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The economic appraisal and prospect study on LNG-powered vessels

Zhiyuan Luo

WORLD MARITIME UNIVERSITY

Shanghai, China

The Economic Appraisal and Prospect Study on LNG-powered Vessels

BY

LUO Zhiyuan

China

A research paper submitted to the World Maritime University in partial fulfillments of the requirements for the award the degree of

MASTER OF SCIENCE

INTERNATIONAL TRANSPORTATION AND LOGISTICS

DECLARCTION

I certify that all the material in this research paper that is not my own work has been identified, and that no materials are included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

LUO Zhiyuan

Supervised by

Professor LIU Wei

World Maritime University

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Abstracts

Title of Research paper: **The Economic Appraisal and Prospect Study on LNG-powered Vessels**

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With the rapid growth of the global oil prices and the deterioration of the environment, more and more high energy-consuming industries began to seek alternative energy sources. According to the data released by the International Atomic Energy Agency in 2002 , the energy is needed for Transport accounts for about 25% of the total energy in the world and 10% of transport energy is needed by the international or domestic marine shipping. LNG is currently the world's most practical and cleanest energy, so the paper is to appraise the economic feasibility of the application of liquefied natural gas on ship and the development feasibility of liquefied natural gas-powered ships in the future.

This paper uses prediction methods to get the trends of the oil and liquefied natural gas price in the next fifty years. The author select three ships, the marine vessel, inner land ship and duel fuel ship, find relevant power plant data from Lloyds list, then calculate the final energy cost. Predict the future choice of the carbon tax price with MARKAL-MACRO model. So we can get the carbon tax coping with the three different ships based on the predicted carbon tax and the fuel consumption. To sum up the energy costs, carbon taxes, and modification costs, we can broadly obtain the different oil and LNG energy economic characteristics. The fifth chapter of the article points out the problems of the transformation of LNG-powered ship. For the mine service life of natural gas is not longer than oil, the sixth chapter talks about the feasibility of future development of natural gas. Cold energy recovery technology and the exploitation of combustible ice technology is maturing, making the advantages of LNG more obvious.

Key Words: LNG, LNG ship, Carbon Tax, Cold energy Recovery, Economy, Combustible Ice.

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1 Introduction

1.1 The background and significance of the paper

On May 15, 2012, the World Wide Fund for nature (WWF) in Beijing released the earth vitality report of 2012 which is called the "earth's physical examination report". The diagnosis results show that "the earth is now not health". The report shows that the global biodiversity health status (earth vitality index) decreased by 28% during 1970 and 2008, the tropics decreased by 60%. On the contrary the demand of human for natural resources was doubled since 1966. Human beings are using the equivalent of 1.5 times of earth resources to maintain their own life. To restore the earth's health, the basic way is to control the population growth and to solve the excessive consumption problems.

Low efficiency in using of resources and energy in industrial production and activity as a global problem, while producing and letting out a large number of wastewater, waste gas, waste, noise, vibration, electromagnetic and other pollutants, has brought human beings serious threat on living space, such as Global warming, ozone depletion, worsening water pollution, life and health damage, physical impact and non-renewable resources depletion. Since the 1970s, the use of "green" operations, aiming at protecting the environment, implementing the utilization of resources and energy rationalization, has risen around the world. With the development of the economic, governments changed the traditional model to achieve sustainable development strategy and implement increasingly strict environmental regulations. The general public awareness of environmental protection is increasing. Green consumerism is booming to replace the current extensive consumption. Energy conservation is necessary for human survival and development. While human using fuels, they are release a lot of harmful gases such as carbon dioxide of CO2, nitrogen oxides NOx, sulfur oxides SOx to the environment. NOx and SOx is the main substances causing acid rain. CO2 gas emissions have resulted in worsening greenhouse effect. Thus, reducing the harmful gas emissions in the energy system is the key issue to improve the global environment. The Kyoto Protocol signed in 1987 severely restricted CO2 emissions of the major industrial countries.

At present, oil and coal are the main energy. With the oil prices showing a sharp rising and ecological deterioration, many nations begin to recognize that it is not a long-term plan to rely

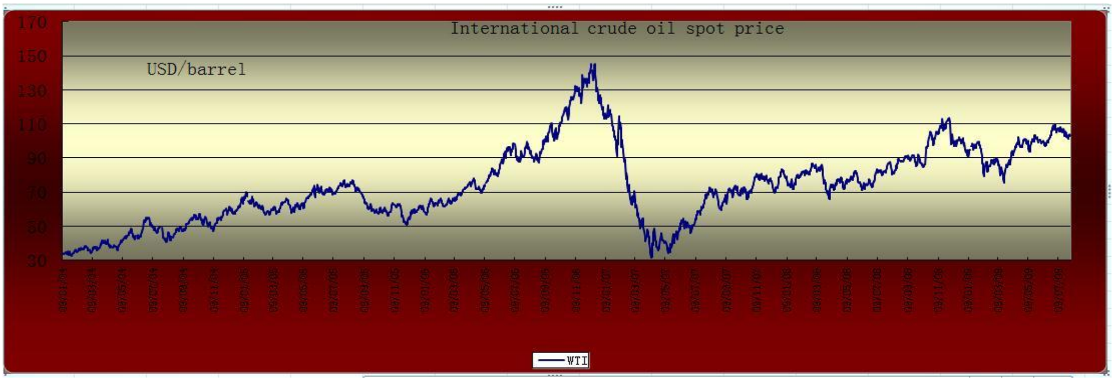

Figure 1-International crude oil spot price

On the internal combustion engine powered by petrol and diesel excessively .Currently, global ships let out nearly 1.2 billion tons of CO2 every year, accounting for 6% of global emissions NOx and SOx are accounted for 20% and 30% of the global emissions respectively. ship's fuel has caused serious pollution on the oceans and atmosphere. Therefore some countries has been dedicated to the green and efficient new power research. In addition to some new energy, such as hydrogen, solar, electric power, Liquefied Petroleum gas (LPG) , Liquefied Natural gas(LNG) ship and vehicle research also has been developed.

This paper aims to appraise the energy transformation of the ship, mainly including the assessment of gasoline and diesel ship LNG transformation

1.2 Methodology

Forecasting is the process of making statements about events which have not yet been observed.

Cost Evaluation is the process of determining how resources are used. It can be on any scale, from as focused as one single project or unit of an organization, to broad, comparative studies of resource allocation in a whole network of organizations. Generally, a cost evaluation is only one part of a broader cost-benefit analysis, with the goal of determining whether resources are being used efficiently.

Markal is a numerical model used to carry out economic analysis of different energy related systems at the country level to represent its evolution over a period of usually of 40 – 50 years. Various parameters such as energy costs, plant costs, plant performances, building performance and so on, can be input and the software will choose an optimal technology mix to meet that demand at minimum cost. It is available from the International Energy Agency

MACRO is a macroeconomic nonlinear programming model. The basic input factors are investment, labor and various forms of energy output, consumption and payment of energy capital costs. The evaluation criteria are to maximize the total discounted utility of consumption at different times.

(www.Wikipedia.com)

2 Literature review

2.1 Overview

In 2008 the scientists of United States and Norway drilled a long piece of 90 m ice in the Antarctic. It contains a lot of tiny bubbles. They used isotopic tracking bubble to make reduction of the temperature and C02 concentration, finding that the two curve of the earth's temperature and the concentration of C02 are surprisingly similar. The earth's ecology was balance, when the C02 concentration in atmosphere was 280 PPM before the industrial revolution. When the surface temperature increased by 0.740℃, when the C02 concentration increased to 435 PPM. If it developed as this situation, by the end of this century, the C02 concentration of the atmosphere will be 750 PPM, the earth's temperatures will increase by 50℃, and it will produce an unbelievable disaster

So we should try our best to make the ecological be balance and more and more people have pay attention to it.

With the improvement of science and technology, the typical and representative new energy such as wind, solar, nuclear energy, biomass energy and tidal are showing a unique advantages and can get more and more economic benefit . The ship traffic transportation industry will make the application and popularization of the new power. LNG is the most realistic energy in the new energy.

2.2 The present situation of the oil

It produces all kinds of environmental problems in every stage of the oil industry, including production, transportation, petroleum refining and the finished products. The chemical emissions of oil industry are usually poisonous and harmful, and some even can cause cancer. What's more, some emissions are related to the formation of photochemical smoke. Oil transportation depends mainly on maritime transport, so that oil tankers oil leakage accident is almost inevitable. The following table is the time and oil leakage of the crude oil leakage accident during the last forty years.

Ship name	West Atlantic Queen	ABT Summer	Castillo de Bellver	Amoco Cadiz	Haven	Prestige	Exxon Valdez
Year	1979	1991	1983	1978	1991	2002	1989
leakage (t)	287000	260000	252000	223000	144000	63000	37000

Table 1-The leakage of crude oil in thirty years

Source: U.S. Energy Information Administration

Though the accident of the Valdez oil tanker of Exxon Corporation just row in No. 35, it also caused the death of 250000 birds, 2800 sea otters, 300 seals, 250 bald eagles and billions of salmons and herring larvae. The clearance work used 10000 workers, 1000 ships and100 airplanes. Exxon Company paid more than $3 billion for the accident.

Country or area	Saudi Arabia	Iran	Iraq	Kuwait	United Arab Emirates
R（B）	264.2	137.5	115.0	101.5	97.8
R/P	65.6	93	>100	>100	97.4
Vene	Russia	Kazak	Libya	Nigeria	Global

zuela		hstan			gross
79.7	74.4	39.6	39.1	35.9	1200.7
72.6	21.4	79.6	63.0	38.1	40.6

Table 2-The oil reserves of the top ten oil producing countries and the R/P value

Source: U.S. Energy Information Administration

Notice: The oil reserves of the top ten oil-producing countries and the R / P value, where r stands for oil reserves and p is the oil production

The prospect of oil is undoubtedly limited. The formation process of oil is up to 300 million years or so. By now, the oil consumption has reached 900 billion barrels. According to British Petroleum (BP) estimates, the total conventional oil reserve of the world is 1.2 trillion barrels (BP, 2006). Conventional oil means the oil exist in liquid form underground, and can take out of the ground. This shows that in the past 300 million years the nature formation of the oil were 2.1 trillion barrels, that was 7000 barrels every years on average. However, the Number is trivial comparing with the current global consumption of 30 billion barrels a year on average. Now sure oil reserves (R)now and the oil company's global oil production (P) ratio, is a useful but not perfect method that calculate the duration time from now to the oil resource exhaustion.

Such as petroleum, the development of fossil fuel follows a predictable model. This model was proposed by Harbert more than 50 years ago. According to Harbert curve we can find global oil production peak is between 2005 and 2015.

For China, by the static index in 2007, the remaining reserves were 2.1 billion tons, with an annual output of 187 million tons. There were 11 years left for mining. It is hard for us to believe it.

2.3 The present situation of liquefied natural gas

2.3.1 Introduction

Methane (CH_4),the main components of LNG, is the minimum carbon fuel that can exist in the nature in quantity . Natural gas will liquefied when it is cooled below -160 ℃. At the mean time the volume shrinks to 600 times smaller of original. It is beneficial to the storage and market supply. Before liquefied, the natural gas has been taken away the waste ,such as dust, sulfur and water. Therefore LNG is a kind of clean energy, which is widely used in developed countries.

Natural gas is the cleanest fossil energy. With crude oil combustion on the environment from the negative influence of the gradually been recognized, and international oil prices.

Continuous wave, the use of natural gas in recent years gradually gets promotion. 20 century 80 ~ 90 s, natural gas in energy use in the proportion of a 2, 2007 in "a energy" consumption 28.63%. But in China's "a energy" the composition of consumption, the proportion of the natural gas is only 3.25%. It shows that China's natural gas utilization degree is still very low, huge development potential.

Decided to natural gas future prospects is one of the key problems of the world of the natural gas infrastructure investment is speed, such as a gas pipeline and LNG facilities investment to gas more efficient from origin transportation to the market. Natural gas relative to coal and oil more environmentally friendly, but the use of unlimited will inevitably increase co2 emissions.

LNG belongs to cryogenic liquid. Its density is lighter than air, in the leak it will automatically spread to the up sky. And it won't produce pollution to the water. At the same time, because of the joint of special smell agent, the gas leak will be found in time. In addition, natural gas's flash point is higher than gasoline and diesel, instantly fire is slow than oil, also is easy to spread, and is not easy to achieve the explosion limit. So its safety performance is high.

According to calculation in theory, the hybrid mode can reduce emission of SOx, NOx, and CO2 respectively by 100%, 85%-90% and 15%-20%, and “low-carbon shipping” can be realized in the true sense. To the delight of the ship-owner, the operation cost has been reduced by 20%-30%.

LNG is the main source of energy for the converted hybrid ship, and the ratio of LNG and diesel oil is 7：3. LNG is stored in several LNG gas storage tanks which could be wholly vertically Installed and fixed on the afterdeck. In case LNG is used up or cannot be refilled due to some circumstances, or the gas system cannot be used due to malfunction. The ship can still operate normally in the pure diesel oil mode.

1 cubic Of LNG is equivalent to1 to 1.1 liter petrol or diesel oil. At present, the average price of diesel oil is 6 yuan／liter and 4.5 yuan／liter for the natural gas. If calculated by replacement ratio of 70％, nearly 200 000 yuan could be saved in a year. In terms of conversion cost the electric control gear of LNG for vessel is approximately 50,000 yuan／set, the storage tank for vessels is about 130,000 yuan/set and the cost of conversion is around 50,000 yuan, in total, the cost is 230,000 yuan／piece to 250,000 yuan/piece(300dwt)which

could be recovered within a little more than one year.

2.3.2 Application fields

The gas is mainly used for chemical production, power generation, residential gas, commercial gas, urban heating and vehicle fuel. Natural gas is widely used in civil and commercial gas stove, water heater, heating and cooling, also used in paper making, metallurgy, quarrying, ceramics, glass and other industries. It can also be used for waste incineration and drying dehydration.

In 1984, the former Soviet Union developed the world's first LNG powered dual fuel car. To the end of last century, LNG power car has been tested successfully in Japan and South Korea etc. In July 2010, the Norway transportation company Fjord signed a contract with Fiskerstrand BLRT, which is planning to build the world's largest LNG powered ferry. The ferry was put into operation on 30 November 2011, and plying the Bokna Gulf between Rogaland, Arsvagen and Mortavika since then. By the end of 2010, Det Norske Veritas (DNV) issued future concept LNG tanker ship "Triality". The ship adopted the creative linear structure and LNG powered internal combustion engine. It almost eliminated the pollution emissions to the atmosphere, leading to a new era of the environmental protection tanker shipping industry.

LNG car can drive for a long mileage for the LNG big density of LNG. The foreign Large LNG van can continuously travel 1000 ~ 1300 miles when full filled, which is very suitable for long distance transportation. With 410 liters of gas cylinders, the domestic lorry can drive about 400km in the city and above 700km in highway. Therefore, LNG is especially suitable fuel for large passenger cars and heavy trucks. If the government constructed LNG stations in the transport hub and along the highway, there certainly would be more vehicles, making long distance, use LNG as the fuel, which would lead the development of LNG.

Inland water transportation is a great potential market of LNG development (including LNG transportation and LNG as ship's fuel). Inland water transportation has the advantage of big volume and low cost. China is a large country with many big rivers and tributaries covering the north and south, rivers and lakes connecting to each other, which constitutes the inland water transportation natural nets. There are more than 50 thousand rivers whose drainage area is more than 100 square kilometers. To sum up, they are about more than 430 thousand kilometers long. There are 900 lakes, whose ice-free water is abundant. All the above provide natural conditions for the development of inland water transport. In 2008, the waterway traffic freight turnover in comprehensive transportation system accounted to 11 was 4% and 45.6%. Inland water transportation will be the country's traffic development and new world (relative highway and railway). This will be prompted LNG as a ship's fuel LNG and shipping the development of LNG. Now the domestic Korea cryogenic company developed by the first set of Marine LNG fuel system has passed the authentication. The system Norway classification society have LNG storage, gasification and natural gas pressure regulation, gas supply function, will ship in the Nordic sea for 1 of the operation of largeo-ro form a complete set, for the ship's gas engines provide fuel a year, the company also in May will be held in the second set of similar equipment. And the shipping LNG has quite mature, our country has been able to build its own large LNG transports. Therefore, inland water transportation is great potential of development LNG market. From the above trend can see, in LNG resources fully guarantee, under the premise of the future and inland water transportation LNG technology application is the main market.

In the international world, more and more countries are trying to install gas fuel engines in various types of ships. A German owner will convert its large ocean container ship to the fuel of LNG powered. And the Nordic countries such as Denmark, Norway have begun to take LNG as the fuel of ferry ships, ro-ro ships, coastguard ships, LNG tanker and platform supply vessels.

On October 26, 2010,the two giants global shipping business world: Norway classification society (DNV) and I.M.Skaugen group (I.M.Skaugen) in Shanghai jointly hold liquefied natural gas (LNG) seminar. Participants think that the price of oil used as energy goods to transport, heating and power generation, is too high. The future oil should serve petrochemical product end users and life science purpose (such as food and medicine). For transportation, heating and power industry, it has rich natural gas as a global energy supplier. The world is rich of reserves of natural gas. At present the LNG supply is unprecedented. Mr Skaugen said." China has become the world's major LNG importer. However, in China the basis of forming a complete set of LNG import construction is not fully developed. I.M.Skaugen Company and China counterparts will cooperate in the development of LNG. Along the Yangtze river and costal they will set up some LPG stations to make convenience for vehicle and ship who use LNG. I.M.Skaugen Company firmly believes, the future world will be cleaner, and everyone could use cheaper energy for the future. With LNG refueling will be our contribution to the sustainable growth of the world.

TianWei said, from domestic construction of China Classification Society, in practice, there are two main challenges from transforming the original diesel from a single power of a single mode to the implementation of ship LNG and diesel hybrid: one is the ship of diesel engine requires a proper transformation to be suitable for the LNG power. The other problem is the position planning of the new gas storage device of the ship. Because the original ship design does not leave enough storage space to LNG storage tank. How to make space planning in the limited space for gas storage device of LNG ships, making it in a safe area and can give appropriate protective especially fire prevention, leakage protection measures become the key point of the design of modification. In addition, if the LNG fuel used for long distance transportation ship, safety design must be achieved by shore-based or by the LNG gas ship to ship gas storage device to fill, rather than through the replacement of removable storage tank group to realize.

As the first LNG fuel user in the field of shipping countries, Norway has used the LNG fuel in light and small ship; the Danish Maritime Authority is experimenting with how to develop LNG infrastructure to facilitate the ship owner to use natural gas-powered ships; Fjord company installed dual-fuel engine and equipped with C-type LNG fuel tanks to two ship a new ferry; Finnish engine supplier Wrtsil help the Swedish Tarbit the Shipping company convert a finished product tankers to LNG fuel vessel. In addition, South America's interest in the LNG fuel is also increasing; the Buquebus company has purchased an LNG-based fuel and high-speed ferry. The traditional bunker fuel oil challenged for LNG fuel enterring the maritime field as a new *type of fuel.*

The support vessel Viking Energy has been built at the Kleven Maritime shipyard in Norway for its owners Eidesvik and started on a ten-year charter for Statoil. It is the world's first LNG-fuelled supply/cargo vessel, designed by Vik-Sandvik as a response to industry demands for minimizing greenhouse gas emissions.

(http://www.enagri.info/knowledge_base/press_view.php?pressID=931&search=&page=1)

The Viking Energy has an overall length of 94.9m and a length between perpendiculars of 81.6m. It has a mounded breadth of 20.4m. The depth to the second deck is 6.6m and the depth to the first deck is 9.6m. The supply vessel has a maximum draft of 7.9m and cargo deck area of 1,030m³.

It has complemented 24 crews and accommodated in 12 single berths and five double cabins.

The vessel will take supply materials to Statoil's North Sea platforms. It can carry 1,300m³ of fuel oil, 2,000m³ of water ballast or drill water, 1,100m³ of potable water, 200m³ of methanol, 800m³ of brine, 900m³ of liquid mud and 450m³ of dry bulk. The vessel has a gross tonnage of 5,073t and a net tonnage of 1,521t. Its deadweight is 2,886t at 5.9m draught.

DUAL FUEL MARINE ENGINES

The Viking Energy features dual fuel engines, with a consequence that it can run on both LNG and ordinary marine diesel oil in any proportion. LNG usage results in a 90% NOx emission reduction (approx 200t a year) as well as a 30% CO2 reduction. Tests have shown that the vessel has a fuel economy rate of 30% better than that of diesel.

In order to use gas as a fuel, safety is a main priority and this has remained an important aspect in the design. The engine system is divided into fire-proof and explosion-proof zones and a number of constructive safety measures have been included. The storage of the LNG is in a vacuum insulated tank with a gross volume of 234m³. This is built as a pressure vessel and a vaporizer with a built-in coil pressurizing the tank.

ENGINES

The electric power for propulsion and other services is derived from four main gensets. The main engines are Wärtsilä 6032 DF 2,010kW engines units, although there is also a Caterpillar 3304T 116kW emergency genset.

These gensets are linked to a pair of Rolls-Royce Contaz 25 contra-rotating 3,000kW stern thrusters and two Rolls-RoyceTT 2200 SS 1,000kW tunnel thrusters in the bow. The vessel also has a Rolls-Royce ULE 1201 880kW azimuthing retractable thruster for manoeuvring. This complement gives the Viking Energy a top speed of 16kt fully loaded.

The electric propulsion systems were supplied by ABB in a work scope that included a complete package of variable speed drives and power distribution as well as the electric propulsion and the thrusters. The vessel uses Direct Torque Controlled (DTC) frequency converters that afford accurate control of thruster magnitude and azimuth, leading to better maneuverability of the vessel. This type of motor drive directly reduces vibration and noise in the vessel, benefiting comfort and the working environment.(Wärtsilä Company)

Because of the existing water LPG station, port facilities can't keep up with the follow-up service, it directly affecting the "from oil to gas" project. Ships in the transport process need engine with long enough promoting continuously power, that is they need to be filled with LNG in the ports. And, at present, the infrastructure of the supplies and storage is not achieved the corresponding ability. The reason is we do not know where to build LNG stations, how to build and so on. China is lack of corresponding technical standard, management standard and the policy support. In addition, ship "from oil to gas" process is a high-risk industry, which needs professional management and technical talents. But the talent shows particularly scarce. At present, the test of ship has success, but the promoting and market training need a period of time. It needs time for people to accept and identify a new born thing. Considering the rules of the IMO emissions constraints and at the same time LNG supply facilities is very few around the world, the application of the LNG engines to the ocean transportation has a large ship difficulty in short terms. Dual fuel engine can simultaneously solve the problems of LNG storage space and LNG supplying in time. To sum up, the dual fuel engine will be focused on research and development for the next five to ten years .

2.3.3 The development of LNG

In recent years, as the world's natural gas industry developing rapidly, liquefied natural gas (LNG) has become an important part of the international natural gas trade. Compared with ten years ago, the world LNG trade seeing strong growth momentum is more than doubled.

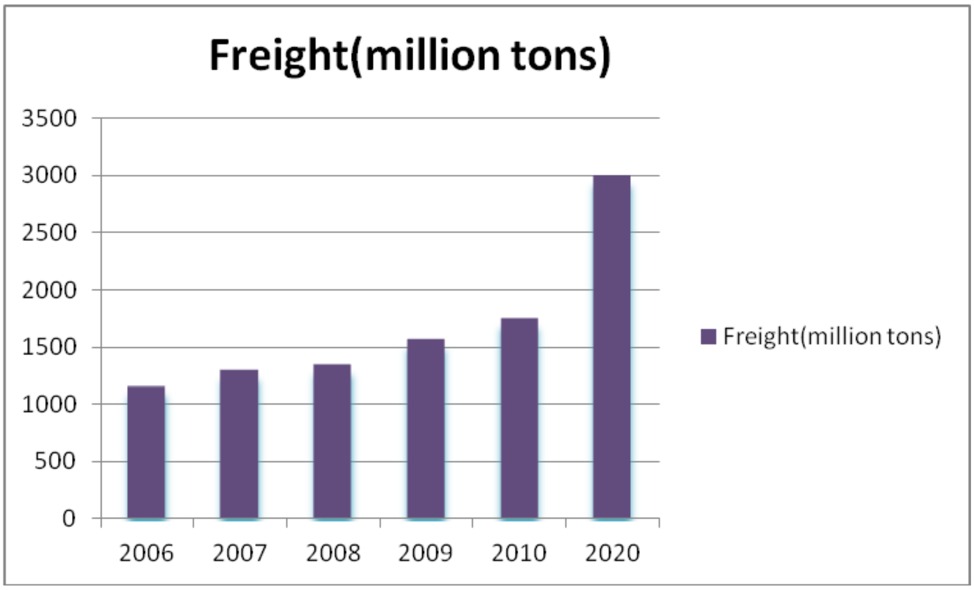

Figure 2-The world LNG trade weight

Source: BP

According to the international energy agency forecasts, in the 2015 international market, the trade of LNG will account for 35% of the total natural gas in 2020 and will reach 40% of the natural gas trade, accounting for 15% of the natural gas consumption.

As the storage and transport way of natural gas, extensive use of LNG is in favor of remote natural gas recovery and storage, long-distance transport of natural gas, the use in peaking hours and expansion of natural gas use form.

In the early sixties, the National Science and Technology Commission has formulated the LNG development plan. In the mid-sixties, China finished the industrial test. Weiyuan Chemical Plant of Sichuan Petroleum Administration has the first domestic natural gas cryogenic separation and liquefaction of industrial production facilities, in addition to the production of He, also produced LNG. In the 1990s, China began the practice of liquefied natural gas technology. The low temperature center of Chinese Academy of Sciences in conjunction with relevant enterprises built two liquefied natural gas installations respectively in Sichuan and Jilin. The one produces 0.3 of LNG capacity per hour, using its own pressure expansion refrigeration cycle. The other's production capacity is per hour for the O.5 square of LNG production, using nitrogen expansion closed refrigeration cycle. Different to with the situation abroad, the domestic natural gas liquefaction studies are aiming at small-scale liquefaction process.

With the development of China's natural gas industry, on the basis of practice in the liquefied natural gas technology and through the introduction of foreign technology, the first accident peaking natural gas liquefaction plant was built in Pudong, Shanghai in 2000 and the first commercial natural gas liquefaction plant was built in 2001 in Zhongyuan oil field. This marks that on the basis of the introduction of foreign natural gas liquefaction technology, the domestic liquefied natural gas application technology began to be fully open, and then in Xinjiang, Sichuan and other places many LNG plant were put into operation, prompting development of application technology of China's natural gas liquefaction from storage, transportation, all-round to the use of LNG to the terminal

At present, China has built nearly 20 sets of LNG production plants, the total size of the annual output is 460 thousand tons. There are still 10 sets under construction whose total size of the annual output is 1.2 million tons of LNG.

With the commercial operation of the LNG production plant, the LNG satellite station has also been rapidly developed. There are more than 100 LNG satellite station built whose daily supply is more than 600 thousand LNG in the country after the Zibo, Shandong LNG satellite vaporization station built in 2001, mainly distributed in South China and Yangtze River Delta and other economically developed coastal regions. LNG satellite station has become an important means of city gas peak shaving and making up the shortage of piped natural gas. LNG satellite stations mainly have the function of loading and unloading, storage and vaporization.

CNOOC in 1995, commissioned by the National Development and Reform Commission, carried out preliminary studies to build large receiving terminal and receive foreign LNG resources in Guangdong coastal. In the end of 1999 China formally approved pilot construction of LNG terminal integration project in Shenzhen, Guangdong. It was the beginning of the construction of China's large LNG receiving station.

In 2003, the Fujian LNG integrated project received state approval to become China's second officially launched LNG project. Subsequently, the three major oil companies carry out a preliminary study of the LNG project in Liaoning, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Hainan, Guangdong, the coastal areas of Guangxi. It actively promoted the construction of large-scale LNG terminal in China.

Project Name	Owner	Putting Time/Year	Stock Tank Number	Reserve Capacity/ Thousand m^3
Fujian LNG	CNOOC	2008	2	320
Guangdong LNG	CNOOC&BP	2006	2	320
Yong An	CNOOC of Taiwan	1990	6	690

Table 3-Exist large LNG terminal

Source: CNOOC

Notice: CNOOC is short for China National Offshore Oil Corporation

Guangdong receiving station integration projects includes LNG receiving terminal and Trunkline Project, as well as supporting new power plants, fuel plant transformation and gas projects of city natural gas pipeline network system. Gas range covered the Pearl River Delta and Hong Kong Special Administrative Region and the gas main route length was 509km. The entire project was completed in two phases. The first phase of the project included a receiving terminal and Trunkline, with the annual LNG imports of 370 × 10^4t and delivery capacity of 40 × 10^8 t/a. The second phase of the project added a storage tanks of 10 × $10^4$$m^3$, with annual imports of LNG up to 700 × 10^4t /a and delivery capacity of 82 x $10^8$$m^3$ / a.

The first phase of the projects put into operation in May 2006, indicates that China has successfully achieved the introduction of foreign natural gas, and by the construction of the project, China introduced the i large LNG terminal design and construction and developed the supporting industries, at the same time trained and exercised talents and teams engaged in LNG application.

For the construction of a large LNG terminal, the most critical technology of application were to the design and construct large storage tanks. The earliest construction of large-scale liquefied gas tank of China was begun in the mid-1990s. They were 80000 Liquefied Petroleum Gas cryogenic tanks in Shenzhen and 10,000 square low-temperature ethylene storage tanks by Yangzi Petrochemical. In the late 1990s, Shanghai built China's first LNG cryogenic storage tank with 20,000 in low temperature. During 2002-2005 Hefei General Machinery Research Institute and other units, assume the topic of major technical equipment research projects of the former State Economic and Trade Commission, “20,000 square LNG storage tanks development”. The topics focus on 9Ni steel welding, nondestructive testing and low-temperature adiabatic materials and structures and LNG storage security.

Project Name	Owner	Putting Time/Year	Stock Tank Number	Reserve Capacity/ Thousand m^3
Liaoning Dalian	CP	2011	2	320
Guangxi	CP	2011	1	160
Hainan LNG	CNOOC & Hainan Government	2011	1	160
Zhejiang Ningbo	CNOOC& Zhejiang Energy	2010	1	160
Shandong Qingdao	SINOPEC	2011	1	160
Jiangsu Rudong	CP	2010	2	320
Shanghai	CNOOC& SG	2009	2	320
Guangdong Shantou	CNOOC	2010	2	320
Hebei Tangshan	SINOPEC	2010	2	320
Liaoning Yingkou	CNOOC	2012	2	320
Guangdong Zhuhai	CNOOC	2012	2	320
Taizhong	CNOOC of Taiwan	2009	3	480

Table 4-Large LNG terminal project in construction

Source: Statistical information of International Petroleum Economics, 2009

Notice:CP stands for Chinese Petroleum; SINOPEC stands for China Petroleum & Chemical; SG stands for Shenergy Group

3 The research of LNG-powered vessel in China

3.1 The current situation of LNG-powered vessel in China

The LNG-powered vessel research of China has just begun. On August 3, 2010, the first China's inland LNG-diesel dual-fuel powered energy “Wutuolun302” boat, invested by Hubei West Blue Natural Gas Co. Ltd and designed by Wuhan Ship Design Co. Ltd., successfully launched in Wuhan trials.

Designed by the Singapore Maime Designs PTEs LTD and constructed by Wuhu Changjiang River Shipbuilding Co., Ltd., the natural gas powered 49. 9 m long and 40TEU container ship manufactured in April 2010, and they were being delivered to the ship-owner. Eight units, including the Beijing oil Group and Jiangsu Science and Technology University, researched and developed the LNG-diesel dual-fuel power boat. In September, "Susuhuo1260" full load of 3 000 t sand, began her test voyage from the Suqian into Huai'an showing good economy and environmental protection characteristic.

In March 2011, the 3 000 t bulk carrier third “Changxun”, transformed by the Beijing ZTE and the Changhang Phoenix co. ltd, took a successful test in Chongqing on the LNG-diesel dual-fuel engine.

The production of gas engine power of Jinan of China Diesel Engine Power Plant ranges extended from 30kW to 4800 kW and technical indicators approaching or has reached the international advanced level. LNG-diesel dual-fuel power transformation successful test set a foundation for low-carbon environmentally friendly LNG Clean Energy towards marine applications.

3.2 LNG hybrid ship

LNG hybrid based on the existing ship diesel engine, set its dual purpose on saving fuel and reducing the emissions through replacing part of the diesel by LNG. It is added a LNG supply system and a diesel and LNG dual powered fuel injection system. LNG hybrid may realize two operation modes, which are the pure diesel fuel state and oil and gas dual fuel state, through the electronic transfer switch. Thus this method transforms the ship from the single diesel power to diesel-LNG dual fuel.

According to the introduction, with the transforming, "lujininghuo 2535" installed a 10 cubic liquefied natural gas tank in the bilge of the ship, whose length is 7 meter. The gas tank monster can store about 4.3 tons of liquefied natural gas, and the ship original oil tanks are still filled with 3 tons of diesel oil. Through the voyage test Zhangjiagang, natural gas replacement of diesel fuel efficiency reached 50%. Insider explained, ship and car are different. Because the ship diesel engine work with compression ignition combustion, while the cars depend entirely on the liquefied natural gas as an alternative fuel. This is only a test data, and to get be true, accurate effective data we should carry on the multiple tests and the comprehensive investigation.

According to the insider, "Before the transforming, as soon as the horsepower soup up, the dense smoke came out and pungent smell made surroundings cannot bear; while the roar of the engine in the cabin made the speaker cannot be heard clearly. After the" Lujininghuo2535 " using the diesel and LNG (liquefied natural gas) hybrid fuel, in addition to the fuel costs decreased, the most obvious phenomenon was that the black smoke emissions were much less, the cabin noise declined obviously and the operation was more smoothly. "

3.3 The advantage of the LNG-powered vessel

It is learned that the world's proven natural gas reserves can be mined for more than 200 years. While the life of the oil extraction by the present rate of consumption, is only 40 to 70 years. In theory, the cleanest fuel is liquid hydrogen combustion which only generates water. However, for a ship in need of high-power internal combustion engines, LNG is the ideal clean fuel. The main advantage of the LNG:

(1) Environmental protection. LNG, as a clean energy, burns to produced carbon dioxide, nitrogen oxides, sulfur oxides and other harmful gases which are less than burning gasoline, diesel, coal by 20% and above. LNG is a clean and efficient fuel, in line with the environmental protection of the shipping industry trend.

(2) Save money. The prices of LNG are generally around 75% of that of the diesel, 1 m^3LNG gas is similar to 1 L gasoline or diesel. LNG fuel ship would save about 25% cost comparing with the diesel fuel. The increased costs of the LNG device vary according to ship types and ship sizes. But it will all return in 1 to 2 years by the savings in fuel costs.

(3) Supply protection. Liquefaction provide the solution of long-distance transport of natural gas in the case of the absence of pipeline transportation. Many large domestic energy companies are actively preparing for the

construction of gas terminals and gas barge.

(4) Technology to mature. Whether the LNG successfully used in the ship mainly depends on the maturity of the LNG-diesel dual-fuel mainframe technology. China's LNG-diesel dual-fuel power machine began to apply the technology on land since 1982 and has matured. Many manufacturers product diesel engine are doing the test of the LNG fuel machine in the ship. There are many dual-fuel main engine with variety of power are via authentication of China Classification Society CCS certification.

(5) Give the relevant parties a great deal of market opportunities. With the development of the market and the technology matures, the dual-fuel technology will be widely used the new shipbuilding and transformation. It means that the ship machine manufacturing enterprises and the LNG storage tank manufacturing enterprises as well as river boat construction enterprises can find business opportunities in this emerging market.

(6) Emissions way meet a criterio**n** of international trends. From the year of 2010, fuel sulfur content of all ships calling at EU ports, shall not exceed the maximum limit of 0. 1%. At present, most of the Chinese ships who want to berth in EU ports commonly used two ways: First, turn off the engine to dock in advance; the other is changing low-sulfur fuel in the surrounding port. Therefore, using of LNG to replace diesel as a fuel would be an inevitable trend.

4 Cost evaluation of LNG-powered vessel applied in China

4.1 The forecast of the oil and LNG price in fifty years

4.1.1 The forecast of the oil price in fifty years

eia Source: U.S. Energy Information Administration

Cushing, OK Crude Oil Future Contract 1 (Dollars per Barrel)

Decade	Year-0	Year-1	Year-2	Year-3	Year-4	Year-5	Year-6	Year-7	Year-8	Year-9
1980's				30.66	29.44	27.89	15.05	19.15	15.96	19.58
1990's	24.50	21.50	20.58	18.48	17.19	18.40	22.03	20.61	14.40	19.30
2000's	30.26	25.95	26.15	30.99	41.47	56.70	66.25	72.41	99.75	62.09
2010's	79.61	95.11								

- = No Data Reported; -- = Not Applicable; NA = Not Available; W = Withheld to avoid disclosure of individual company data.

Release Date: 5/9/2012
Next Release Date: 5/16/2012

Table 5-The crude oil price in the last 30 years

Source: U.S. Energy Information Administration

Select our data, then use Insert > Chart, and chose the XY(Scatter) option.

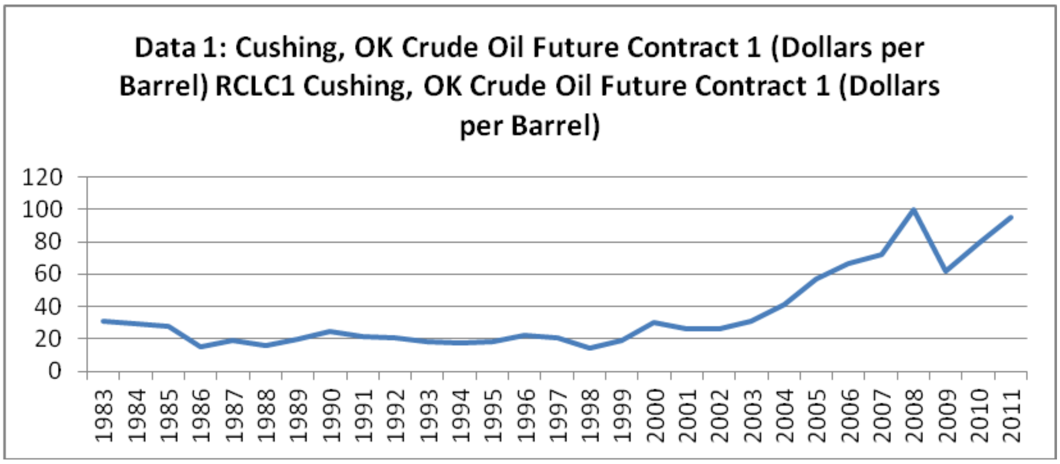

Figure 3-Crude oil price in the last 30 years

Source： U.S. Energy Information Administration (EIA)

Oil Forecast regression

In Excel, the Forecast function returns a prediction of a future value based on existing values provided

Create a trend line

Now, we have to select the relationship that seems to "fit" (i.e. best describe) our data. Here again, we use our eyes: In this case, the dots are not in a straight line, so we use the "polynomial" setting. Later on, we will use other - more complex, but often more realistic - settings, like "exponential".

Our trend line is now displayed on the chart. Then we choose the best one whose degree of fitting is 0.8966. The Polynomial is as below.

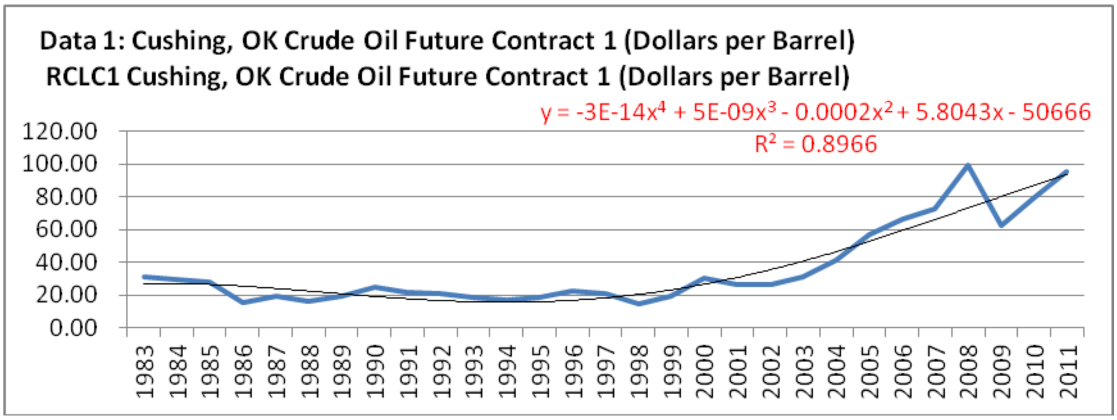

Figure 4-The oil price fitting line

Give the year number respectively to the fitting formula; we can get the table below:

L	M^3	Gallon（US）	Gallon（B）	Barrel	T
158.98	0.15898	42	34.973	1	0.24

1	0.001	0.26418	0.21998	0.00629	0.00151
1000	1	264.18	219.98	6.29	1.5096

Table 6-Volume unit conversion

Source: College Physics

Years	2010	2020	2030	2040	2050
Price/$/barrel	89.73633	140.3186	190.8667	241.3808	291.8608
Price$/t	659.562	1031.341	1402.87	1774.149	2145.177

Table 7-Long term oil price forecast

Source: The excel forecasting

Oil Prices Figure of New York Mercantile Exchange is as below:

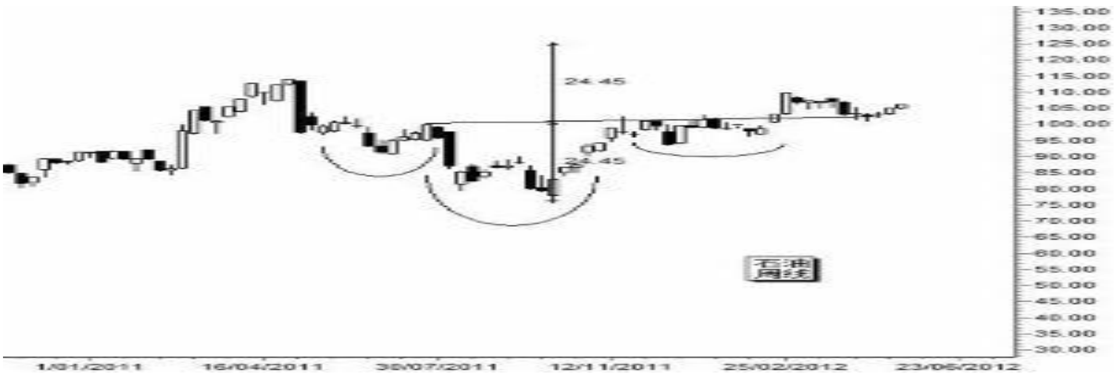

Figure 5-Oil price of New York Mercantile Exchange

Source: New York Mercantile Exchange

The graph of the New York Mercantile Exchange shows rising trend of oil prices may continue

The growth of oil price is expected to be a gradual slow down in long-term trends, followed by a slight decline and oil price volatility will become more rational. The main reason is:

(1) The economic growth of the world's major crude oil importing country will slow down. Slower rate of economic growth will enable the global oil demand growth rate slowed; the slowdown in oil demand growth is conducive to the increase of the global crude oil market supply and demand balance and OPEC spare production capacity, also better regulation of international crude oil prices.

(2) OPEC spare production capacity is expected to be improved in the future.

(3) Countries in the world focused on the development of alternative energy sources. Our government has been established in the energy planning great efforts to develop wind, solar, geothermal, biomass and other new and renewable energy policy in the past 15 years.

For these reasons, the oil price forecasts for the further integration of prediction are in the following table:

Years	2010	2020	2030	2040	2050
Price/$/t	659	1031	1399	1611	1822

Table 8-Oil prices after integration

4.1.2 The forecast of the LNG price in fifty years

Source: U.S. Energy Information Administration

United States Natural Gas Industrial Price (Dollars per Thousand Cubic Feet)

Decade	Year-0	Year-1	Year-2	Year-3	Year-4	Year-5	Year-6	Year-7	Year-8	Year-9
1990's								3.59	3.14	3.12
2000's	4.45	5.24	4.02	5.89	6.53	8.56	7.87	7.68	9.65	5.33
2010's	5.49	5.02								

- = No Data Reported; -- = Not Applicable; NA = Not Available; W = Withheld to avoid disclosure of individual company data.

Release Date: 4/30/2012

Table 9-The price of the natural gas in the last 20 years

Source: U.S. Energy Information Administration

Select our data, then use Insert > Chart, and chose the XY(Scatter) option. Now, we have to select the relationship that seems to "fit" (i.e. best describe) our data. Here again, we use our eyes: In this case, the dots are not in a straight line, so we use the "polynomial" setting. Later on, we will use other - more complex, but often more realistic - settings, like "exponential".

Our trend line is now displayed on the chart. Then we choose the best one whose degree of fitting is 0.8966. The Polynomial is as below.

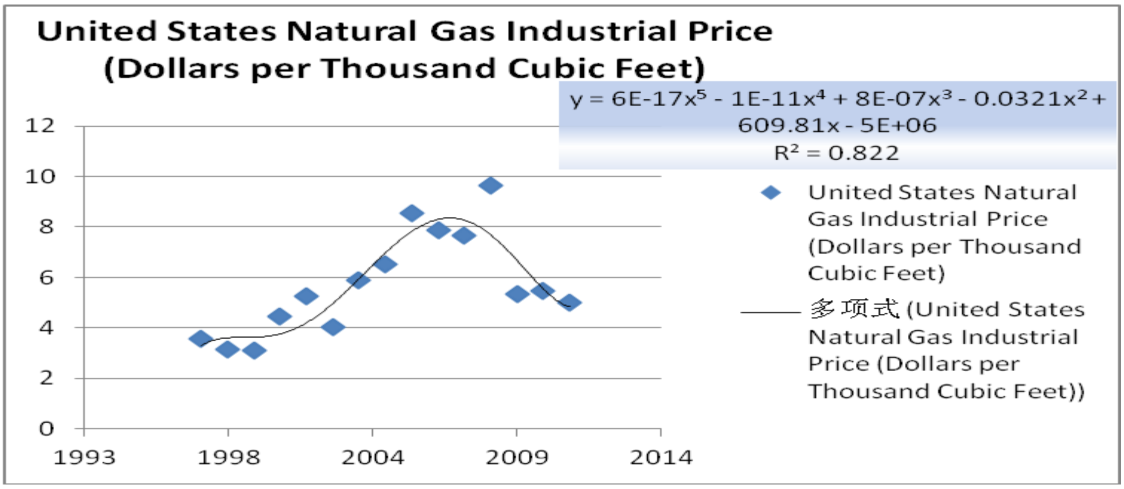

Figure 6-The LNG price fitting line

Source： U.S. Energy Information Administration (EIA)

Give the year number respectively to the fitting formula; we can get the table below:

Years	2010	2020	2030	2040	2050
Price/$/thousand cubic feet	16.08	23.12	27.28	32.88	42.08
Price/$/t	791.5539	1138.105	1342.885	1618.551	2071.43

Table 10-Long term LNG price forecast

4.2 The calculation of the oil consumption of different types of vessels

4.2.1marine Vessel voyage fuel consumption method

Vessel voyage fuel consumption calculation function(1)

$Q=Q_z+Q_f+Q_g$ (4.1)

In the function:

Q--------- Vessel voyage fuel consumption, unit is ton(t);
Q_z---------main engine fuel consumption, unit is ton(t);
Q_f---------power unit fuel consumption, unit is ton(t);
Q_g---------vessel furnace fuel consumption, unit is ton(t).

Vessel main engine fuel consumption calculation function(2):

$Qz=\sum_{i=1}^{m}(Q_{zi1}+Q_{zi2})$ (4.2)

In the function:

Qzi1--------- main engine fuel consumption of normal voyage, unit is ton(t);
Qzi2--------- main engine fuel consumption of maneuver navigation, unit is ton(t);
m----------- the number of sectors in the same voyage.

$Q_{zi1}=10^{-3}[\alpha+(1-\alpha)D_1/D_0]P_{z1}g_{ez1}t_1$ (4.3)

In the function:

α------------the influence coefficient of the ship load to the main engine fuel consumption, as follow table:

Vessel types	Liquid bulk carrier	Dry bulk carrier	General cargo ship	Container ship	Passenger ship
α 值	0.85~0.95	0.90~0.98	0.85~0.95	0.90~0.98	1

Figure 7-The influence coefficient of the ship load

Source: GBT 7187.1-2010 “The calculation oil consumption of the transport ship”

D_1-----------the actual ship load, unit is ton(t);
D_0-----------the rated ship load, unit is ton(t);
P_{z1}----------the power of the main engine at frequent running state, the unit is kw;
g_{ez1}--------the fuel consumption of the main engine at frequent running state, the unit is [kg/(kw.h)];
t_1------------the time at frequent running state, the unit is hour (h).

$$Q_{zi2}=10-3q_{zj}t_2 \quad (4.4)$$

In the function:

q_{zj}------------the fuel consumption per hour at maneuver navigation state, 40% of the main engine fuel consumption per hour at frequent running state, unit is kg/h;
t_2----------- the time at mobile navigation state, the unit is hour(h).

Ship generator fuel consumption calculation method function:

$$Q_f=Q_{f1}+Q_{f2}+\sum_{i=3}^{m} Q_{fi} \quad (4.5)$$

In the function:

Q_{f1}-----------diesel generator fuel consumption during the voyage, unit is ton(t);
Q_{f2}----------diesel generator fuel consumption during berthing, not tipping state, unit is ton(t)
Q_{fi}-----------additional fuel oil consumption for auxiliary engine

$$Q_{f1}=10^{-3}q_{f1}(t_1+t_2) \quad (4.6)$$

q_{f1}= diesel generator fuel consumption per hour during the voyage, 60% of rated condition of the generator, unit is kg/h.

$$Q_{f2}=10-3q_{f2}t_0 \quad (4.7)$$

In the function:

q_{f2}----------diesel generator fuel consumption per hour during berthing, not tipping state, 50% of rated condition of the generator, unit is kg/h;
t_0----------- berth, not tipping state time, unit is hour(h).

$$Q_{fi}=10^{-3}q_{fi}t_i \quad (4.8)$$

In the function:

q_{fi}----------additional fuel oil consumption per hour for auxiliary engine;
t_i------------the time of auxiliary engine using time.
Ship boiler fuel consumption calculation function

$$Qg=10-3q_gt_g \quad (4.9)$$

In the function:

q_g------------ship boiler fuel consumption per hour, unit is kg/h;
t_g------------boiler using time, unit is hour(t)

Note: (1) The specific route of the ship will not affect the final computation results of this thesis, so for simplicity, only to take a period of leg only for one day.

(2) The ship power data are the confidential data of the ship owners from the Lloyd List. The writer just used them to calculate, so the names use the vessel are Marine, Inner River and Dual fuel to instead.

Tonnages and Dimensions of a Marine Container Ship			
Gross Tonnage(GT)	90757	Length Overall	335.000
Deadweight(DWT)	137288	Length(BP)	320.060
Light Displacement tonnage(LDT)	34892.4	Breadth Mounded	42.800
Net Tonnage	57364	Draught	14.950
Formula Deadweight	139331	Depth	24.800

Table 11-Tonnages and dimensions of a marine container ship

Source: China Shipping Line

Devices	Main Engine	auxiliary boiler	Generator	Emergency Generator
Type	MITSUI-MAN	LSK5.5-0.7	W6L32	HC.M434F2

	B&W12K98MC-C			
Number	1	1	4	1
Rating/kW	68520		2880	375
Rotate Speed/rpm	104		720	1800
Consumption Rate/t/h	10.96	0.13~0.549		
Reserves Oil/t	11273.5			

Table-12 Marine power plant data

Source: China Shipping Line

After the calculation, the ship oil consumption is 275t/d

Further construction of large coastal LNG terminal will lead to China's LNG application of technology to further develop and refine. This also makes large-scale application of LNG powered ocean-going vessels become possible.

4.2.2Inland Vessel voyage fuel consumption method

Inland vessel voyage fuel consumption calculation function (10)

$$Q=Q_z+Q_f+Q_q \quad (4.10)$$

In the function:

Q--------- Vessel voyage fuel consumption, unit is ton (t);

Q_z---------main engine fuel consumption, unit is ton (t);

Q_f---------auxiliary engine fuel consumption, unit is ton (t);

Q_q---------the others' fuel consumption, unit is ton (t).

Vessel main engine fuel consumption calculation function (11):

Q_2= [α+(1-α)W_1/W_0]G_zt+ Q_m (4.11)

Q_z---------main engine fuel consumption, unit is ton(t);
Q_m---------main engine auxiliary fuel consumption, unit is ton(t);
W_1---------fact conversion operating weight of ships, t.km;
W_0---------rated conversion operating weight of ships, t.km;
G_z---------main engine fuel consumption per hour, kg/h,
t------------the regulation voyage time, h;
α-----------the main engine comprehensive consumption coefficients

Vessel types	Tanker	Bulk cargo barge	Container ship	Tugboat	Passenger ship
α	0.7	0.73	0.80	0.6	1

Table 13-The comprehensive consumption coefficients

Fact conversion operating weight of ships

$$W_1=\sum_{i=1}^{n} L_i D_{1i} \quad (4.12)$$

In the function:

W_1----------- fact conversion operating weight of ships, t.km;
L_i-----------sector distance, km;
D_{1i}-----------fact weight in each sector, t;
n-----------sector number

Rated conversion operating weight of ships

$$W_0=D_0\sum_{i=1}^{n} L_i \quad (4.13)$$

W_0---------rated conversion operating weight of ships, t.km
D_0---------rated weight, t;
L_i--------- sector distance, km.

Main engine fuel consumption per hour

$G_z=P_zg_z$ (4.14)

In the function:

G_z---------main engine fuel consumption per hour, kg/h;

P_z---------power of main engine at frequent state, kw;

g_z---------fuel consumption of main engine at frequent state, kg/kw.h.

The regulation voyage time

$t=\sum_{i=1}^{n} t_i$ (4.15)

$t_i= L_i /(v\pm u_i)$ (4.16)

In the function:

t------------the regulation voyage time, h;

t_i-----------the regulation voyage time of each sector, h;

L_i-----------sector distance, km;

u_i-----------average water velocity of each sector, km/h;

v------------the regulation ship velocity, km/h.

Main engine auxiliary fuel consumption

$Q_m= \sum_{i=1}^{n} G_{zj} t_{zj}$ (4.17)

In the function:

Q_m---------main engine auxiliary fuel consumption, unit is ton(t);

G_{zj}--------- main engine auxiliary fuel consumption per hour, t/h;

t_{zj}---------main engine auxiliary time, h;

m--------- the number of auxiliary work.

Auxiliary engine fuel consumption

$Q_f=G_ft_f+G_{f1}t_t+G_{f2}t_y$ (4.18)

In the function:

Q_f--------- auxiliary engine fuel consumption, unit is ton(t);

G_f---------auxiliary engine fuel consumption on sailing, t;

t_f--------- sailing time while auxiliary engine on, h;

G_{f1}--------- auxiliary engine fuel consumption at berth, t;

t_t--------- berthing time while auxiliary engine on, h;

G_{f2}--------- auxiliary engine fuel consumption at work, t;

t_y--------- working time while auxiliary engine on, h.

Auxiliary engine fuel consumption on sailing

$G_f=P_fg_f$ (4.19)

In the function

G_f---------auxiliary engine fuel consumption on sailing;

P_f---------power of the auxiliary engine on sailing, kw;

g_f---------auxiliary engine fuel consumption rate on sailing, t/(kw.h).

Uxiliary engine fuel consumption at berth

$G_{f1}=P_fg_{f1}$ (4.20)

In the function:

G_{f1}--------- auxiliary engine fuel consumption at berth, t;

P_f--------- power of the auxiliary engine at berth, kw;

g_{f1}--------- auxiliary engine fuel consumption rate at berth, t/(kw.h).

Auxiliary engine fuel consumption at work

$G_{f2}=P_{f2}g_{f2}$ (4.21)

In the function:

G_{f2}--------- auxiliary engine fuel consumption at work, t;

P_{f2}---------power of the auxiliary engine at work, kw;

g_{f2}---------auxiliary engine fuel consumption rate at work, t/(kw.h).

The others' fuel consumption

$Q_q=Q_g+Q_s$ (4.22)

In the function:

Q_q---------the others' fuel consumption, t;

Q_g---------fuel consumption of the auxiliary boiler, t;

Q_s---------fuel consumption of life equipment; t.

Tonnages and Dimensions of an Inland Ship			
Gross Tonnage(GT)	54263	Length Overall	243.820
Deadweight(DWT)	82488	Length(BP)	236.020
Light Displacement tonnage(LDT)	16387	Breadth Mounded	42.020
Net Tonnage	23219	Draught	13.051
Formula Deadweight	84058.2	Depth	19.200

Table 14-Tonnages and dimensions of an inland ship

Source: GBT 7187.1-2010 “The calculation oil consumption of the transport ship”

Devices	Main Engine	auxiliary boiler	Generator	Emergency Generator
Type	6L70MC	LSK5.5-0.7	W6L32	HC.M434F2
Number	1	1	3	1
Rating/Kw	16980		670	100
Rotate Speed/rpm	104		720	1800
Consumption Rate/t/h	2.95	0.13~0.549		
Reserves Oil/t	2252			

Table-15 Inland ship power plant data

Source: GBT 7187.1-2010 “The calculation oil consumption of the transport ship”

After the calculation, the ship oil consumption is 159.5t/d

Rolls-Royce said in the ship LNG fuel tank will not affect the deadweight tonnage and the quantity of goods of the vessel

4.2.3 Dual fuel vessel

Reederei Stefan Patjens Company of German combined with Det Norske Veritas is converting a 4-year age 5000TEU container ship to LNG fuel. The project is expected to be completed in the end of 2012. According to the introduction the two sets of auxiliary machine and auxiliary boilers will be replaced by the device using the LNG fuel, so that it can navigate in the emission control area. Cargo area near the engine room will be converted into a gas chamber, and added additional LNG containers on the deck, so that only the operation of the container can supply LNG.

Tonnages and Dimensions of a dual fuel Ship			
Gross Tonnage(GT)	5014	Length Overall	94.90
Deadweight(DWT)	6500	Length(BP)	83.00
Light Displacement tonnage(LDT)		Breadth Mounded	20.40
Net Tonnage	1521	Draught	7.90
Formula Deadweight	7089.07	Depth	9.60

Table-16 Tonnages and Dimensions of a dual fuel ship

Devices	Main Engine	auxiliary boiler	Generator	Emergency Generator
Type	Wärtsilä 6L32DF	LSK5.5-0.7	AMG 630 S10	SR4-368
Number	4	1	4	1
Rating/kW	2010		2160	117
Rotate Speed/rpm	720		720	1800
Consumption Rate/t/h		0.13~0.549		

Reserves Oil/LNG/MT	960	86

Table 17-Dual fuel ship power plant data

According to the calculation, the oil consumption of two sets of auxiliary machine and auxiliary boilers is 21.56 ton/day; the oil consumption of others is 53.27 ton/day. The total oil consumption is 74.83 ton/day.

The Heat value

The heating value or energy value of a substance, usually a fuel or food (see food energy), is the amount of heat released during the combustion of a specified amount of it. The energy value is a characteristic for each substance. It is measured in units of energy per unit of the substance, usually mass, such as: kJ/kg, kJ/mol, kcal/kg, Btu/lb. Heating value is commonly determined by use of a bomb calorimeter.

Common sense about heat value

1 calorie (kal) = 4.1868 joule (J)

1 large kal = 4186.8 J

Fuel types	Heat value				Density
	MJ/kg	kcal/kg	MJ/m^3	kcal/m^3	(kg/m$^{3)}$
Heavy oil	40.19	9599.22	34322.26	8197730.96	854
Diesel oil	46.04	10996.47	38213.20	9127066.02	830

Natural gas	55.44	13240.73	39.77	9498.90	0.7174
LNG	55.44	13240.73	24946.33	5958329.51	450

Table18-The heat value of the fuel

Source: College Physics

Notice: all the data are obtained under the standard condition, that is 0℃ and 101.325 kpa.

The densities of heavy oil and diesel oil are average value.

	Marine	Inner river	Dual fuel
Oil weight/ t/day	275	159.5	74.83
Heat value/MJ/day	12661000	7343380	3445173
Replacement rate/%	100	100	28.8
LNG weight/t/day	228.373	132.4563	17.897
		Oil weight/t/day	53.279

Table 19-The oil weight and LNG weight in the same ship

Source: Excel calculation

Years	2010	2020	2030	2040	2050
LNG Price/$/t	791.5539	1138.105	1342.885	1618.551	2071.43
Diesel Price/$/t	659	1031	1399	1611	1822

Table 20-The price of LNG and diesel

	Marine			Inner river			Duel fuel			
	Diesel cost	LNG cost	Saving rate	Diesel cost	LNG cost	Saving rate	Diesel Cost(BT)	Diesel Cost(AT)	LNG cost	Saving rate
2010	181225	180770	455	105110.5	104846	264	49312.97	35111	14166	36
2020	283525	259912	23613	164444.5	150749	13695	77149.73	54931	20369	1850
2030	384725	319494	65231	223140.5	185306	37834	104687.2	74537	25038	5112
2040	443025	367909	75116	256954.5	213387	43567	120551.1	85832	28832	5887
2050	501050	416096	84954	290609	241335	49274	136340.3	97074	32608	6658

Table 21-The cost if transferred

Source: Excel calculation

Notice: BT stands for before transform; AT stands for after transform

4.3 Carbon tax collection

4.3.1 The economic problem bring by carbon emission

The signing of the Kyoto Protocol changed the old rules of the international community. It made the free charge of carbon emissions become history. Carbon dioxide and other greenhouse gases will no longer be unfettered, uncontrolled discharge. The atmospheric environment will become a true sense of the common resource. It provides that between 2008 and 2012, the industrial carbon dioxide emissions of the world's major industrial countries should averagely decrease by 5.2% comparing with 1990. Among a large number of CO2 emission reduction methods, carbon taxes and carbon trading (i.e. greenhouse gas emissions tradable permits) are commonly used.

Carbon trading root in the differences of the abatement costs and emissions credits of the entities. Companies with emissions rights whose emissions have been reduced below the level of emissions law provision, can get emission credits to pay for other places where the standard emissions are higher than the permission of the law.

Obviously, carbon trading is different from the traditional demand control of the Government. The regulation right is grasped in the hands of manufacturers who can cut emissions with lower cost. So the fairness issue of emissions warrants has not been settled in a good solution. In this case, there come the increasing demands for carbon tax.

At present, Denmark, Finland, Netherlands, Norway, Italy and other countries has levied carbon tax. Among them, Denmark is the first country of the world levying carbon tax. In 1991 Denmark carbon tax passed and the tax rate in descending order were: transport, residential and commercial electricity, light industry, heavy industry. The carbon tax levied in the Nordic countries can be divided into "upstream" and "downstream". Upstream includes coal and lignite mining, peat extraction, the production of coke, petroleum products refining, nuclear fuel gas, the pipeline transportation of fuel gas, oil and natural gas extraction and ancillary services and electricity production, transmission and distribution. "Downstream" mainly includes manufacturing industry, railway transportation and fuels and lubricants, domestic fuel of other land transport, air transport, personal transport equipment. Now China is in a period of economic structural adjustment, economic growth relies heavily on industry, manufacturing and other traditional industries. Therefore, the carbon tax would be imposed within the range of "downstream" to avoid the loss of profits of the energy-intensive industries and to protect the competitive advantage of the related industries of China in the international market. To select downstream levying tax, on the one hand, will avoid the most adversely affects on export industries; on the other hand, give the energy user indirect signal, then save energy initiatively. Among the downstream, the transport industry bears the brunt of carbon tax. So China's carbon tax levying is just a matter of time.

The carbon tax is a consumption tax levied on a product based on the carbon content of fossil fuels or carbon emissions. If the tax rate is reasonable, the carbon tax is a direct and effective mean to internalize the external costs of greenhouse gas emissions, and better suited to solve the long-term environmental problems such as global warming. Carbon tax has effects on China's national economy, energy use, income distribution. There is some degree of controversy on the affections and the selection on the collection of objects. However, in the long run, carbon tax reducing the emissions of carbon is benefit to the nation and the people. Therefore, this paper estimates this consumption with the method of forecast.

country	Industrial diesel and gasoline	Industrial natual gas

Denmark	264	55
Finland	70	55
France	99	4
German	51	62
Dutch	132	106
Norway	99	180
Spain	132	15
Sweden	234	205
Japan	4	44

Table 22-Energy products carbon tax rates of some nation ($)

Source: Tsinghua Univ(Sci&Tech),2002,vol 42, No10

4.3.2 The optimal carbon tax

In theory, the carbon tax is intended to provide a carbon emission reduction incentive. While in practice there are other purposes, such as incentive-based purpose and raising funds for fiscal purposes. Therefore, these taxes are not the carbon tax of true sense.

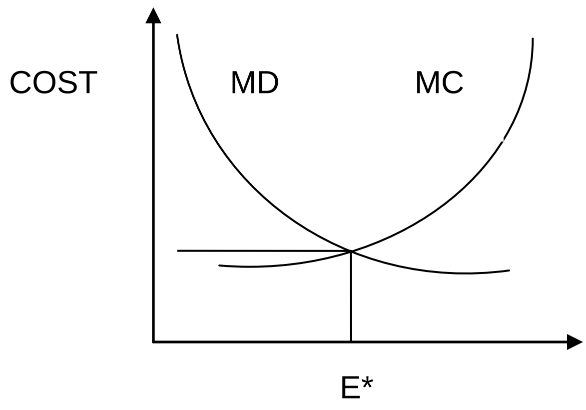

Figure 8- The best carbon tax and best carbon emissions

Theoretically, the carbon tax levying principle is shown as below. The horizontal axis represents the carbon emissions and the vertical axis represents the cost. Curve MC represents the marginal cost of carbon abatement, while curve MD shows the marginal damage of carbon emissions. The intersection of the two curves T * corresponds to the optimal carbon tax standard and E * is the best carbon emissions point.

However, for carbon emissions, to determine the damage and be quantification and monetization are very difficult. Thus we generally choose the sub-optimal emission to control costs smallest. First determine the world's largest carbon emissions quantity that can control of atmospheric CO_2 concentrations below the dangerous level. Then distribute the allocation of carbon emissions between countries or regions according to some rules. At last determine the carbon tax standards on the basis of carbon emission allowances. Each carbon emissions in the role of price signals for carbon tax will base on their carbon emission reduction cost function to choose the appropriate emissions. Countries adjust the carbon tax T* to control carbon emissions.

This section uses the MARKAL-MACRO model to select the optimal carbon tax T *. MARKAL-MACRO model coupling is made by the MARKAL and MACRO. MARKAL is a dynamic linear programming model based on the energy flow network diagram. It can make a detail description on carrier resources between the end-use of existing and alternative path with existing and alternative energy technologies. different paths and different energy cost, consumption and investment.

MARKAL-MACRO is an experiment in model linkage for energy and economy analysis. This new tool is intended as an improvement over existing methods for energy strategy assessment. It is designed specifically for estimating the costs and analyzing the technologies proposed for reducing environmental risks such as global climate change or regional air pollution. The greenhouse gas debate illustrates the usefulness of linked energy-economy models. A central issue is the coupling between economic growth, the level of energy demands, and the development of an energy system to supply these demands. The specific model is calculated as follows.

General assumptions under the baseline scenario are shown in the following Table. The idea on the economic and social development get results from the prediction and research of China's economic and social development and the strategic objectives of economic and social development of the Chinese government which come out from some international organizations and research institutions. This is the assumption on China socio-economic development with MARKAL-MACRO.

	2010	2020	2030	2040	2050
Population*Billion)	1.386	1.495	1.560	1.590	1.575
Urbanization**	42.4	51.4	58.4	65.0	70.0
GDP(billion $)	6048.37	14934.21	43128.96	76344.39	172613.41
GDP per capita($)	4363.9	9989.4	27646.8	48015.3	109595.8

Table 23-The forecast of the population and GDP in China

Resource：* Internal report of national economic information centre,

**IEA: Link between Energy and Human Activity

***Chinese government development goals, from internal report of national economic information centre

The author's studies on possible future global carbon emission quota allocation principles and methods show that 2050 China's carbon emissions limits were 1.846,2.131,1.282,1.737 Gt the per capita principle, to consider the per capita principle of historical responsibility, the principle of efficiency and the weighted average of per capita principle (mixed distribution), the per capita CO emissions baseline and at the same time taking into account the efficiency (hybrid allocation method 2), carbon emissions by 2030 under the baseline scenario for 1.655Gt2050 carbon emissions 2.394Gt. Relative to 2050 baseline emissions and emission reduction rates were 23, 11, 46.4 9/6, 27.4%. China's future carbon abatement cost is quite high, when the reduction rate of 0% to 45%, the marginal abatement costs of the carbon in the 0 to $ 250 / t, and the sooner the implementation of carbon emission reduction constraints in the equivalent emission reductions, carbon dioxide marginal abatement costs will be higher. The following are in 2030 began to implement a carbon tax policy is the basis of calculation.

Reduction rate and GDP losses in different carbon tax levels according to the fitting calculation

Carbon Tax Level $/t	**Carbon Emission Reduction Rate/%**				**the Loss of GDP/Billion $**			
	2020	2030	2040	2050	2020	2030	2040	2050
30	0.7	7.0	12.0	16.4	1.0	8.5	19.3	27.2
50	2.7	16.3	26.1	29.9	1.2	18.8	40.5	51.1
100	5.7	26.2	33.6	33.4	3.9	38.7	70.4	85.0
150	5.8	37.4	37.5	36.4	4.5	69.1	102.5	120.8
200	6.0	44.3	48.7	48.5	4.8	94.3	159.0	193.3

Table 24-Reduction rate and GDP losses in different carbon tax levels

An important finding is that carbon reduction effect is not significant when the carbon tax at the higher level, but the loss of GDP increases dramatically. Therefore the paper makes up a flexible index, reduction rates / loss ratio, to characterize the effect of a carbon tax on reducing emissions.

Carbon Tax	**the Loss of GDP/GDP**	**Reduction Rate/the Loss of GDP Rate**

Level $/t	2020	2030	2040	2050	2020	2030	2040	2050
30	0.01%	0.04%	0.05%	0.03%	5227	17759	23734	52038
50	0.02%	0.09%	0.11%	0.06%	16801	18697	24600	50500
100	0.05%	0.18%	0.18%	0.10%	10913	14599	18219	33913
150	0.06%	0.32%	0.27%	0.14%	9624	11672	13965	26006
200	0.06%	0.44%	0.42%	0.22%	9334	10131	11692	21655

Table 25-The loss GDP rate and the reduction rates over loss ratio

The table above shows that, at about $ 50 tax rates, the elasticity is the largest and emission reduction effect is the best.

A carbon tax is an important means to reduce carbon emissions, but carbon tax will lead to a large loss of GDP, so we need a optimal tax rate to make the GDP loss in an appropriate range.

The best tax rates, in accordance with the calculation results, the final choice $ 50. This data is the following ship carbon tax calculation data base.

	Marine	Inner river	Dual fuel
Oil weight/ t/day	275	159.5	74.83
LNG weight/t/day	228.373	132.4563	17.897
		Oil weight/t/day	53.279

Table 26-The oil weight and LNG weight

According to the information provided by BP China's carbon emissions calculator:

Save one liter of diesel = 2.63 kg CO_2 = reduction of 0.717 kg of carbon emissions

Save 1 kg of diesel oil = 3.06 kg CO_2 = reduction of 0.83 kilograms of carbon emissions

	Marine	Inner river	Dual fuel
LNG carbon emission	628	364	49
LNG carbon tax	31401	18213	2461
Diesel carbon emission	842	488	229
Diesel carbon tax	42075	24404	11449

Table 27-The LNG and diesel carbon tax

Source: Excel calculation

4.4 Construction and modification cost

LNG, as vessel fuel, will have to change the design and layout of the main engine and bunkers, cylindrical pressure tank required is about 3-4 times space of the diesel required. Special gas tank and cabin structure increase the storage weight of LNG, about 1.5 times that of marine diesel. The construction costs will increase about 8% -20% and maintenance costs will also increase.

5 Analysis on the pros and cons of the development of LNG-powered vessel in China in the future

5.1 The policy support from the government

Source: Jiangsu province transportation hall

The policy support from the government will undoubtedly propel the development of LNG-powered vessel. The first one is to develop the refueling station construction planning. To meet the demand of the diesel-LNG powered dual fuel ship, the government should recently carry out the LNG refueling station putting planning along the river. According to the principle of " boat after the vessel, two longitudinal and four transverse channel after the Grand Canal ", the government preliminarily planned, to gradually form the Grand Canal demonstration effect, 36 refueling station should be layout before 2013 in the Grand Canal of jiangsu section, and strive to layout no less than 100 refueling station along the two longitudinal and four transverse channel of Jiangsu before2015, making Jiangsu inland water transport green.

The second one is to research and formulate relevant technical standards. At present, China Classification Society (CCS) have finished “Guide of Gas Fuel Dynamic Vessel Inspection "(draft for approval), the diesel-LNG dual fuel power systems" Operating Manual " and the “Crew Safe Operations and Maintenance Notice " protocolled by Jiangsu blue Marine power Co.LTD.

For the smooth realization of the LNG application and promotion on transport ships, the government will further research the relevant technical standards, mainly including two aspects: one is to further complete the codes and standards system, fully pushing ahead the publishment of “Guide of Gas Fuel Dynamic Vessel Inspection; speeding up the certification and accreditation of the modified shipyard assessment and shipping facilities equipment product; further improving the operational guidelines of the crew and carrying out the crew training and issuing certification work.   The second one is to realize ship transformation technology standardization, further optimizing of the design of the tanks and pipeline. Aiming at different types and different tonnage of ships, the government should put out different design schemes and formulate relevant construction procedure to realize the standardization of the design and construction.

The third one is to publish relevant supporting policies. In the early pilot promotion, the relevant supporting policies mainly include three aspects: the first one is the capital support. Through the methods of establishment of special subsidy funds, government discount and passing fee cuts, the government give appropriate capital support in the early promotion of diesel-LNG dual fuel dynamic modification ships. The second one is land policy support. The government gives appropriate policy support on land requisition of LNG station and fuel depots along the river. The third one is to establish the project of work coordination mechanism. The government takes the central treatment and one-stop processing way to simplify the process, aiming at the LNG station putting planning and project examination and approval, shipping facilities equipment and crew license issuing.

5.2 The application problem analysis of the LNG-powered vessel in China

(1) Weak endurance. LNG fuel ships still cannot meet the need of ocean transport for the LNG storage tank is large. LNG storage tank system is complex and difficult to distribute. It is very difficult to design and reconstruction of the ship. Therefore, the current LNG technology is limited to be applied in inland ships and coastal ships.

(2) Application to the ship is still not completely covered all the ship types. As the gas tanker is large, some ships with small space on the deck of the ship, such as container ships, may have to lose some container capacity.

(3) Matching supply facilities are expected to be increased. The current global LNG terminal is only 303(source: LNG journal 2009(6)), far from large-scale coverage and cannot effectively meet the needs of sailing ship gas. China's inland and coastal are lack of LNG fuel and power ship refilling piers or barges, and urgent need to intensify construction.

(4) Filling technology also faces some problems. Due to the high tide and ebb tide, the ship parking location Cannot be determined, LNG pipeline, the low-temperature pipeline, is not easy to extend and retractable. Ship to ship aerated, still faces many technical challenges to be overcome. Therefore, the LNG stations must be scientific planned and constructed to ensure a stable supply of LNG and leading a rational pricing mechanism.

(5) Further standardize the market of dual-fuel ships and machine. March 16, 2011, the China Classification Society website issued “gaseous fuel-powered ship Inspection Guide” for Approval, making the dual-fuel ships took the

LNG-diesel dual-fuel internal combustion engine as a power-driven. Marine LNG single fuel machine development needs to conduct in-depth study of related businesses, to overcome technical difficulties and accelerate the development process, making the gases emitted more environmentally friendly and cleaner.

6 Research of the prospect of the LNG-powered vessel

In the modern days, the price of oil is rocketing and the whole world advocate the concept of low carbon. Beyond all doubt, LNG power ships will flourish. Because of the International Maritime Organization (IMO) has implemented the new rules on marine emissions, that is, from January 2015, the ships sulfide emissions limits should decrease from now 1% to 0.1% in some areas. Then the shrewd owners will explore the cleaner fuel more fully for the ship. It is predicted that the LNG-powered vessels will be added 10 times in the coming five years. By 2015, global LNG fueled ship will increase to about 800 ~ 1 000.

6.1 Study of LNG cold energy utilization

LNG is -162 ° C cryogenic liquid mixture obtained from the purification and liquefaction of the natural gas. When 1 ton of LNG is vaporized in standard atmosphere, it can release about 230kWh cold energy from -162 ° C to 5 ° C.

Recycling the cold energy in this process is called LNG cold energy utilization.

A LNG receiving terminal of 3 million tons / year can use cold power of 65MW deducting the loss of pressure energy, equivalent to about 1 billion kWh electrical energy .

At present, China's LNG imports reached 10 million tons / year. The cold energy existed is equivalent to about 3.3 billion kWh / year of electrical energy. The cold energy will make a decrease of 340,000 tons of carbon dioxide emissions if used. In accordance with the international level market price of 8 Euros per ton to calculate, year additional carbon dioxide emissions reduction will be about 2.72 million Euros (about 23.2 million yuan).

The cold energy projects of Guangdong Shunde Ganghua Gas Company have been put into operation in Shunde Xingtan LNG satellite station. The company uses the cold energy for cold storage (-30 ° C freezer and -15 ℃ vault whose capacity of a total is 3000 tons). Liu Zongbin, the company's supply operations manager, said they also plan to enlarge cold storage up to 8000-9000 tons, and plan to carry out cold work business.

The world's LNG cold energy utilization projects is almost single user, rarely have more user-integration projects. So far, only 20% of the LNG cold energy can be arranged to use for utilization accounting for only 8% of the total cold energy of LNG.

According to the completed plan, the LNG cold energy comprehensive utilization will reach more than 70% and effective utilization can strive to achieve 30-40%. After extensive research, we believe that the use of plate-fin heat exchanger and low temperature difference process will be able to achieve better temperature correspond and cascade utilization to maximize the recovery rate of cooling capacity.

What’s the effect ,if we use the cold energy utilization on the LNG fuel ship?

6.2 Future Prospect: Flammable Ice

Natural gas hydrates, known as the 21st century strategic resources with commercial development prospects, is a new energy-efficient energy whose composition is similar to the natural gas that people usually use, but purer. While mining, the workers just warm and decompress the solid gas hydrate to release large amounts of methane gas. According to the Potential gas confederation (PGC, 1981), the estimated quantity of gas hydrate resources is 1.4×10^{13} $3.4 \times 10^{16} m^3$ in the permafrost zone. The total resources are 7.6 × $1018m^3$ including the marine gas hydrates. Only in the seabed area, the distribution of combustible ice area reaches 40 million square kilometers, accounting for 1/4 of the total area of the Earth's oceans. At present, the number of the combustible ice distributions found in the world is up to 116. The thickness of its seam and large scale both cannot be compared by the conventional natural gas fields. Scientists estimated that the seabed combustible ice reserves can at least meet the need of human for 1000 years. On the morning of May 1, 2007, China sampled successfully in the northern part of the South China Sea for the first time, confirming that the northern South China Sea are rich in natural gas hydrate resources. Chinese geological department announced in September 2009, the environmental protection and new energy called flammable ice (also known as gas hydrates) found in the Tibetan Plateau, was expected to put into use a decade or so. This is China's first time found combustible ice on the land, so that China has become the third country who had passed the plan on drilling combustible ice after the United States and Canada. Rough estimated, vision resources reserve at least 35 billion tons of oil equivalents.

According to the incomplete results of the existing test mining data, the cost of mining combustible ice is very high, up to $ 10 for the cost per cubic meter of natural gas, and $ 200 / barrel equivalent if converted into oil. Of course, the conclusion only obtained in the case of small-scale test mining, and cannot be admissible. When the combustible ice mined in large-scale, the cost will naturally and significantly go down. Coal, oil and other fossil energy exploitation of the gas all follow this principle, so does the naturally combustible ice.

But each coin has two sides. Exploitation of gas hydrate will change the temperature and pressure conditions it relies on resulting in the decomposition of gas hydrate. During the mining process of combustible ice, if the temperature and pressure conditions cannot be effectively controlled, it may trigger a series of environmental problems, such as the intensification of the greenhouse effect, changes in the marine ecosystem, undersea slump and so on.

Consolidation of the hydrate and marine sediments can change the physical properties of sediments once the methane gas released from the hydrate because of the changing of conditions. Then it can greatly reduce the engineering mechanical properties of seabed sediments and soften the seabed leading to large-scale submarine landslides and destruction of seabed engineering facilities, such as: undersea transmission or communication cables and offshore oil drilling platforms. Therefore, the exploitation of combustible ice is still unresolved technical problem. The scientists believe that once there come a breakthrough in mining technology, combustible ice will immediately become a major source of energy of the 21st century.

7 Conclusions

The paper focuses on the LNG-powered vessel, calculating the cost concerning to the different fuel and comparing the different cost in different ships. The author researched the present situation of China and looked forward in the future. This paper uses prediction methods to get the trends of the oil and liquefied natural gas price in the next fifty years and predict the future choice of the carbon tax price with MARKAL-MACRO model.

7.1. The economic cost

To sum up the carbon tax and fuel consumption cost, the author obtained the following table:

	Marine			Inner river		
	Diesel cost	**LNG cost**	**Reduction rate**	**Diesel cost**	**LNG cost**	**Reduction rate**
2010	223300	212171	4.98%	129514	129250	0.20%
2020	325600	222845	31.56%	188848	175153	7.25%
2030	426800	301987	29.24%	247544	209710	15.28%
2040	485100	361569	25.47%	281358	237791	15.48%

2050	543125	409984	24.51%	315013	265739	15.64%

	Duel fuel			
	Diesel Cost(BT)	Diesel Cost(AT)	LNG cost	Reduction rate
2010	60761	46560	16627	0.69%
2020	88598	66380	22830	1.33%
2030	116136	85986	27499	2.28%
2040	132000	97281	31293	2.60%
2050	147789	108523	35069	2.84%

Table 28-The total cost

Source: Excel calculation

The following conclusions can be drawn from the entire table:

The LNG average daily cost of the whole table is less than the diesel-powered ship, due to price differences. With time flies, the reduction rate is growing. The max reduction rate is 29.24% in 2030.

The LNG applied on marine ship has the obvious advantage. Take an one hundred million ship as an example, the construction cost is 15% high than the diesel-powered ships. It just needs to take 5 years to cover up the redundant cost. The modification cost of the duel fuel ship is very small.

According to the practical experience, the cost recovery takes about five years.

7.2 Environment and fuel resource involved

From the above sections, LNG-powered ship is with the obvious economy. LNG is more conducive to the environment, so the characteristic increases its value. LNG cold energy utilization is a considerable income for the ship owner. World LNG reserves are not more than the oil, but because of the discovery of combustible ice, natural gas is inexhaustible in quite some time. We can clearly foresee the prospect of LNG-powered ship is very broad

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Appendix1–The Horizontal Comparison of the Consumption of Fuel

Due to the data limitations, this paper only conducts the vertical comparison of the fuel saving rate, and there is no. So the author adds the fuel saving rate at different ship speeds.

The experimental data show that with the increasing speed and load, fuel consumption goes down in the state of mixed fuel. When the replacement rate increases from 45.21% to 84.88%, the oil pressure and temperature remain basically unchanged, but the water temperature and exhaust gas temperature slightly decrease and the value of smoke significantly decreased. Select the rotate speed 800, 1000 and 1 200 r / min as the calculation state from the experimental data. The price of diesel is \$ 7360 / t, and the price of LNG is \$ 5000 / t. The calculation of consumption of pure diesel fuel and mixed fuel are as shown in the table below. We can obtain the fuel cost saving rate.

The table of economic benefits analysis						
Engine behavior		Pure diesel	Dual fuel			Fuel cost saving rate/ %
Rotate speed/ $r.min^{-1}$	Power / kW	Diesel consumption/ $kg.h^{-1}$	Diesel consumption/kg. h^{-1}	Natural gas consumption/kg. h-1	Replacement ratio/ %	
1200	397	73.38	13.5	58.31	84.88	27.6

1000	230	43.95	11.56	31.05	77.73	25.7
800	118	23.79	9.13	14.21	66.90	21.0

From the test data and benefit analysis table we can see that the mixed fuel engine power and fuel diesel are equivalent, therefore, its power performance can meet the marine propulsion needs of the main engine and greatly improve the economy. The fuel cost saving can reach 27.6% at the rated speed. In addition, due to the heat load decrease when using mixed fuel, exhaust smoke is greatly reduced and cylinder carbon deposits are rarely. So it can reduce the wear between the cylinder and piston, which is conducive to extend engine life while dramatically to improve the environmental performance of diesel engines

Appendix1- The Introduction of Wärtsilä Company

Wärtsilä has been at the forefront in the development of highly efficient dual-fuel engine technology, allowing the same Wärtsilä 34DF engine to be operated on either gas or diesel fuel with full U.S. Environmental Protection Agency (EPA) emissions compliance. This dual-fuel capability means that when running in gas mode, the environmental impact is minimized since nitrogen oxides (NOx) are reduced by some 85 percent compared to diesel operation, sulphur oxide (SOx) emissions are completely eliminated as gas contains no sulphur, and emissions of CO2 are also lowered. Natural gas has no residuals, and thus the production of particulates is practically *non-existent.*

The shipping industry finds the operational savings that gas offers to be very compelling. When comparing the price levels of various fuels, and especially low sulphur marine fuel, gas is an obvious economic alternative. Similarly, the significant environmental benefits that LNG fuel provides are of increasing importance. Drawing from decades of experience in the development and application of natural gas engines for both the power generation and marine industries, Wärtsilä is the global leader in this advanced technology. Wärtsilä's dual-fuel engines, used in both land-based and marine applications, recently passed the significant milestone of 5 million running hours.

In August 2010, Wärtsilä announced that it had signed a turnkey project with Tarbit Shipping to convert the Bit Viking to LNG operation. The scope of the conversion package from Wärtsilä included deck-mounted gas fuel systems, piping, two six-cylinder Wärtsilä 46 engines converted to Wärtsilä 50DF units with related control systems and all adjustments to the ship's systems necessitated by the conversion. The Bit Viking was the first product tanker conversed by Wärtsilä from heavy fuel oil to liquefied natural gas (LNG) operation. The vessel's classification certificate was also updated. It was the first LNG fuelled vessel to be classified by Germanischer Lloyd. Handed over to Tarbit Shipping in October 2011, the Bit Viking is operated by Statoil along the Norwegian coast. The conversion carried out by Wärtsilä enables it to qualify for lower NOx emission taxes under the Norwegian NOx fund scheme, a cooperative effort whereby participating companies may apply for financial support in return for introducing NOx reducing measures. According to Wärtsilä Company, it is the first marine installation in the world to involve converting Wärtsilä 46 engines to Wärtsilä 50DF engines, and the first 50DF *marine installation with mechanical propulsion. By operating on LNG, the Bit Viking becomes one of the most environmental friendly product tankers in the world.*

In May 2011, Wärtsilä, the marine industry's leading solutions provider, had been contracted by Kleven Maritime of Norway to design a new LNG powered Platform Supply Vessel (PSV) of the Norwegian operator Rem Offshore. The scope of the order also includes the propulsion machinery, automation and other equipment for the same vessel. Rem Offshore's new LNG powered PSV, the first such vessel for its fleet, will be a Wärtsilä Ship Design VS499 LNG PSV, a state-of-the-art vessel based originally on the successful VS489 LNG PSV design. The ship features outstanding energy efficiency, a unique hull form, fuel flexibility, and exceptional performance in areas such as fuel economy and cargo capacity. In addition to the complete design of the vessel, Wärtsilä's scope of supply for the new PSV includes the dual-fuel main engines and generating sets, the electrical power and propulsion systems, integrated automation, and the power management system.

In October 2011, Wärtsilä had been awarded a contract to deliver an integrated propulsion system for two additional LNG offshore support vessels (OSV) to Harvey Gulf International Marine. This order took Harvey Gulf to a fleet of four LNG OSVs on order, establishing the company as the world's second largest operator of LNG powered OSVs. Wärtsilä will deliver an integrated system that includes the dual-fuel machinery, electrical and automation package, complete propulsion, and also the LNG fuel storage and gas conditioning system. The LNG storage capacity provides for more than a week of vessel operational time.