Study on the Industry of Natural Gas in Japan Comparing with USA by MFM and GIS

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Abstract: *In this paper, a new semantic and graphic model is introduced to analyze the present status of the natural gas industries and markets in Japan and USA. The proposed method is based on the simulation of the physical flows and transaction flows of natural gas (NG) by using MFM(Multilevel Flow Model) and GIS(Geographic Information System), and it is used for the inter-comparison of supply, transportation, distribution and consumption situations of NG in Japan and USA. The obtained analysis results by the proposed method suggest that mainly due to the geography factors, the transportation methods of NG in Japan are very complicated to be compared with those of USA. This is the main reason why the natural gas downstream prices are so high in Japan. But recently, the downstream prices in Japan are decreasing with the improvement of NG market efficiency through the introduction of deregulation and the development of the energy saving techniques, while the upstream prices are increasing.*

Keywords: Natural gas, LNG, Physical flow, Transaction flow, MFM and GIS

1. INTRODUCTION

This paper first investigates the NG industry (including production, transportation, distribution, etc) and the NG market (from upstream price to downstream price) in Japan comparing with USA by using MFM(Multilevel Flow Model) and GIS(Geographic Information System), then the hydrogen industry in them is predicted and analyzed basing on the analysis result of NG industry.

This study is motivated by the follow reasons: first, NG is a vital component of the world's supply of energy. It is one of the cleanest, safest, and most useful of all energy sources. With the problems of the energy lack, the environmental pressure and the high price of oil, the NG will be the most quickly growing energy in future because of the environmental friendship and long R/P ratio. Second is that, the NG industries and markets in different countries are different due to the natural resource condition geography factors and market mechanisms and the liberalizing schedule, Japan and USA are two representative ones with different development level in the world. Third, the MFM as a semantic graphic is very suitable to simulate the NG physical flow and transaction flow, and the GIS can provide the spatial data to analyze the geography factors which affect the NG industry. And the combination of MFM and GIS can provide us a very comprehensive, detailed and easy understanding evaluation on the NG industry and market.

The following section introduces the MFM, GIS and the design of MFM&GIS analysis system. Section 3 and 4 describe the NG industry and market of Japan comparing with USA by using MFM and GIS. The results and discussions are reported in section 5 before the section 6 in which the conclusions and further plans are presented.

2. DESIGN OF THE NG ANALYSIS SYSTEM BY MFM AND GIS

2.1 Introduction of MFM

The MFM is one kind of semantic graphic modeling method and display design method which was originally developed by Lind as an attempt to formalize the abstraction hierarchy[1]. Multilevel flow model uses a series of standard symbols, not only describe the hierarchy structure of objects from goal to function and to component, but also represent the ‘‘internal process’’ of physical behavior by mass flow, energy flow and information flow clearly. The advantage of MFM is that first it can provide a set of formalized symbol language to describe the common properties, including flows and abstraction hierarchy structure of natural gas industry and natural gas market, and then can provide a flexible approach for analysis support of the natural gas physical flow and transaction flow. Thus, people can very easy to understand the natural gas industry physical processes, the transaction processes and the working principle of the natural gas market based on a formalized and universal way, and through comparing the MFM in different countries, it is very easy to understand the differences between them. The basic definition of MFM functions are displayed in Fig.1, mainly including: Goals: The goals describe a system's objectives. Source: It can provide unlimited mass or energy, only has the outflow without the outflow, for example it can be used to represent that the natural gas fields produce natural gas; Sink; It drains mass or energy, only has the inflow without outflow, for example, it can be used to represent that the end users consume the natural gas; Transport: it can transport mass, energy, or information, for example, can be used to represent the natural gas pipelines to transport the natural gas, or the LNG ships to transport the LNG, and so on; Barrier: it can prevent the transport of mass, energy, or information. It can represent the valve is closed to prevent the natural gas from going through in pipeline; Storage: it can store mass or energy. For example, the natural gas storage facilities store the natural gas, or the LNG tanks store the LNG at the LNG terminal; Balance: it can connect one or more inflows and one or more outflows. For example, the intersection of the major pipeline systems; Networks: Functions are grouped into networks, each describing a flow of mass, energy, or information[2].

Table.1 displays the basic connection and calculation rules for the MFM symbols, in which the "ε" means the maximum difference in the acceptance limitation. For example, the "source" only has the output and must connect with "Transport", the "Sink" only the input and must connect with the "Transport", only the "Balance" can have multiple input and output. For the "Transportation" and "Balance" the calculation rules is that all input amount must equal to that of output, and for the "Storage" the change of the storage amount equals to the amount that output minus input. In the MFM, if we know enough data of some symbols we can calculate the others by using the calculation rules. However, sometimes between the variables represented by the MFM functions exists a long-run equilibrium relationship mathematic formula, so a new function and a new calculation rule-"Relationship Function" are introduced as shown in the fig.1.

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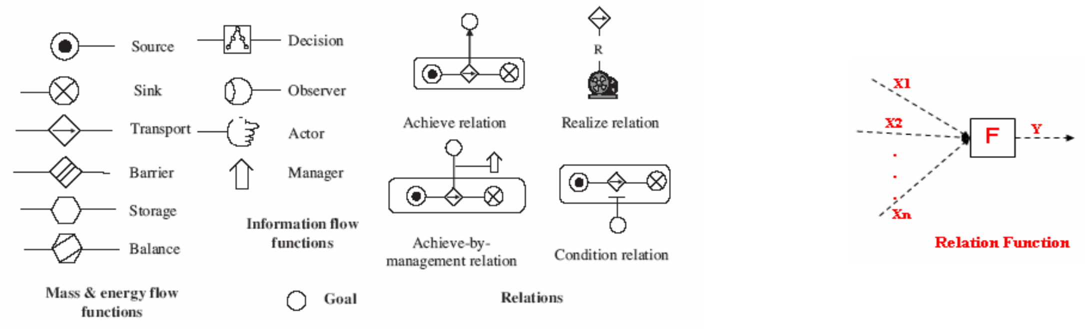

Fig. 1 The basic definition of the functions of the MFM and the "Relationship Function"

Table 1 Basic connection rules and the calculation rules of MFM

Rules / Function	Connection (Input/Output)	Calculation rules
Source	Transport(0/1)	
Sink	Transport(1/0)	
Transport	Source, Balance, Storage and Sink(1/1)	$\|Fi+Fout\|<\varepsilon$
Storage	Transport(1/1)	$\| \Delta V-Fi+Fout \|<\varepsilon$
Balance	Transport (Multi/Multi)	$\| F1+F2\ldots+Fn \|<\varepsilon$

2.2 Introduction of GIS

The geographic information system (GIS) technology provides better methods to understand, represent, manage, and communicate the many aspects of the earth as a system. In our work, ArcGIS Library 9.1(the most advanced edition) made by the ESRI which is the world leader of the GIS field is employed. Including the necessary analysis tools, for example the spatial analysis tools, 3D analysis tools, network analysis tools and the data management tools, and so on. The ArcGIS also provides a very good embeddable GIS component for developers to build custom applications- ArcGIS Engine (abbreviation: AE). Using AE, developers can incorporate ArcGIS functions into applications such as Microsoft Word and Excel as well as into custom applications developed by such as Visual Basic 6, Microsoft Visual Studio .NET, and numerous Java developer environments and so no that deliver focused GIS solutions to many users[3].

3. PHYSICAL FLOW OF NG

3.1 Physical flow of NG in Japan

As the NG industry of Japan shown in the fig.2 by GIS, the process of natural gas industry in Japan can be divided into four stages: upstream supply, transportation, distribution and downstream consumption. As for the upstream supply, at the 2004 the domestic production is 2.957Bcm only 3.7% of the total supply, which is produced by the domestic gas developers-JAPEX (Japan Petroleum Exploration Company) and Teikoku Oil Company, all the 76.95Bcm[11][12] natural gas-96.3% of total supply of Japan is imported from foreign counties in the form of LNG through the 25 LNG terminals. The LNG terminals not only act as a terminal to unload the LNG from the tanker, but also act as short term storage. As for the transportation, the LNG power plants are very near to the LNG terminals, so LNG is transported to the power plants by very short pipelines from the terminals also owned by the electric companies after regasfication. And for the plain areas, the LNG is regasified first, and then transported by the pipelines. However, due to the mountainous geographic environmental and the high cost of the land, material and human resources, it is not economical to construct the pipeline in some areas which are far from the LNG terminals. So, the LNG satellites are constructed in these areas, which is can be used as a supplier for a small region or a big industrial park. LNG trunks, railway containers and domestic ships are used to transport the LNG from the LNG terminals to the LNG satellites. In Hokkaido province, due to no any LNG terminal and the limited pipelines, the natural gas produced from the domestic natural gas field is first liquefied at the liquefaction plant just near the gas field, and then transported by LNG railway containers to the LNG satellites. Generally speaking, when the distance from the LNG terminal to LNG satellite is more than 100Km, the usage of railway or the domestic ship is more economical than truck. As for the distribution, owners and operators of gas distribution pipelines in Japan are regional gas companies and more than 200 local distribution companies. The natural gas can be distributed to end users who are near the LNG terminals or domestic natural gas fields directly by using the pipeline, for example, the end users around the LNG terminal of Tokyo Gas, Osaka Gas and the Toho Gas or the end users around the big domestic natural gas fields in Niigata and Hokkaido province. However, most of natural gas is distributed by the local natural gas companies after the regasficaiton at the LNG satellites. The gas holders are usually used to store the natural gas before deliver to the end users[4][5][6].

According to the natural gas industry situation of Japan described above and the rules of MFM construction, the MFM of Japan natural gas physical flow is constructed, as shown in fig.3. The gas fields are considered as the sources to provide the natural gas; the pipelines, LNG ships, trucks, railways and domestic ships are considered as transports to transport the natural gas or LNG; the LNG terminals, LNG satellites and gas holds are considered as the storages to store the LNG; the pretreatments, liquefactions and the regasfications are considered as balance; at last all the natural gas consumptions are considered as sinks. The explanations of the functions in this MFM are displayed in the Table.2.

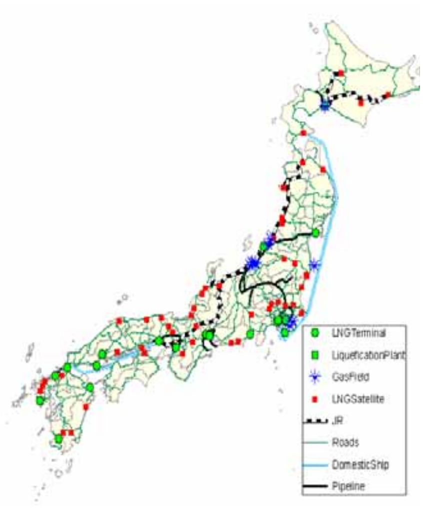

Fig.2 Physical flow of NG in Japan by GIS

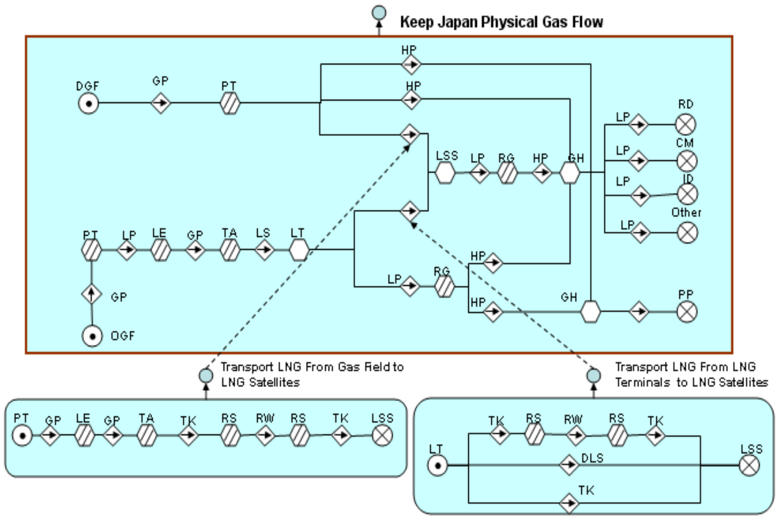

Fig.3 Physical flow of NG in Japan by MFM

Table 2 Explanations of the MFM fuctions for physical flow of NG in Japan

Functions	Explanation
DGF	Natural gas production from domestic natural gas fields
GP	Natural gas gathering through the gathering pipelines
PT	Natural gas Pretreatment after produced from the gas field
HP	Natural gas transportation by high pressure pipelines
LP	Natural gas transportation by low pressure pipelines
RD	Natural gas consumption by residential
CM	Natural gas consumption by commercial
ID	Natural gas consumption by industries
Other	Natural gas consumption by others
PP	Natural gas consumption by power plants
OGF	Natural gas production from oversea natural gas field
LE	Natural gas liquefaction
TA	LNG storage in LNG tank
LS	LNG transportation by LNG ship
LT	LNG storage at LNG terminals
RG	LNG regasficationtion
GH	Natural gas storage in gas holders
TK	LNG transportation by trucks
RS	LNG transportation from truck to railway container at railway stations
RW	LNG transportation by railways
DLS	LNG transportation by domestic ships
LST	LNG storage at LNG satellite stations

3.2 Physical flow of NG in USA

The physical flow of natural gas of USA is displayed in the fig.4, and only the different functions from the model of Japan are e xplained in table.3. The same with Japan, we also can divide the physical flow of natural gas in USA into four stages from production to consumption. However, the detailed processes are absolutely different in two countries. First, as for the supply, at the end of 2004, the natural gas domestic production in USA is 542.9Bcm, import from Canada by pipeline is 102.05Bcm, LNG from foreign is 18.4 7Bcm[11][12]. The United States currently relies on North American supplies for most of its gas, but with those reserves being depleted at a rapid pace and few untapped fields available for exploitation, need for gas from other regions is growing which are all in the for m of liquefied natural gas (LNG) through the 5 existing LNG terminals and more than 30 in planning As for the transportation, there are essentially three major types of natural gas pipelines: gathering systems, transmission pipelines, and distribution systems. Gatheri ng systems collect raw (unprocessed) gas at the wells and transport it to processing plants or other separation and purification facilitie s. The purpose of these facilities is to remove natural gas liquids or to remove other impurities to get the "pipeline quality" dry natura l gas. Gathering lines are typically smaller in diameter compared to the large transmission lines. Transmission pipelines consist of bot h higher pressure and larger diameter pipelines to quickly deliver the natural gas long distances across the state boundaries. Distributi on systems then deliver the natural gas to homes, commercials and small industries in a special state. In USA, the transmission pipeli nes are advanced enough so as to across the entire country. The intersection of the two or more major pipelines is called "hub", the h ub is the most import component in the MFM of USA. That is because, apart from transportation, the hubs also provide a lot of other services, the hubs are always market centers, for example, the most famous one is the Henry hub in Louisana the physical delivery pr ice in which is already used as the standard of the whole country. And the natural gas storage facilities are always near the hubs. Stor ed natural gas plays a vital role in ensuring that any excess supply delivered during the summer months is available to meet the increa sed demand of the winter months and maintaining the reliability of supply needed to meet the demands of consumers. The distributio n is primarily carried out by local distribution companies (LDCs) that purchase gas supplies at the city gate in USA. Many large indu strial customers and most power plants are supplied directly off the high-pressure system, bypassing the LDC system. Increasingly, o ther industrial and commercial customers supplied off an LDC grid are able to contract directly with gas marketers or producers; they pay distribution charges to the LDC as well as transportation fees to the pipeline companies[4].

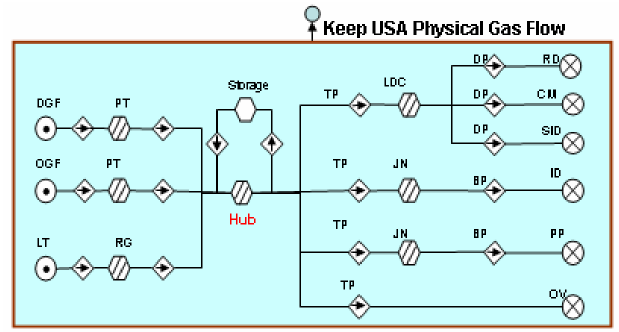

Fig.4 Physical flow of NG of Japan by GIS

Table 3 Explanations of the MFM fuctions for physical flow of NG in USA

Functions	Explanation
NS	Natural gas storage by the storage facilities
Hub	Natural gas transportation by the hubs
TP	Natural gas transportation by the transmission pipelines
BP	Natural gas transportation by bypass pipelines to big users
JN	Natural gas transportation by Joint of transmission pipeline to bypass
DP	Natural gas distribution by the distribution pipelines
OV	Natural gas consumption by overseas, Canada and Mexico

4. TRANSACTION FLOW OF NG

4.1 Transaction flow of NG in Japan

In recent years, the natural gas market of Japan has being deregulated step by step. From 1995 only the big users whose annul co nsumption is more than 2Mcm can take part in the wholesale market to 2004 more than 0.5, and this number will become 0.1 in 2007 . It means more and more players take part in the natural gas market in recent years. From the transaction flow MFM of Japan shown in the fig.5, first, the gas-fired power plants owned by the electric companies only need pay the basic cost to the electric companies. And the big users can buy the natural gas from the wholesale market directly, while the small users only can buy from the LDCs (Loc al Distribution Companies). Now, the TPA (Third Part Access) is permitted in the natural gas market of Japan, and the Ministry of Ec onomy, Trade and Industry (METI) regulates gas tariffs and pipeline access through its Office of Natural Gas Regulation. The main s uppliers of the wholesale market are domestic producers, gas companies and the electric companies. In this model, the CIF (i.e. Cost, Insurance and Freight) price is the price of a good delivered at the frontier of the importing country, including any insurance and frei ght charges incurred to that point, and comparing with CIF, the FOB doesn't include the shipping freight and insurance.

In Japan, the CIF price of LNG is linked with the JCC (Japan Crude Cocktail) which means the average of all the import crude oil from oversea, the formula (1) displays an example of JCC. According to the properties of shipping, the freight can be calculated o ut by using the formula (2)[7].

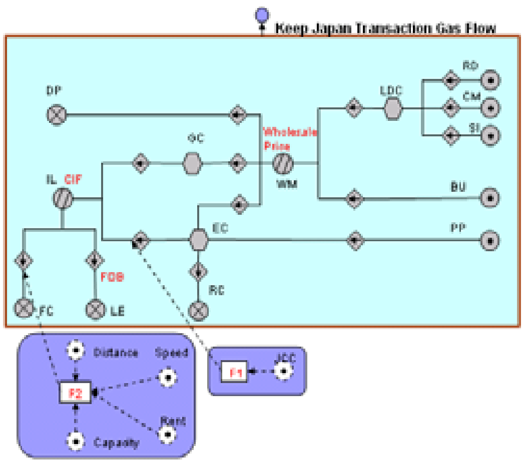

Fig.5 Japan physical flow of natural gas MFM

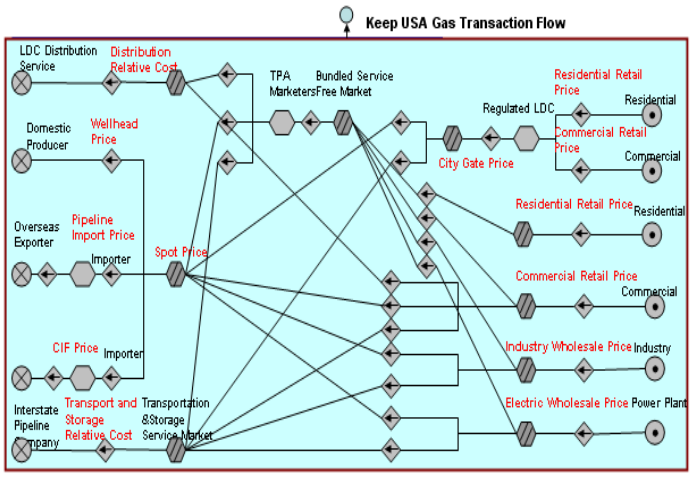

Fig.6 USA transaction flow of natural gas MFM

Table.4. Explanations of the Japan transaction flow of natural gas MFM Functions

Functions	Explanation
PP	Power plants pay electric companies for the natural gas
EC	Electric companies receive money from users and pay for LNG and cost
RC	Regasification cost of LNG
BU	Big users take part in the wholesale market, and pay for the natural gas
LDC	Local distribution companies receive money from small users(RD: Residential, CM: Commercial and SI: Small I ndustries) and pay for the natural gas in the markets
WM	Natural gas is transacted in the wholesale market
GC	Gas company receive money from end users and pay for the LNG in international LNG market
DP	Domestic producers receive money from the users
IL	LNG is transacted in the international LNG market
FC	The freight of the LNG
LE	LNG exporters receive money from LNG buyers
F1	Relationship function which calculate the CIF of LNG according to the JCC
F2	Relationship function which calculate the freight according to the properties of the shipping

$$P_{LNG} = \begin{cases} a \times JCC + b + S(P_{Middle2} < JCC \le P_{Max}) \left(S = \dfrac{JCC - P_{Middle2}}{P_{Middle2} - P_{Max}} \times c \right) \\ a \times JCC + b + S(P_{Middle1} \le JCC \le P_{Middle2})(S = 0) \\ a \times JCC + b + S(p_{M\text{in}} \le JCC < P_{Middle1}) \left(S = \dfrac{P_{Middle1} - JCC}{P_{Middle1} - p_{M\text{in}}} \times c \right) \end{cases} \quad (1)$$

$$C_{transportation} = \frac{\left(\dfrac{Dis\tan ce / Speed}{24} + 2 \right) \times \mathrm{Re}nt}{\left(Capacity \times 0.036 \times 600 \right)} \quad (2)$$

In formula (1), the PLNG is the LNG price, "a" is a coefficient dependent on the JCC which is smaller than 1(always is 0.86) whe n both in equivalent heat quantity term (for example "MBtu"). It can prevent the LNG price from rising 100% in reflection to its link to the crude oil price, when skyrocketing for protecting the consumer interests. The factor "b" is added to the price to take account fo r the relatively fixed transportation cost. In this formula, the factor-"S" is introduced, this factor makes the LNG price change slower in lower or higher JCC price periods (between P_{Min} and $P_{Middle1}$ and between $P_{Middle2}$ and P_{Max}) comparing with the middle JCC price period (between $P_{Middle1}$ and $P_{Middle2}$). When the crude oil price surpasses the threshold price, the LNG price will change relatively les s than that of crude oil price. We can predict simply that in low oil price era , the LNG price of Japan is higher than that of oil; while i n high oil era, the LNG price of Japan is lower than oil price, and the higher the world crude oil, the bigger of the gap between the L NG price and crude oil price[8]. In formula (2), the "Distance" means the distance between the export terminal and import terminal (K m), "Speed" means the speed of the LNG tanker (Km/hour), and 2 days stay at the port is assumed; the "Rent" means the rent of the LNG tanker($/day) and the "Capacity" is the capacity of the LNG tanker (Cbm), the "0.036" is the ratio between the Cbm and the M Btu, the number "600" is the volume ratio between the LNG and NG.

4.2. Transaction flow of natural gas in USA

As the display of fig.6, the natural gas market in USA is a retail competition market. The customers contract separately for gas fr om sellers and transportation service from pipeline companies. Customers determine the least-cost combination of transportation rout e and source of gas supply by themselves. Almost all the electric power companies, as well as big industrials and big commercials co ntract the gas and transportation service by themselves. Customers also can buy a bundled service from marketers-TPA(Third Part A ccess). At the same time, about half of the states provide the retail choice for residential customers as well. But in a free competition market like USA, the gas transportation through pipes is considered to be in most cases a natural monopoly- particularly in local distr ibution. Because of the cost of implementing the transportation and distribution infrastructures, it would be uneconomical to lay overl apping transportation, and distribution networks in any one area, meaning that in most areas there is only one interstate pipeline comp any or LDC offering transportation or distribution services. So, prices charged for transportation, storage and distribution services ne ed to be controlled to prevent the monopoly service provider from exploiting the potential for excessive profits. The Federal Energy Regulatory Commission (FERC) is responsible for regulating access to and tariffs for using the interstate pipelines and storage faciliti es linked to those pipelines. And the State Public Utility Commissions take charge the oversight and regulation of investor owned loc al distribution companies. So the natural gas upstream prices and downstream prices share the same development trend, because the d ifferences between them are the transportation and distribution tariffs which are calculated out by the COS(Cost Of Service) method[9] [10].

5. RESULT AND DISCUSSION

According to the physical and transaction flows of NG in Japan and USA, we can simplify the retail natural gas price into three segments-commodity price, transportation cost and distribution cost. In which, the commodity price is the price of natural gas itself, f or example the spot price, the transportation cost consists of not only the cost in the transportation process, but also the upstream stor age cost and the profit of the pipeline companies, in the same way the distribution cost not only consists of the cost in the distribution process but also the downstream storage cost and the profit of the LDC. The fig.7 displays the composing of residential prices in Jap an and USA at the end of 2004. The price for natural gas itself (the wellhead price of domestic production or the CIF price of LNG) o f USA is the highest among them due to the free competition market mechanism and the high crude oil in recent year. The transportat ion cost and distribution cost in Japan are the much highest that those of USA due to the complicated transportation methods, the hig h cost of pipeline construction, the high price for the land and the much less consumption per family than other countries.

On the other hand, in the domestic of Japan, in recent years the residential price almost keep the same even become lower althou gh the LNG import price increases every year as shown in fig.8, that is because the downstream price is mainly decided by the transp ortation, distribution cost and the margin profit of the gas companies, and with the deregulation of the natural gas domestic market of Japan, the big end users can choose the sellers by themselves freely, and the pipeline owners must provide the transportation service t o the TPA that make the load factor of the pipeline and the efficiency of market improved also the monopoly deceased, maybe the im provement of techniques also have a active action. So, we can say the high price in international LNG market can not affects the retai l price of natural gas in Japan.

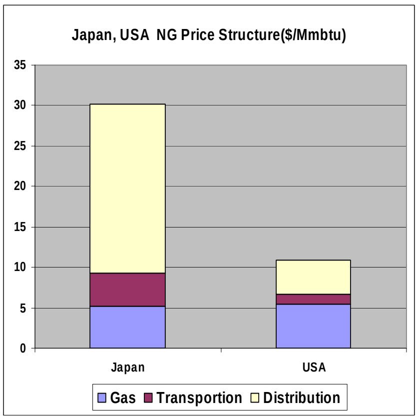

Fig.7 Residential prices in Japan and USA

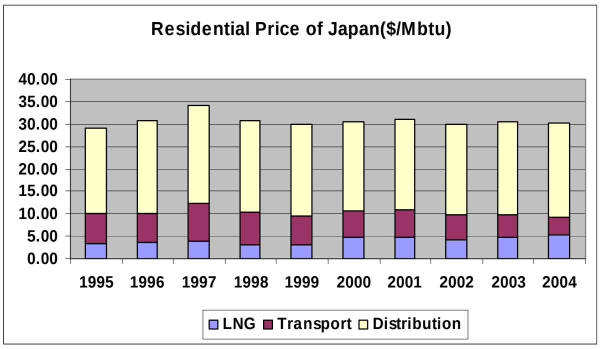

Fig.8 Residential prices in Japan

6. CONCLUSION

The NG industries and markets in Japan and USA are discussed by using MFM and GIS, and the conclusions thus far obtained are summarized as follows; First, in Japan, about 96% NG come from LNG, and due to the Japanese limitations of geographical land use with its high land cost and poor natural resources, the pipeline construction in Japan is not economical in some areas unlike USA. In Japan, as many as 25 LNG terminals are constructed in her coastal areas and the LNG is mainly transported to the consumer areas by trucks, railway containers and domestic ships from the LNG terminals to the LNG satellite stations located in the pipelines not economical regions. This is the unique infrastructure of NG usage in Japan. Second, because of the above stated complicated NG transportation methods with the high cost of pipeline construction and the much less consumption per family, the end user price of NG is much higher than those of USA . Third, with the recent introduction deregulation of the NG market and the improvement of the technologies, the end user price of NG in Japan which is mainly decided by the transportation and distribution cost is decreasing while the LNG CIF price is increasing in recent years. As the succession of this study, more GIS analysis tools will be used to explain the reasons for high end user price in Japan, the pipelines construction cost in Japan also will be calculated. And in future, the authors are thinking of conducting the evaluation study on the feasibility of hydrogen generation by the co-generation system of High Temperature Gas Reactor (HTGR) (transportation and storage of the hydrogen generated by HTGR and then distributed for end-users) by using the present LNG and NG distribution infrastructures in Japan by using MFM and GIS, since the HTGR development projects are now going on in Japan for the promising cogeneration system in future.

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