%) and NPV, as compared to Z-16RS IRR (10.5%) and NPV which in turn shows that Z-16T is more viable than Z-16RS.

Development of the world largest above ground full containment LNG storage tank

Authors: Young-Myung Yang, Korea Gas Corporation, Korea.

This article tells about the Korea LNG industry rapid growth and their outstanding abilities in building of LNG storage tanks. The emphasis here is on the design of the 200000 cubic metre above ground LNG storage tank. The technical specification of the inner and the outer tank design are properly explained along with the type of material needed for construction. They are making the use of 9 percent nickel steel for inner tank and pre stressed concrete for the outer tank. Further the emphasis is also made on the static design, seismic design, hoop loadings, resistance to overturning, shell compression seismic sloshing, secondary bottom, corner protection system, suspended deck, roof sheeting, roof fittings, and thermal design of the LNG tank. Further comparison between 150000 cubic meter LNG tank and 200000 cubic meters is also made and analysis of this showed that 200000 cubic meter LNG tank is expected to reduce the construction cost by 12% and tank building site by 33%.

Floating LNG/CNG Processing and Storage Offshore Platforms Utilizing a New Tank Containment System

Authors- Regu Ramoo, Prof. Thomas Lamb

The paper talks about the benefits of Cubic Doughnut Tank System (CDTS), specially its ability to operate with liquid levels in the tank from full to empty. The authors have given the description of CDTS which is formed by 12 identical intersecting cylinders that forms 12 edges of a cube giving better volumetric efficiency than other designs, it has 81.5% volumetric efficiency when compare to 52.4% of spherical. After the description, the construction benefits of CDTS are given which can be constructed with the help of aluminum or steel. The application of CDTS design in CNG is also considered In CNG application, gas can be stored at a high pressure of up to 125 bar, in a 20 m tank size having a volume of 6500 m^3 and it can hold 2104700 scm of CNG. CNG tank design is also mentioned in the paper, the internal pressure has a stress constraint of 4000 Bar and a mass constraint of 500 tones. It can be inferred that large amount of

CNG can be stored in these special design tanks, and although it is designed for offshore, the onshore development of these tanks might be a possibility in future.

Underground storage – A summary on first Indian cavern for LPG storage

Authors: K.S.R.K. Verma, K. Vijaya Bhaskar, S. Elangovan

This paper talks about the first Indian cavern LPG storage facility which was constructed by Larsen and Toubro (L&T) limited in Vishakhapatnam, it briefly discusses about the merit of such kinds of underground storage systems, some of the merits of these kinds of projects are as follows: it provides safety from natural calamities, safety as compared to above ground storage systems etc. This storage is located in a 13 acre site, and the site was chosen based on the existing LPG infrastructure facilities like pumping facilities etc. With the depth of 162 m below sea level, it is one of the world's deepest LPG caverns. The construction included 125000 m^3 of hard rock excavation through two vertical shafts; construction's fixed cost is high as compared to the variable cost. The drill pattern and the cavern's cross section is also discussed in the paper. Authors finally concluded by stating the importance of LPG, crude oil storages by quoting that the underground cavern being the right solution for technical and commercial viability. The significance of this project is high for India's strategy to overcome demand and supply gap, and to manage the LPG in unforeseen circumstances.

Environmental, health and safety guidelines for liquefied natural gas (LNG) facilities

International Finance Corporation, World Bank Group.

This article throws light on the guidelines for LNG storage facilities related to environment, occupational health and safety and community health and safety. Under environment the article provide information related to comprehensive assessment and management programs for hazardous materials, wastewater, air emissions, waste management, noise and LNG storage. Under occupational health and safety the assessment and management program related to fire and explosion, roll over, contact with cold surfaces, chemical hazards and confined spaces are well discussed. Community health and safety during construction and operations of LNG facilities with emphasis on security are well discussed. Further guidelines related to performance indicators and industry benchmarks are also described for better understanding of emissions and effluent guidelines, resource use and energy consumption, environmental monitoring etc.

Gasholders and their tanks

Author: Dr. Russell Thomas

This paper tells about the construction and operation of gas holder and their tanks. The gasholders has been classified into five main categories i.e. gasholders guided by wire cables, telescopic gasholders, flying lift gasholders, spiral guided holders and piston gas holders. Further the paper also focuses on the design consideration of crowns, cups and grips along with gas holder tank specifications. The material with which the gasholder will be build depends upon the available local building material and the ground conditions. The different types of material that can be used to build gasholders are stone, brick, concrete, cast iron and steel, hewn from the bedrock or a combination of these. So as to determine the size of the gas holder calculations has also been done in the paper for different types of gasholders respectively.

Leffer Waterless Gasholder (System M-A-N)

Stahl-UND Apparatebau Hans Leffer GMBH

This paper focused on the design and constructional aspect of a Leffer Waterless Gasholder. This type of gasholder can be constructed within a capacity range of 10000 cubic meters to 350000cubic meter. The gasholder is a polygon hollow shell with a roof attached to the upper end and the lower end is stiffened by a foundation along with a piston. The piston controls the pressure of the tank and can be varied according to the content of gas. These types of gasholders are good alternative to watered gasholder because the gas stored requires no dehydration of gas when gas is taken out, further they require less ground space for set up and there are least hazard possibilities in starting or shutting down the gas holder due to no dead space, no sealing water and no heating requirements. The paper also focuses on the structural elements of the gasholder i.e. bottom, shell, roof, piston, piston seal, flanged plates, sealant circuit, ventilation, safety blow off pipes and internal lift. Further the foundation aspect of the gas holder is also explained which include the standard foundation, foundation subsoil, light mining damage and heavy mining damage. Step by step erection details i.e. how actually to set up the gasholder is also explained. This generally include the following steps roofing, shell columns, support between piston and roof, guide roller system and piston. Information regarding maintenance and servicing is also explained along with the list of piston gasholder fabricated by Leffer all across the globe like in Germany, Brazil, Spain, China, Korea etc are given.

Line pack storage valuation under price uncertainty

Authors- O. Arvesen, V.Medbo, S.-E Fleten, A. Tomasgard, S. Westgaard

This paper analyzes the line pack valuation while ignoring the cost associated in fuel consumption in compressor stations. Conventional storage capacities like underground storage and LNG storage are in most cases constrained by the geography of the location and by the price. Line pack however because of high flexibility is a valuable tool for short term balancing between supply and demand. While doing the valuation authors first gave the power price model, then used it as a variable in gas price model, after developing the model. Finally the valuation is done with the help of Least Squares Monte Carlo (LSMC) simulation. Authors concluded by stating that Line pack is under-utilized despite having various advantages like environmental friendliness, cost efficiency. It is also concluded that the flexibility of having line pack was beneficial for the power plant in this study. In fact the plant can increase the value of gas by 34% with the option to store gas for up to 10 hours and in most cases storing gas to generate power later is more beneficial than selling gas in the market. In future line pack will enable the players in natural gas value chain to more efficiently utilize the gas.

Estimating the required underground natural gas storage capacity in Brazil from the gas industry characteristics of countries with gas storage facilities

Authors- Mario Jorge Figueira Confort, Cheila Goncalves Mothe

In Brazil, the consumption and production of natural gas has increased in recent years and more infrastructure for its transport has been built. However Brazil doesn't have geography to support the development of UGS facilities. For the analysis of storage capacity requirement, the authors related this with other countries and analyzed the relationship between storage and various characteristics of gas sector by linear regression analysis. This research was conducted in 38 countries with operational UGS facilities; they evaluated the extent to which the storage is related to proven reserves, production, consumption, infrastructure, gas imports and exports, and the use of natural gas in energy mix. A very strong relationship is emerged between gas storage and gas consumption, gas storage and gas infrastructure, gas storage and gas production volume, the remaining aspects didn't affect significantly in developing gas storage facility. After analyzing the linear regression of the data obtained from different countries, the estimation for required gas storage capacity for Brazil is given by authors which is between 1.98 – 6.70 BCM. The point worth mentioning is that factors like geology and demand seasonality were not considered in this study. Finally the authors concluded by stating that the storage development is largely driven by the development of gas pipelines and the gas consumption in a particular country and this research can be extended in following ways: 1. UGS can be combined with cryogenic gas storage to get to know how both these storage types and influenced by industry characteristics. 2. Other parameters can be considered like geology, regulatory framework, etc. 3. Non-linear regression and hypothesis tests can also be considered for further analysis. It can be inferred from this paper that the storage capacity for India can also be estimated similarly how it is estimated in this paper in the case of Brazil.

3.5 Summary of Literature Review

Table- 3.5 Literature review Summary

S. N.	Context	Year	Study /Author	Factor Categorization	Key Theme
1	High efficiency gas Distribution system	2008	Mitsunori Komori, Kyosuke Wakasa	Gas Storage	Investigation of vertically buried pipe type gasholder for city gas distribution.
2	Underground Gas Storage in India.	2012	Abhinav Sharma, Abhishek Chaudhary.	Geology of India	Analysis of geology of Indian subcontinent for possible UGS.
3	Natural gas business & market in India	2013	Subrat Sahu, Varun Singh	CGD components	Analysis of natural gas consumption and its application keeping City gas distribution components in background.
4	Line Pack	2005	E. Shashi Menon	Gas Storage in pipeline	Basics of line pack and the study of parameters in calculating line pack.
5	Low Pressure versus High Pressure	2012	J.M. Campbell	Pressure in line pack	Study of pressure variations using compressors in a

	Dense Phase Natural Gas Pipeline Transportation				pipeline, keeping all the factors constant.
6	Gas Balancing Rules Must take into account the Trade-off between Offering Pipeline Transport and Pipeline Flexibility in Liberalized Gas Markets.	2010	Nico Keyaerts, Michelle Hallack, Jean-Michel Glachant and William D'haeseler	Line Pack flexibility	Analysis of importance of line pack and the strategic advantage it offers.
7	Gas storage in Great Britain	2013	Chris Le Fevre	Gas Storage and regulatory scenario in U.K	Analysis of regulatory framework along with economic dimension for gas storage in U.K.
8	Prospects for development of Underground Gas Storage system in North East Asia	2012	Serger Sorokin, A. Goryachev	UGS scenario in North East Asia.	The prospects and challenges of UGS in countries like Russia, Eastern Siberia, China, Japan and South Korea has been discussed.

9	Current State of and issues concerning Underground Natural Gas Storage	2004	Federal Energy Regulatory Commission (FERC)'s Staff	Economics of Underground gas storage	Study of history, economics, options, technology used in UGS facilities.
10	The Netherlands: A case of optimization of recovery and opportunities for re-use of natural gas assets	2006	J.N. Breunese	Underground Gas Storage	Depleted field development in early stage is analyzed, co2 storage along with natural gas is also emphasized to meet up the Kyoto target in Netherlands.
11	Construction and Consideration of America's Underground Gas storage	2012	Jianzhang Wu, Journal of petroleum science research	Types of Underground Gas Storages	Detail explanation of types and number of UGS in America and China along with challenges in construction and further development required in China.
12	Economic viability of underground natural gas storage in depleted oil reservoir in Nigeria	2012	Anyadiegwn C.I.C, Anyanwu E.E and Obah B	Underground Gas Storage	Two depleted oil reservoirs (Z-16 T and Z-16RS) has been analyzed and their economic viability has been compared.

13	Development of the world largest above ground full containment LNG storage tank	2006	Young-Myung Yang, Korea Gas Corporation, Korea	LNG storage tank	Detail explanation regarding the construction and design of 200,000 cubic metre has been discussed with more emphasis on inner and outer tank construction.
14	Floating LNG/CNG Processing and Storage Offshore Platforms Utilizing a New Tank Containment System	2011	Regu Ramoo, Prof. Thomas Lamb	CNG/LNG Storage in Cubic Doughnut Tank System (CDTS)	Revolutionary design of CDTS in tanks is described, which helps in improving the volumetric efficiency in the storage of CNG/LNG.
15	Underground storage – A summary on first Indian cavern for LPG storage	2008	K.S.R.K. Verma, K. Vijaya Bhaskar, S. Elangovan	LPG Storage	Study of India's first LPG cavern storage facility in Vishakhapatnam.
16	Environmental, health and safety guidelines for liquefied natural gas (LNG) facilities	2007	International Finance Corporation, World Bank Group	HSSE for LNG	The article focuses on the guidelines for LNG storage facilities related to environment, occupational health & safety and community health and safety.

17	Gasholders and their tanks	2010	Dr. Russell Thomas	Gas Storage	The emphasis is on the construction and operation of five categories of gasholders. These are gasholders guided by wire cables, telescopic gasholders, flying lift gasholders, spiral guided holders and piston gas holders.
18	Leffer Waterless Gasholder	2012	Stahl-UND Apparatebau Hans Leffer GMBH	Gas Storage	The emphasis is on the construction and operation of waterless gasholders with piston as sealing element. Further the structural element and construction steps has been well discussed.
19	Line pack storage valuation under price uncertainty	2013	O. Arvesen, V.Medbo, S.-E Fleten, A. Tomasgard, S. Westgaard	Line Pack valuation	Valuation is done with the help of Least Squares Monte Carlo simulation, under-utilization of line pack is emphasized.
20	Estimating the required underground natural gas storage capacity in	2014	Mario Jorge Figueira Confort, Cheila Goncalves	Underground Gas Storage	Relation of storage with proven reserves, production, consumption etc. is explained. Required gas storage capacity for Brazil is

	Brazil from the gas industry characteristics of countries with gas storage facilities.		Mothe		determined and it is emphasized that storage development is driven by the development of gas pipelines and the gas consumption in a particular country.
21	Introduction to underground storage	2012	Energy Delta Institute	Underground gas storage	This show about the type of underground gas storage are being operational in world. The estimated operating cost of various type of storage. The purpose, benefit & market demand of storage
22	Oil & Gas Industry, India	2012	PWC	Growth of natural gas in India's future energy mix	Oil and gas are important for fueling India's growth story. The gap between production and consumption of crude oil and natural gas has increased over the past decade, and that is further projected to widen leaving India vulnerable on the energy security front
23	Global Energy Scenario	2012 `	International Energy	Natural gas	Keeping in view the global population and the

			Outlook	demand	increase in population in the Asian countries it is very pertinent to focus on the sources of natural gas to meet the current and future demand.
24	Global Energy Scenario	2012	Mckinsey	Growth of natural gas in world's future energy mix	The overall energy demand is likely to grow at a compounded annual rate of 1.3% over the next 40 years.
25	Understanding natural gas market	2011	Energy Information Administration	Natural gas business	Growth rate of natural gas market since mid-1990, as natural gas is a clean, & efficient fuel. Price trends of natural gas worldwide.
26	Pricing of natural gas in India	2011	Harsh Kakani	Natural gas pricing trend	The pricing of natural gas is complex in India due to growing country, high demands, low domestic production, regulations & pricing issues. Proposed road map for price pooling.
27	Natural gas in India: An	2011	Oxford Institute for	Policies for	The identified issues need to be addressed in a

	Analysis of Policy		Energy Studies	natural gas growth	focused manner for ensuring the growth of natural gas industry in India and to achieve Energy Security
28	Natural gas in India	2010	International Energy Agency	Natural gas market	Analysis of natural gas production, consumption, LNG import, unconventional sources of natural gas & their projections for Indian gas market.
29	Global LNG supply & demand – Review & outlook	2010	Hydrocarbon Asia	LNG Market	With natural gas being the primary alternative fro crude. LNG plays a vital role in global energy scenario. This gives in-depth look of LNG demand & supply
30	The economics & regulation of natural gas storage: Ensuring security of gas supply across Europe	2010	Florent Silve, University of Cambridge	Storage for energy security	Role & operation of gas storage in market, mechanism for appropriate investment in market, potential policy & regulations for gas storage.
31	Natural Gas	2009	Rajeev	Natural	There is need for a policy

	Sector in India		Mehrotra Natural Gas Sector in India	gas demand in India	or clear strategy clearly enunciating the priorities relating to the development of fuels that are environmentally sustainable in the long run. This should address the issues so identified thereby providing, clean and green, competitively priced fuel options to the end users.
32	Pre- feasibility report for underground gas storage	2008	EIL / PE Energy Storage Services Inc.	Underground gas storage in India	Underground storage of natural gas in Indian scenario. Address estimation of various costs, type of storage and their capacity. Report shows that strategic storage may require in future.
33	Natural gas storage valuation	2007	Yun Li Natural gas storage valuation	Cost of storage	In this report one methodology for natural gas storage valuation is developed & two methodologies are improved. All three are applied to a storage contract.

34	Gas storage valuation: Price modeling Vs Optimization methods	2008	Petter Bjerksund / Gunnar Stensland	Underground gas storage valuation	Analysis of gas storage as a separate asset, using market value context for utilization & valuation. The gas storage valuation analyzed using simple one factor price dynamics.
35	Underground storage : A summary of first Indian Cavern for LPG storage	2008	KSRK Verma / K Vijay Bhaskar	Construction and commissioning of Underground storage	The story of successfully constructed & commissioned first Indian cavern for LPG at Visakhapatnam (AP) through vertical shaft and international safety standard
36	Natural Gas Sector in India	2007	Petrofed	Natural gas demand in India	Riding on a strong yearly economic growth, till 2030 the natural gas industry is projected to become a 400 BCM market. A challenging task which would require alignment of the varied interests of the various stakeholders for the healthy development of gas market in India.
37	Natural gas storage	2002	Matt Thompson/	Natural gas	An algorithm for valuation & optimization

	valuation & optimization: Real Option Application		Matt Davison/ Henning Rasmussen	storage valuation	of operation of natural gas storage developed. Real option theory is used to derive optimal operating strategies.
38	Russia		The Energy Research Institute Of Russian Academy of Science	Seasonal Peak Demand	Prospects for development of UGS in North east area
39	Natural Gas in India: An Analysis of policy	2011	Anil Jain &Anupama Sen	Policy Analysis	This paper talks about the natural gas policy in India.
40	Gas Property Requirements in UGS	2012	Joachim Wallbrecht Storengy Deutschlan d	Propertie s of gas.	The emphasis is on gas quality surveillance and components.
41	GSE discussion paper	2008	Rue Ducale	Strategic storage increases security of supply.	The emphasis is on the various components of UGS which will help in maintaining adequate supply.
42	Gas Storage & Single point Failure risk		John M. Hopper	Analysis of risk associate d with gas storage.	The paper analysis the risk associated with gas filling in the storage.

43	Strategic storage and competition in European gas market	2007	Edmond Baranes, Francois Mirabel	Analysis of European market.	Detailed analysis of gas storage facilities present in Europe and the current trend of natural gas in Europe.
44	Will natural gas vehicles be in our future	2011	Alan J. krupnick	Natural gas vehicles potential in future	This paper talks about the future potential of natural gas vehicles
45	Impact of reservoir properties on mixing of inert cushion and natural gas in storage reservoirs	2006	KashyAmi nian	Reservoir propertie s	The paper emphasis on reservoir properties so that it can withstand the amount of gas for storage purpose and injection and withdrawal can be made with ease
46	Valuation of Energy Storage	2005	Mike Ludkovski	Valuatio n	The emphasis is on natural gas dome storage and hydroelectric pumped storage.
47	Understanding natural gas market	2006		Market analysis	The paper emphasis on natural gas market in United States

48	A rough examination of the value of gas storage	2011	University of Warwick. Department of economics	Value of gas storage	This paper shows the impact of fire in 2006 which eliminated the possibility of access to the rough gas storage facilities which covers almost 80 percent of total UK storage

The literature review summarized in key theme format is given below:-

Table- 3.6 Key themes literature review

S. No	Themes	Select Author(s)	Context	Inferences
1	Gas storage building in limited space with safety consideration	Mitsunori Komori, Kyosuke Wakasa, Tomoaki Takeuchi	Use of vertically buried pipe type gas holder in Tokyo	To increase the efficiency of gas distributing companies, gas storage plays an important role. Gas storage building in populated area considering limited space and human safety
2	Gas balancing rule and role of gas storages in different	Chris Le Fevre Nico Keyaerts, Michelle Hallack, Jean Michel	Gas storage	Gas Storage help in building peak and base load demand. Need for storage based on market conditions and economic viability.

	seasons			
3	Prospects for development of gas storages in north east Asia.	Serger Sorokin, A. goryachev, Federal Energy Regulatory commission	North east Asia	There is shortage of gas storages in North East Asia. Building more gas storages will help in development of gas market in this region. Gas storages helps in managing price of natural gas.
4	Economic viability of gas storages and use of technical innovation to built up facilities	Jjianzhang Wu, Anyadiegwn CIC, Anyanwu EE, Obah B.	Gas storage in China	Development of gas storage facilities in China is in starting stage and more emphasis is required on technical aspect through technical innovation and management creation to build storage facilities. Economic viability by analyzing Acquisition cost, Development cost, cost of cushion gas and annual storage cost.
5	Environment , Health and Safety	International Finance Corporation World Bank group	LNG storage facility	Guidelines related to environment occupational health and safety for LNG storage facilities need to be developed. Community health and safety during

				construction and operation of LNG facilities with emphasis on security to be considered.
6	Estimating gas storage capacity	Mario Jorge, Figueira Confort, Cheila Goncalves Mothe	Gas Storage Capacity estimation for Brazil	Gas storage capacity of any country can be estimated based on gas industry characteristic of countries with gas storage facilities. A strong relation emerged between Gas Storage with gas consumption, gas infrastructure and gas production volume of that country.

3.6 Research gap

As there is a significant demand and supply gap in India, and with low level of indigenous gas, India is relying on imported LNG and domestic gas. This scenario will continue to grow in future as the demand increases. Countries like U.S, Russia, Ukraine, Germany, France, U.K. etc. already have strategic gas storages as seen in the literature review section. More and more storage facilities are being developed by many gas distribution companies around the globe.

Considering the case of India, where many City Gas Distribution (CGD) companies are operating in various geographical areas. CGD companies are mostly connected with single source pipeline and presently not a single CGD company has any kind of strategic natural gas storage. On the other hand, in other countries around the world, CGD companies takes the service of already established gas storage facilities connected to national gas grid. In India, gas grid is not yet fully developed. Gas market is also developing at rapid pace. Thus due to non-availability of strategic gas storages in India, CGD companies depends upon available line pack in the supply pipeline only in case of any emergency or disruption in supply.

It is evident from the review of literature that no research has been done till now which specifically focus on storage for CGD companies. Thus no literature in public domain is available regarding its feasibility in Indian scenario. Based on the above review, the gapes in literature can be summaries as given below:-

- ❖ To the best of researcher knowledge, Variable and factors which are specifically related to Natural gas storage for CGD companies in India are not known
- ❖ No literature is available which defines framework for establishment of Natural Gas Storage for City Gas Distribution in India

This research will help in filling the research gap by studying the available storage in other countries like U.S, U.K, Russia, Germany etc. and developing a conceptual framework for establishment of Natural Gas Storage for City Gas Distribution in India.

3.7 Motivation for Research

Efficient, reliable and competitively priced energy supplies are prerequisites for accelerating economic growth. Efficient use of resources and long-term sustainability remains core objective to establish delivery mechanisms and self-reliance. In India the demand of natural gas is increasing very rapidly and so as to cope up with this demand more focus is required on exploration, imports and storage facilities. The need of gas storage is due to following reasons:

- **Supply and Demand:** Gas has a high seasonality of demand. Generally the demand of gas is more during winters than during summers. Hence storage plays a very important role in storing gas during the summer months and allowing withdrawal during the winter months, thus acting as a bridge between the supply and demand of gas. Further storage helps in meeting the supply commitments as per demand.

- **Short and long term flexibility:** Gas storage helps in providing short and long term flexibility. Base load storages like depleted reservoirs have the potential to store large volume of gas and provide the stored gas for meeting long term seasonal demands. On the other hand peak load storages like salt caverns, aquifers have the potential to provide high deliverability rates and generally used on daily or weekly basis so as to meet the demand. Following two graphs shows the variations in gas pricing.

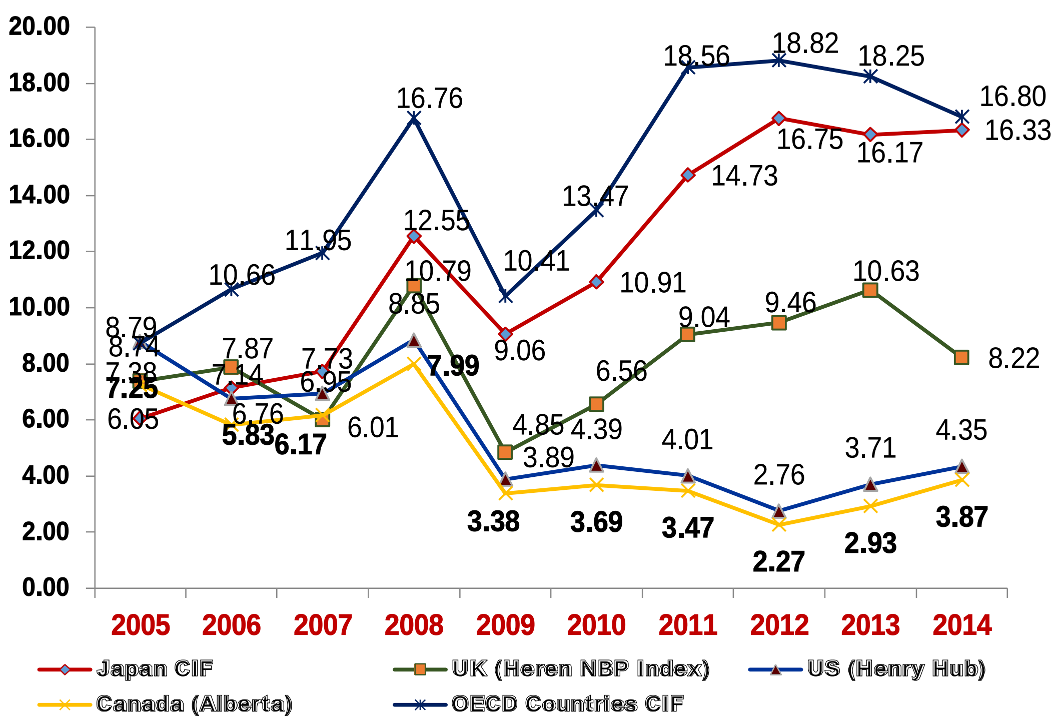

Fig- 3.6 International Natural Gas Price Fluctuations,

(Source https://www.eia.gov/)

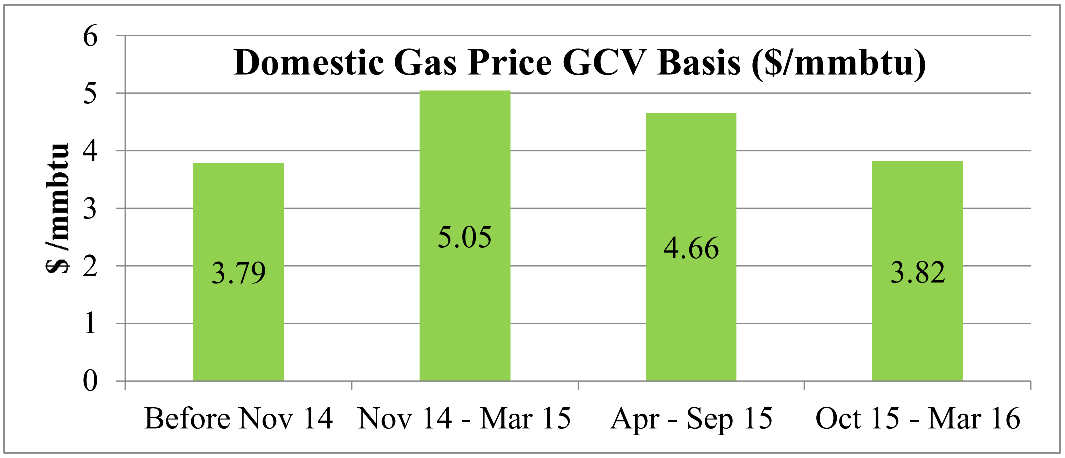

Fig- 3.7 APM Price variation India ($/mmbtu),

(Source: petroleum.nic.in/docs/committee_report_on_gas_pricing)

- **Arbitrage:** In case it is expected that the price of gas is likely to increase in the future gas storage facilities provides the opportunity to store gas at current time and sell it later when the prices are high.

- **Supply resilience:** Gas storage helps in managing overall supply distribution. If due to any unforeseen circumstances the main source of supply is cut off then stored natural gas helps in maintaining steady supply.

- **Efficient Usage:** Storage helps in better work load leveling, higher service utilization, higher asset utilization and lower overall production cost.

- **Maintenance management:** In case the plants and pipelines are under maintenance, gas can be stored in storage facilities. If storage will not be there then the production of gas needs to be completely stopped which in turn will lead to cost issues and loss of revenue.

Storage also plays a very important role in market centers/hubs. Here with the help of storage hubs/ market centers provide services like parking, lending etc. The major concern of a CGD company is ensuring the uninterrupted supply which may be halted because of any unwarranted cause. Certain examples of gas supply interruptions which lead to the Business Problem are as below:

- July 2015 –ONGC production cut by around 14 MMSCMD for 24 days for subsea pipeline repair –
- March 2015- RIL East West pipeline fire in Telangana – around 10 MMSCMD for few days
- June 2014- GAIL pipeline explosion in Andhra Pradesh: supply stoppage for CGD industry, power & fertilizer for many days –
- Aug 2013- GAIL/RIL/ONGC - 4 pipelines snapped due to flood across Narmada river in district Baruch Gujarat- around 5MMSCMD for few months

3.8 Concluding Remark:

Post identification of Business problem and problem statement in chapter -1, this chapter basically gives the brief overview of literature review of the research topic wherein variables influencing the establishment of gas storages in India for City Gas Distribution is described. As first step in literature review, a detailed literature survey was carried out to identification of variables influencing establishment of gas storages. Then literature analyzed and categorized based on key theme such as safety, seasonal variations, peak and base demand, price management, development cost, cushion gas, storage capacity, environmental issues, government policies, land availability, etc.