Methanol New Energy Applications in China: Boilers and Cook Stoves

甲醇新型能源应用：锅炉和灶具

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Methanol Institute

EXECUTIVE SUMMARY

As with many developing countries looking to keep the lean balance between economic growth and environment protection, China has a soaring demand for fuel and is facing the most challenging air pollution situation since its industrialization. Methanol, one of the most abundant chemicals and fuels in China, is being used as a clean-burning alternative fuel in industrial boilers and cook stoves.

According to recent studies, the direct burning of coal either for domestic uses like heating and/or cooking or industrial purposes is the main contributor to air pollution particularly for Northern China population centers, like Beijing, Tianjin, Hebei and Shandong. In just the past several years, the commercial introduction of methanol-fueled industrial boilers and cook stoves have emerged as important tools for Chinese leaders looking to address air pollution challenges.

Industrial boilers are a widely used pressure vessel which burns fuel and transmits the heat to produce hot fluid or steam. China has over 600,000 boiler units which consume over 700 million metric tons (MMts) of coal each year. Those with the capacity to produce 10 tons/hour (t/h) of steam have numerous applications from manufacturing, pharmaceuticals, to residential buildings, providing heat and steam, account for 80% of the total population of boilers. Unfortunately, these units largely lack any emission controls, and hence have a much higher impact on air quality compared other pollution sources. Even worse, low quality coal with higher content of sulfur and ash aggravates this situation due to its low retail price.

Eliminating smog in major Chinese cities for the people's better lives is regarded as a significant task for the central government. National plans/policies have been continuously issued by the State Council such as "Ten Measures of Air Pollution Control" and "Air Pollution Control Action Plan" to reduce direct coal burning at all levels. Chinese local governments are closing down unqualified boilers, especially those within 10 steam t/h capacity, and introducing new alternatives like natural gas, electricity, biomass and other new energies.

Methanol has begun to be used as an affordable clean alternative in this clean air movement. Neat methanol, usually compounded with other additives, forming "alcohol based fuel" can be combusted in retrofitted gaseous/liquid boilers (mainly involving changes to the combustion component, called a burner, with capacities around 10 steam t/h). Emission tests from such boilers in different parts of China have shown the emissions from methanol combustion in these boilers can easily meet the strictest pollutant limit for key regions like Beijing in the latest "Emission Standard of Air Pollutants for Boilers (GB13271-2014)."

In the theoretical economic analysis, such boilers are compatible to electricity which is not subsidized for commercial use. While natural gas retail price varies in different regions of China and industry/business purpose, the boiler fuel economics of methanol and natural gas are similar for domestic and industrial markets. To be noted, for a new build boiler fueled by natural gas, there are additional costs for pipelines and connections that can be considerable and fall upon the consumers, which reduces the competitiveness of natural gas to liquid methanol, which can be easily distributed and stored. Some cases of methanol boilers for different applications in regions around Shanghai, Xi'an and Tianjin are introduced with users' fuel cost comparison.

Since 2012, we estimate the total number of methanol boilers introduced for commercial use across China is more 1000 units, consuming over 500,000 metric tons of methanol annually.

Chinese cooking traditions require cook stoves to generate large heat flow in a short time for stir frying. Due to the lack of natural gas pipelines and limited liquid petroleum gas (LPG or propane) coverage, methanol cook stoves have quickly developed in Chinese restaurants, central kitchens and other catering businesses with different heat powers and functions. Methanol cooking fuel, usually blended with additives and water is sold to increase the heat value, reduce costs, and enhance the fuel flow.

Two national standards, "Alcohol Base Liquid Fuel (GB16663-1996)" and "Domestic Alcohol Base Cook Stove (NY312-1997)" have been issued by the Ministry of Agriculture. However, these standards are not methanol specific and have not been updated for a long time. The direct burning of coal as a cooking fuel in China is also regarded as a major air pollution contributor, and governments are calling for clean cooking fuels especially in urban areas. Gansu Province and Tianjin City have included methanol as a cooking fuel, and released supportive policies to promote methanol. In emissions testing, methanol cooking fuels have strong benefits in nitrogen oxides (NOx) and particular matter (PM) reduction.

Due to pricing advantages, methanol is mainly competing with LPG to reach markets where pipelined natural gas is not available. This is realized by a distribution chain of methanol cooking technology companies, franchisees (suppliers), and end customers. In fact, methanol cook stoves and fuels are readily available for purchase from the Internet in China. The wide availability of methanol cook stoves has led to a surge of methanol demand in China with consumption already reaching more than 3 million metric tonnes of methanol. In rural areas of China, methanol cooking fuel also has potential to replace biomass and bio-gas from agricultural waste.

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1 METHANOL BOILERS

1.1 OVERVIEW OF METHANOL BOILERS

A boiler is a type of energy conversion device that uses the chemical energy of a fuel or other energy sources to heat water and/or generate steam. Boilers are widely used in China, to generate heat in the processes of manufacturing, food production, and hot water for bath, or to generate steam for sterilization and dehydration. The boiler design includes the boiler proper (main components), auxiliary and safety devices. The two major components of the boiler proper are the "boiler drum" (water vessel for heating over a flame) and the furnace (combustion chamber and burner) as shown in Figure 1-1. Based on the sources of primary energy in the furnace, boilers are classified into coal-fired boilers, pulverized coal boilers, oil boilers, gas boilers, dual-use gas boilers, and electric boilers, etc. Based on evaporation capacity, they can be classified into: small boilers of less than 20 tons of steam per hour (t/h), medium-sized boilers of between 20 t/h to 75 t/h and large boilers of more than 75 t/h. Currently in commercial practice in China, methanol fuel can convert up to 10-15 steam t/h in a boiler.

A methanol boiler is similar to a natural gas or oil burner where the burner has been designed to use methanol, which is a clean and efficient fuel. Methanol is a liquid alcohol with a simple structure (CH3OH) consisting of oxygen atoms in the molecule which facilitate combustion. Methanol contains very low amounts of impurities and can be easily purified. Under proper combustion control, methanol fuel hardly emits any sulphur compounds, nitrogen compounds, particulates and other pollutants. Combustion of the fuel is primarily through an atomised combustion method. Like other liquid fuels, methanol is pumped from a storage tank into the burner/furnace, and an atomisation technique in the burner ensures that the liquid is broken down into droplets to facilitate thorough mixing with air to aid in the combustion. The better the atomisation, the smoother the combustion. The smaller the droplets, the greater the surface area will be and the easier it is to mix with the air. Combustion will be more complete, which in turn increases the combustion temperature and efficiency. As a simple molecule, methanol conserves fuel and significantly reduces the emission of harmful substances.

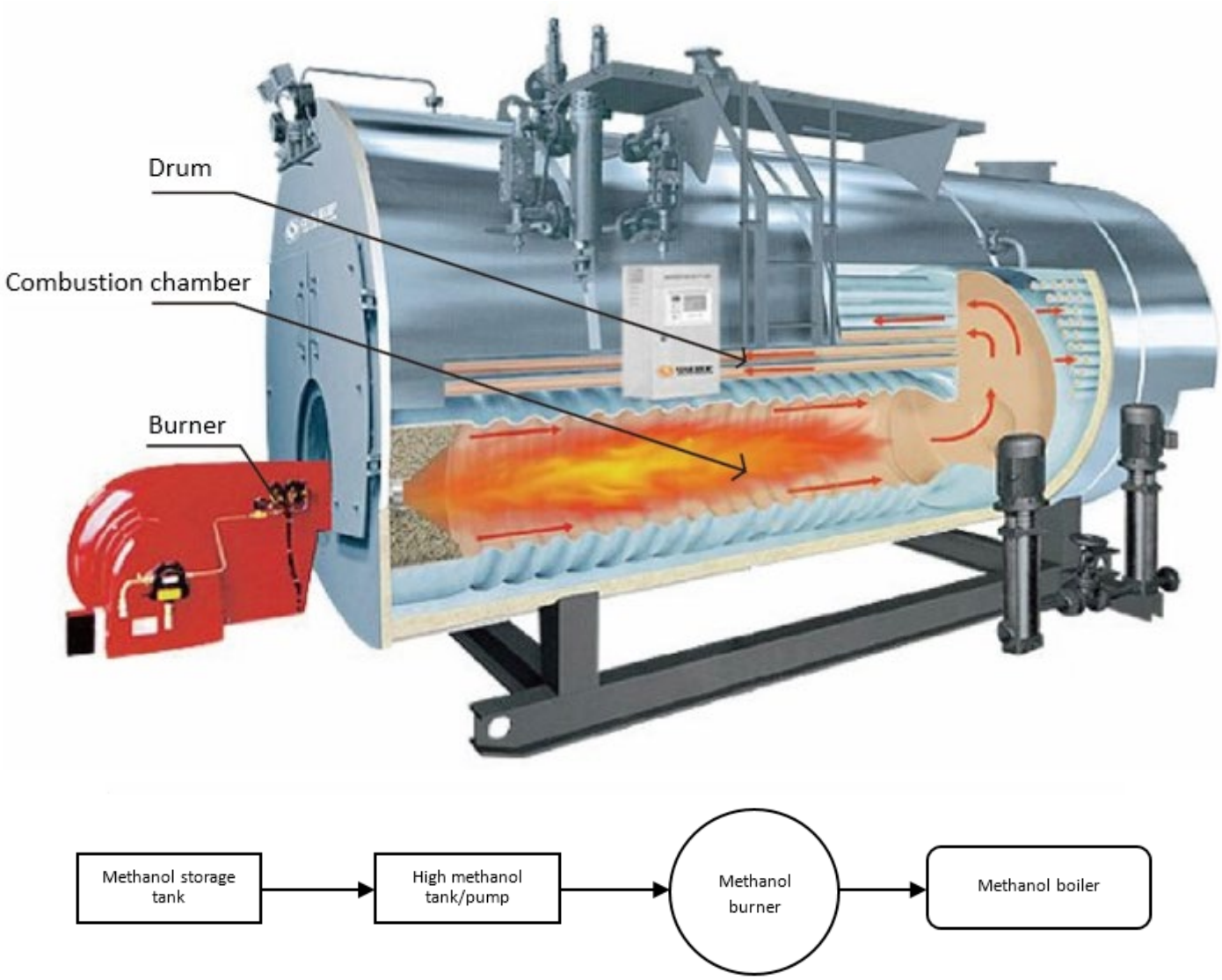


Figure 1-1: Flowchart of a Methanol Boiler and its Basic Structure

1.2 STANDARDS AND POLICIES

1.2.1 STANDARDS

In China, boilers are regulated by different standards for product quality, safety, emission, etc. Relevant standards that are based on the prevailing regulations and technical standards for methanol boilers in China are summarized in Table 1-1.

Table 1-1: Relevant Chinese Standards on Boilers

Name of Standard	Standard Number
A. Product Standards	
General Technical Conditions for Atmospheric Hot Water Boilers	JB/T7985-1995
Industrial Boiler Water Quality Standard	GB1576-2001
Industrial Boiler Thermal Performance Test Procedures	GB/T10180-2003
Technical Conditions for Industrial Boilers	JB2816-80
General Technical Conditions for Industrial Boilers	JB/T10094-2002
Technical Conditions for Boiler Pressure Test	JB/T1612-1994
Steel Pressure Vessels	GB150-1998
Environmental Testing for Boilers	GB4427-89
Air Pollutant Emission Standard for Boilers	**GB13271-2014**
Regulations for Safety Technical Supervision of Hot Water Boiler	LMCZ[1997]No.74
Regulations for Steam Boiler Safety Technical Supervision	LM[1996]No.276
Stipulations on Safety Supervision of Small Size and Normal Pressure Hot Water Boilers (2000)	
Regulations on Supervision and Administration of Manufacture of Boilers and Pressure Vessels	AQSIQ Decree No. 22
Regulations of the People's Republic of China on Supervision and Administration of Import and Export of Boilers and Pressure Vessels	
Rules for Construction of Power Boilers	American Standard: ASME Section I
Pressure Vessels	Division 1, Section VIII
Pressure Vessels - Alternative Rules	Division 2, Section VIII
Technical Specification for Steam Boilers	French Standard: BV Certification
Technical Specification for Pressure Vessels	
Pressure Vessel Standards	
B. Design Standards	
Boiler Room Design Specifications	GB50041-1992
City Gas Design Specifications	GB50028-1993
Urban and Regional Environmental Noise Standard	GB3096-93

Name of Standard	Standard Number
C. Engineering Standards	
Code for Acceptance of Construction Quality of Industrial Metallic Piping	GB50235-1997
Code for Construction, Installation and Acceptance of Industrial Boilers	GB50273-1998
D. Atlas of Relevant Standards	
Gas (Oil) Boiler Room Engineering Design and Construction Atlas	02R110
Small-scale Vertical and Horizontal Tank Atlas	02R111
Tank Vault Atlas	02R112

To cope with the air pollution challenges caused by boilers, in 2014 the National Ministry of Environment Protection (MEP) issued an updated boiler emission standard with the strictest ever emission limits, see Table 1-2. In the end of 2015, MEP classified methanol (alcohol based fuel) boilers into the same category as oil-fired boiler (liquid fuel category) for emission regulation[2].

Table 1-2 :
PM, SO2 and NOx Emission limits regulated in the GB13271-2014 standard (Unit: mg/m3)

	Effective for the **In-use Boilers** since 1st of July, 2016			Effective for **New Boilers** since 1st of July, 2014			Effective in **Key Regions** when needed and regulated by MEP or provincial government*		
Fuel	Coal	Oil	Gas	Coal	Oil	Gas	Coal	Oil	Gas
PM	80	60	30	50	30	20	30	30	20
SO_2	400	300	100	300	200	50	200	100	50
NO_X	400	400	400	300	250	200	200	200	150

*Key Region means the region which is densely developed with decreasing environmental supporting capacity OR relatively limited atmospheric environment capacity and fragile ecological environment. Severer air pollution issues tend to occur in it hence stricter pollutants are needed, i.e. “special limitation for air pollutants”.

[2] Ministry of Environment Protection pf PR China, http://www.zhb.gov.cn/gkml/hbb/bh/201512/t20151228_320576.htm, latest subscription date:2016/7/21

1.2.2 POLICIES

1. National Policies

Coal boilers are the primary source of air pollution in many Northern and manufacturing centered areas in China due to the inefficiency of the equipment and low quality of the coal used. In recent years, incidents of serious haze in many regions across China have led to the promulgation and implementation of planning studies, programs, and action plans on air pollution control at the State, provincial (autonomous regions and municipalities), district and county levels. These documents have identified the governance and reformation of high-polluting boilers as key tasks and proposed new energy and other alternative fuel boilers. The "Air pollution control action plan" issued by the State Council, also set clear objective to urge boiler reform: "in the city-level urban areas, coal fired boilers less than 10 t/h should be basically eliminated by 2017, new coal fired boilers less than 20 t/h are not allowed; in other regions, new coal fired boilers less than 10 t/h are not allowed in principle." More such policy details are listed in Table 1-2.

Table 1-3: China's Policies on the Boiler Industry

National Policies	Document Number	Date of Issue	Contents related to Methanol Boilers
The 12th Five-Year Special Equipment and Technology Development Plan		May 2011	Focus is mainly on energy-saving and safety of boilers
The 12th Five-Year Energy Conservation and Environmental Protection Industry Development Plan	No.19 [2012] of the State Council	June 2012	Encourage the promotion of fuel-based industrial boilers
Opinions of the State Council on accelerating the development of energy saving and environmental protection industry	No.30 [2013] of the State Council	August 2013	Proposal to increase the adaptability of varieties of boiler fuels and the possible use of fiscal funds to guide and drive energy transformation of boilers
Air pollution control action plan	No.37 [2013] of the State Council	September 2013	Principal of eliminating coal fired boilers especially those with small capacity; specific mention of the need to switch to new energy boilers and promote the use of environmentally-friendly and energy-efficient boilers
Air Pollution Control Targets Agreement		January 2014	Eight provinces including Beijing, have been given the most stringent emission reduction tasks (priority regions to promote methanol boilers)
Strengthening Air Pollution Prevention Efforts for the Energy Sector	No.506 [2014] of the NDRC, NEA and MEP[1]	March 2017	Mentioned the use of new energy boilers to replace coal-fired boilers

[1] [Note: NDRC (National Development and Reform Commission), NEA (National Energy Administration), MEP (Ministry of Environmental Protection of the People's Republic of China), MOF (Ministry of Finance), AQSIQ (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China), MIIT (Ministry of Industry and Information Technology of the People's Republic of China), NGOA (National Government Offices Administration)]

Table 1-3: China's Policies on the Boiler Industry

National Policies	Document Number	Date of Issue	Contents related to Methanol Boilers
Action Plan for Energy Conservation, Emissions Reduction and Low Carbon Development in 2014-2015	No.23 [2014] General Office of the State Council	May 2014	All provinces have been tasked with energy conservation and emission reduction targets and the phasing out of 250, 000 tons of steam from coal-fired boilers
Comprehensive Implementation Plan for Improving Energy Savings and Environmental Performance of Coal-Fired Boilers	No.2451 [2014] of the NDRC(1), MEP, MOF, AQSIQ, MIIT, NGOA and NEA(1)	October 2014	Promote optimal adjustment of fuel composition and switch to clean fuel boilers in areas where heating and gas network cannot cover
Energy Development Strategy Action Plan (2014-2015)	No.31 [2014] General Office of the State Council	June 2014	Control coal consumption in key areas where coal is used, focusing on economically developed regions and medium to big cities.

(1) [Note: NDRC (National Development and Reform Commission), NEA (National Energy Administration), MEP (Ministry of Environmental Protection of the People's Republic of China), MOF (Ministry of Finance), AQSIQ (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China), MIIT (Ministry of Industry and Information Technology of the People's Republic of China), NGOA (National Government Offices Administration)]

2. Provincial Policies

In response to State policies, every region has introduced corresponding local policies to restrict the use of high-emission coal-fired boilers, which mostly concentrate on eliminating the use of small capacity (less that 10t/h) coal-fired boilers in cities, with replacement targets, and promoting new energy or clean energy alternatives. Local environment protection authorities have increased the enforcement on emission inspections. In most occasions, high polluting boilers are shut down until they meet the standard by changing fuel or adding after treatment. Table 1-3 outlines the relevant provincial policies that have emphasized the transformation of coal-fired boilers as the primary mission.

In addition, provinces such as Guangdong, Jiangxi, Hubei and Yunnan that have no immediate urgency to eliminate the use of coal-fired boilers have also introduced the respective local policies and proposed similar missions and targets to use clean energy alternatives or regulate the use of coal-fired boilers and accelerate the elimination of smaller coal-fired boilers.

Region	Regional Policies	Document No.	Promulgation	Replacement Targets (t/h)	Related Content
Shandong	2013-2020 Shandong Air Pollution Control Plan	No. 12 (2013) issued by Shandong People's Government	July 2013	23,000	Encourage the use of clean energy in industrial furnaces and boilers, limit coal-fired, heavy oil, residual oil and direct biomass-burning boilers
Hebei	Hebei Air Pollution Control Action & Implementation Plan		September 2013	22,000	Places with no access to natural gas pipeline network may carry out transformation of boilers for new energy
Zhejiang	Zhejiang Air Pollution Control Action Plan (2013-2017)	No. 59 (2013) 59 issued by Zhejiang People's Government	December 2013	14,000	Places with no access to natural gas pipeline network may carry out transformation of boilers for clean energy, limit boilers that burn oils and biomass
	Hangzhou People's Government on the Issue of Hangzhou Air Pollution Control Action Plan (2014-2017)	Hangzhou People's Government Letter No. 80 (2014) 80	May 2014		
Tianjin	2012-2020 Tianjin Air Pollution Governance and Measures	No. 87 (2012) issued by Tian-jin Municipal Government Office	July 2015	12,000	Promote transformation of boilers for natural gas and other clean energy
Jiangsu	Jiangsu Air Pollution Control Regulations (Draft) (Invitation for Opinion			11,000	Promote transformation of boilers for natural gas and other clean energy, prohibit the use of coal, heavy oils and residual oils
Henan	2014 Henan Blue Sky Action and Implementation Plan	No. 53 (2014) issued by Henan Municipal Government Office	May 2014	10,000	Promote transformation of coal-fired boilers for clean energy, prohibit construction of new coal-fired, heavy oil, residual oil and direct biomass-burning boilers
	Air Pollution Control Implementation Plan (2014-2018) issued by Zhengzhou Municipal Government		May 2014		

Region	Regional Policies	Document No.	Promulgation	Replacement Targets (t/h)	Related Content
Shanxi	Shanxi Air Pollution Control Action and Implementation Plan	No. 38 (2013) issued by Shanxi People's Government	October 2013	10,000	Areas not covered by natural gas shall promote transformation of boilers for new fuels
	2014 Shanxi Air Pollution Control Action Plan	No. 13 (2014) issued by Shanxi Municipal Government Office	March 2014		
Heilongjiang	Heilongjiang Air Pollution Control Action Plan Implementation Rules	No. 1 (2014) issued by Heilongjiang People's Government	January 2014	10,000	Areas not covered by gas supply pipeline network may be transformed to adopt new energy
Liaoning	Liaoning Air Pollution Control Action and Implementation Plan	No. 8 (2014) issued by Liaoning People's Government	March 2014	10,000	Areas not covered by thermal and gas supply pipeline network shall be transformed to adopt electricity and clean energy
Beijing	Beijing Air Pollution Control Regulations	Beijing Municipal People's Congress Public Notice No. 3	March 2014	9,000	Industrial boilers and furnaces that use coal, heavy oil and residual oil as fuels shall convert to clean energy
Inner Mongolia	Inner Mongolia Autonomous Region People's Government Opinion on Thorough Implementation of Air Pollution Control Action Plan	No. 126 (2013) issued by Inner Mongolia People's Government	2013	9,000	Eliminate the use of small coal-fired boilers and convert to natural gas and other clean energy
Shaanxi	"Reduce Haze Pollution, Defend Blue Sky" 5-Year Action Plan (2013-2017)	No. 54 (2013) issued by Shaanxi People's Government	December 2013	8,000	Eliminate the use of small coal-fired boilers and use new energy in places not accessible to natural gas pipeline network
	Strengthening Air Pollution Control Implementation Plan in Shaanxi's Energy Industry	Shaanxi Energy Development and Reform No. 804 (2014	July 2014		

Remarks: The rectification task in the Table refers to the elimination of coal-fired boilers in specified regions in every province regulated under "Action Plan for Energy Conservation, Emissions Reduction and Low Carbon Development in 2014-2015".

1.3 SUPPLIERS AND APPLICATIONS

1.3.1 SUPPLIERS OF METHANOL BOILERS

The design parameters of methanol and natural gas furnaces are essentially the same. Therefore, most of the furnace manufacturers are also capable of manufacturing methanol furnaces. There are many domestic suppliers of specialized burners for methanol boilers. The burner is either dedicated or retrofitted: dedicated burner manufacturers primarily include companies such as Dongguan's Brilliant Thermal Technology Co., Ltd. and Wuxi SWT Burner Manufacture Co., Ltd.

Figure 1-2 Wuxi SWT's Methanol Burner

Manufacturers of methanol boiler burners in China that adopt retrofitting lines have small-scale production, as shown in Table 1-4. The more renowned international burner manufacturers currently do not supply methanol burners.

Table 1-4 Methanol Boiler Burner Manufacturers

Manufacturer	Remarks
Primary domestic manufacturers of methanol burners with dedicated production lines	
Dongguan Brilliant	Specializes in the manufacture of methanol burners. Customers surveyed use these burners. Website: www.dg-brilliant.com
Wuxi SWT	A renowned domestic burner supplier. Focuses on specialty gas burners. Main customers include boiler manufacturers. Methanol burners form a small portion of the business Website: www.china-burner.com
Primary domestic suppliers of methanol boiler burners that use retrofitting lines	
Xi'an Tianwaitian	Manufacture of burners of less than 1 ton
Tianjin Enguang	Original equipment manufacturer of burners, up to 15 tons
Beijing Jinjingda	Manufacture of burners of less than 10 tons
Zhongke Bosheng	Manufacture of methanol burners of less than 1 ton
Shanghai Linjing	Able to reconstruct 4-ton methanol burners

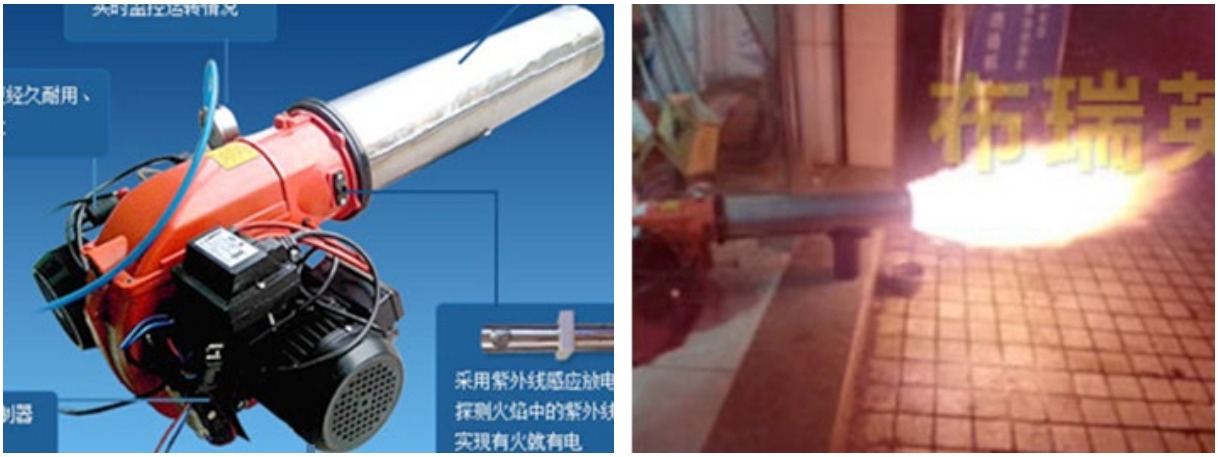


Figure 1-3 Brilliant's 4th Generation Methanol Burner

1.3.2 APPLICATIONS

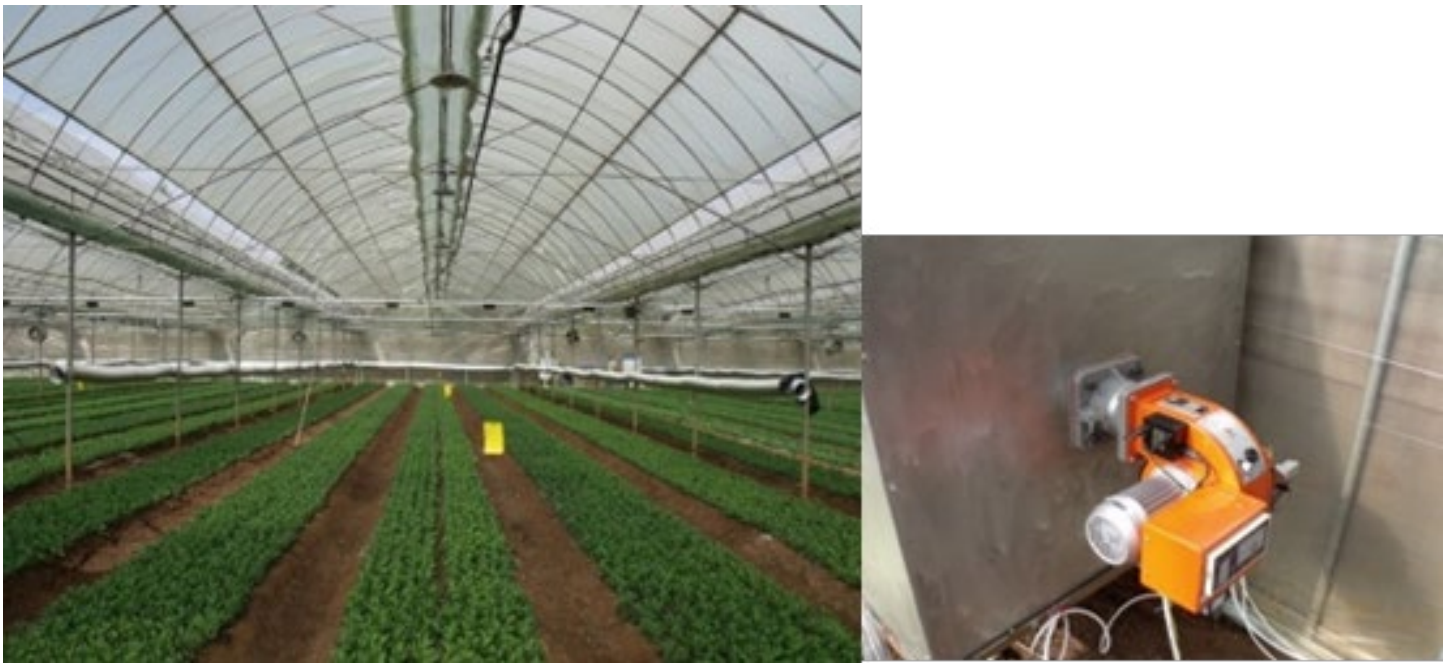


Figure 1-4 Methanol Boilers for a Flower Greenhouse and the burner

Chinese companies began to explore methanol as a boiler fuel around 2012, to replace boiler fuels like coal and fuel oil, now there are methanol boilers applications in over 10 provinces in China, like Shanxi, Shaanxi, Shanghai, Shandong, Tianjin, Chongqing, Beijing, Hebei, etc. Some applications are for industry in manufacturing and heating, food processing, agriculture warming (as shown in Figure 1-4), pharmacy and medical sanitation. In the survey conducted for this study, we find that methanol boilers are penetrating into the market very quickly. In many manufacturing concentrated provinces like Shandong and Hebei, over 100 methanol boiler units are already in commercial operation. We estimate the total number of methanol boilers in use across China today to be over 1000 units, consuming over 500,000 metric tons of methanol annually.

Figure 1-5 shows a 6 t/h methanol boiler in a pharmacy plant in Shaanxi province which has been used for two years, consuming 2,500 metric tons of methanol per year. Based on the past operation, the economics for this sized unit are shown as Table 1-5. According to the actual consumption and fuel prices historically, one year use of methanol saved annual fuel costs around ¥684,000 (USD$103,000) (11%) to natural gas and ¥5,340,000 (USD$801,000) (49%) to diesel respectively, with consideration of maintenance and additional safety investments.

Figure 1-5 A 6 T/h Methanol Boiler for pharmacy plant and the burner in Xi'an

Table 1-5 Economics Comparison of 6 t/h Boiler among Different Fuels

Fuel	Fuel Consumption/ Hour	Fuel Consumption/ Day	Unit Fuel Cost (RMB)	Daily Fuel Cost (RMB)
Coal	1.62MT	19.44MT	400/MT	7,776
Natural Gas	476m^3	5712m^3	3.09/m^3	17,650
Diesel	393Kg	4.72MT	6,480/MT	30,585
Methanol	**525Kg**	**6.3MT**	**2,500/MT**	**15,750**

An example of a high capacity methanol boiler is found in a musical instrument plant in Tianjin, where a 15 t/h boiler is used to produce steam for wood and coating drying, as shown in Figure 1-6. Methanol is stored in an underground tank. When the boiler is in operation, methanol fuel is first pumped into a higher, expansion tank to form a stable flow avoiding air trapped in the pipe. Methanol is measured and mixed with air, heated by the heat recovery process, and then combusted in the burner. There is no physical limit or technical challenge for methanol to be used in larger boilers. In practice, capacity over 20 t/h consumes considerably larger amounts of methanol due the energy required, increasing the total fuel cost, which indirectly pushes the users to turn to pipeline natural gas or coal with after treatment technologies.

Figure 1-6 A 15 t/h Methanol Boiler for a Musical Instrument Plant in Tianjin

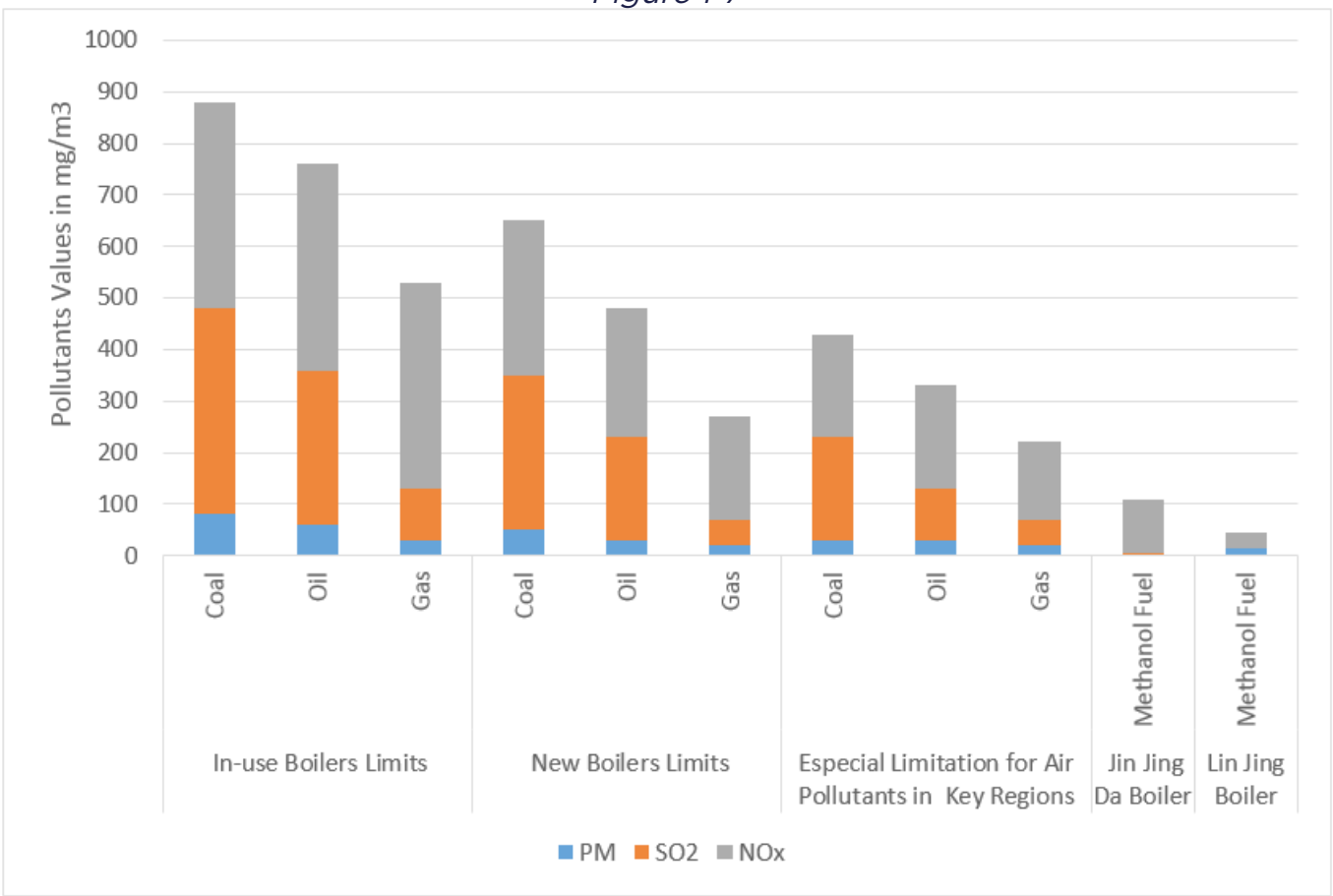
1.3.3 EMISSIONS

Given the simple molecular composition of methanol, boilers fueled with methanol have superior emission performance and meet the strictest pollution limits under Chinese standards. Two testing results are selected here, and have been compared with the pollutant values in the current national boiler emission standard, in Figure 1-7.

Compared with coal fired boilers, methanol boilers shows superior emission benefits, at least 75% lower than the total emissions in terms of PM, SO2 and NOx. In the current standard on emission limits, natural gas boilers have the lowest values in terms of PM, SO2 and NOx, and are widely promoted by the government. However, testing results show that methanol boilers have total emission amounts well below that of the natural gas boilers. Neat methanol does not have sulphur, both of the two boilers tested show significant SO2 reduction, over 90% less than the most strict limit of new natural gas boilers. SO2 is detected in the Jin Jing Da boiler, because sulphur-containing additives are blended into the methanol fuel to increase the heat value and reduce the total fuel cost.

Similar to internal combustion engines, NOx is inevitable in high temperature nitrogen/oxygen atmospheres. Testing conducted by the Burner Test Lab of China Special Equipment Inspection and Research Center in Shanghai, demonstrates that methanol boilers generally produce less NOx than that of natural gas, probably due to the high evaporation and latent heat of methanol, which decreases the burning temperature. In the emission test of the boiler from Lin Jing Co., the exhaust gas was also collected to measure the formaldehyde content, the value is below 0.5 mg/m3. At present time, there is no requirement for formaldehyde emission in boilers, reference data is needed for direct comparison and future regulation.

Figure 1-7



1.4 MARKET ANALYSIS

1.4.1 ECONOMICS

1. Operating Costs

There are no significant differences in price among the boiler bodies and burners that use different types of fuels, while 90% of the boiler operating costs comes from fuel. Therefore, the main topic of discussion in this section will be fuel economy.

There is no unified formula and pricing for methanol used in boilers. It is essentially methanol with a small amount of additive which provides either anti-corrosion protection or higher heat value which aid the combustion. The requirements for the additive are also not as stringent as those for methanol additive used in cars in China today. Therefore, the calculations in this report are based on pure methanol as an approximate baseline.

Currently, most industrial boilers in China primarily use coal while some regions use diesel, fuel oils, and other petroleum products. In recent years, with the continuous improvement of boiler emission standards, natural gas and electricity are also being introduced as boiler fuels in the market. In the market segment of Industrial Small Boilers, economics for methanol among boiler customers comes mainly from a comparison with the above forms of energy as tabulated below.

Table 1-6 Heat Values and Economics of Fuels for Small Boilers in Industry

Fuel	Methanol[1]	Natural Gas[2]	Natural Gas (High Price)	Diesel	Coal	Commercial and Industrial Electricity[3]
Unit price of fuel (RMB)	**1.8/kg**	2.2/m^3	4.5/m^3	5.5/kg	0.4/kg	0.9/kWh
Unit price/0.1 Cal (RMB)	**3.8**	2.6	5.4	5.5	0.8	10
Thermal Efficiency[4]	**90%**	90%	90%	90%	55%	96%
Actual Economics (RMB/0.1 Cal)	**3.7**	2.7	5.2	5.4	1.45	11.

NOTE:

1. In the research, Methanol Fuel for boilers is either neat methanol or methanol with additives, for simple, the calculations here are based on neat methanol, with average price of RMB1,800/MT during the second half of 2015.

2. For industrial purposed natural gas, there are significant price differences between different regions in China due to pipeline shipment cost or LNG import/process cost. Two pricing scenarios, low and high prices are used to represent different NG prices.
3. For industrial purposed electricity, there is some variations in prices across China, but not significant, hence 0.9RMB/kWh is used here.
4. The thermal efficiency of liquid and gaseous fuels are simplified to 90%, common boil energy saving technologies are used.

Based on this analysis of fuel prices, simply from an economic viewpoint, coal still has the best economy but hardly meets the current emission standard without additional treatment, as well as being banned in some cities. Other dirty boiler fuels, fuel oil and refinery coke are similar to coal, and are not considered as appropriate boiler fuel due to high emissions. Among the three potential fuels that could meet the emission requirement, methanol has a significant cost advantages compared with diesel and electricity, and falls in the middle of the two price scenarios of natural gas. Methanol could find its market in regions where natural gas is pipelined through long distance or gasified from LNG, which increases the retail price to the end users.

2. Costs of Installation and Construction

From the analysis above, methanol mainly competes with natural gas boilers in terms of clean boilers. The costs of installation and construction for these two types of fuels are similar. Based on the project calculations of 3*10 t/h boiler as heating source for 200,000 m2 of residential area, the investments for natural gas boilers and methanol boilers amounted to ¥3,520,000 (USD$528,400) and ¥3,510,000 (USD$527,000) respectively.

However, in the case of natural gas boilers, further investment of ¥2,200,000 (USD$330,250) is required for the construction of natural gas pipeline network, bringing the total investment to ¥5,720,000 (USD$858,600); higher than methanol boilers by ¥2,210,000 (USD$331,750). Due to the inadequate infrastructure of natural gas, it is a common practice in China that consumers bear the cost of construction of the pipeline network from the main pipeline to the final user, this extra cost is often called an “open cut fee” or “connection fee.” Such costs can be greatly reduced by using methanol as a liquid fuel by simply installing a methanol storage tank above ground or an underground tank for saving space at surface level.

1.4.2 NATIONWIDE MARKET ESTIMATIONS

Through years of development, the Chinese boiler industry fleet has grown to approximately 624,000 units. Boilers in China are mainly coal-based, including those in coal-fired electric power plants. The rest of the coal-fired boilers are industrial boilers, with a large number located in dense, urban areas with high energy consumption and heavy pollution. Given the overall effort to improve energy efficiency and control pollution, there is huge potential for energy conservation and emission reduction for the industrial boiler fleet.

According to Ministry of Industry and Information Technology (MIIT), as of the end of 2013, China had fleet of 467,000 coal-fired industrial boilers, which generated a total capacity of up to 1,780,000 t/h and consumed approximately 700 million tons of raw coal annually. This represented more than 18% of the total amount of coal consumed in the country. The overall energy efficiency of coal-fired industrial boilers in China is relatively low, approximately 15% of the actual operating efficiency of advanced international standards. There is clearly a potential for greater energy conservation. At the same time, industrial boilers are one of the major air pollutant contributors, representing 33% of soot; 27% of SO2, and 9% of NOx nationwide.

Reducing coal use in industrial boilers is a long-term goal for the Chinese central government, especially for small capacity boilers. Currently, there are 276,000 units of coal boilers within 10 t/h capacity, accounting for 70% of total coal boilers and consuming 170 MMTs of coal . According to the statics from MEP and controlling target in “Air pollution control action plan” by the State Council, there are around 45,000 units of coal boilers within 10 t/h, total capacity of 53,000 t/h, which need to be eliminated . This capacity vacuum will be filled by various, alternative solutions, such as central heating supply and natural gas delivery improvements. If methanol can be officially accepted as boiler fuel and the environmental policies continue, considering the large volume of coal to be replaced, even capturing a small fraction of this market could lead to a large consumption of methanol. **Assuming methanol captures 10% of the market in the next five years, around 1.6 MMTs of methanol can be consumed annually.**

[3] Ministry of Industry and Information Technology, http://www.miit.gov.cn/n1146290/n4388791/c4216991/content.html, latest subscription date:2016/7/21

[4] Ministry of Environment Protection pf PR China, http://www.zhb.gov.cn/gkml/hbb/qt/201405/t20140530_276302.htm?from=timeline&isappinstalled=0, latest subscription date:2016/7/21

[5] China Industrial Boiler Association, http://www.cibb.net.cn/NewsDetail/16214, latest subscription date:2016/7/21

Besides coal, petroleum products used for heating, as described in terms of intermediate consumption of heating energy in the Chinese National Statistics Bureau reached over 5 million tons in 2014, including fuel oil consumption of 1.87 million tons.

Methanol is gradually taking over the oil fired boilers due to the better emission performance and slightly lower fuel costs. Fuel oil and diesel will also be replaced by various fuels, like natural gas, biomass and LPG. There is no reliable data on the petroleum products consumption in various industry applications for steam generation, but considering the scale of manufacturing in China, the potential market for methanol is very promising.

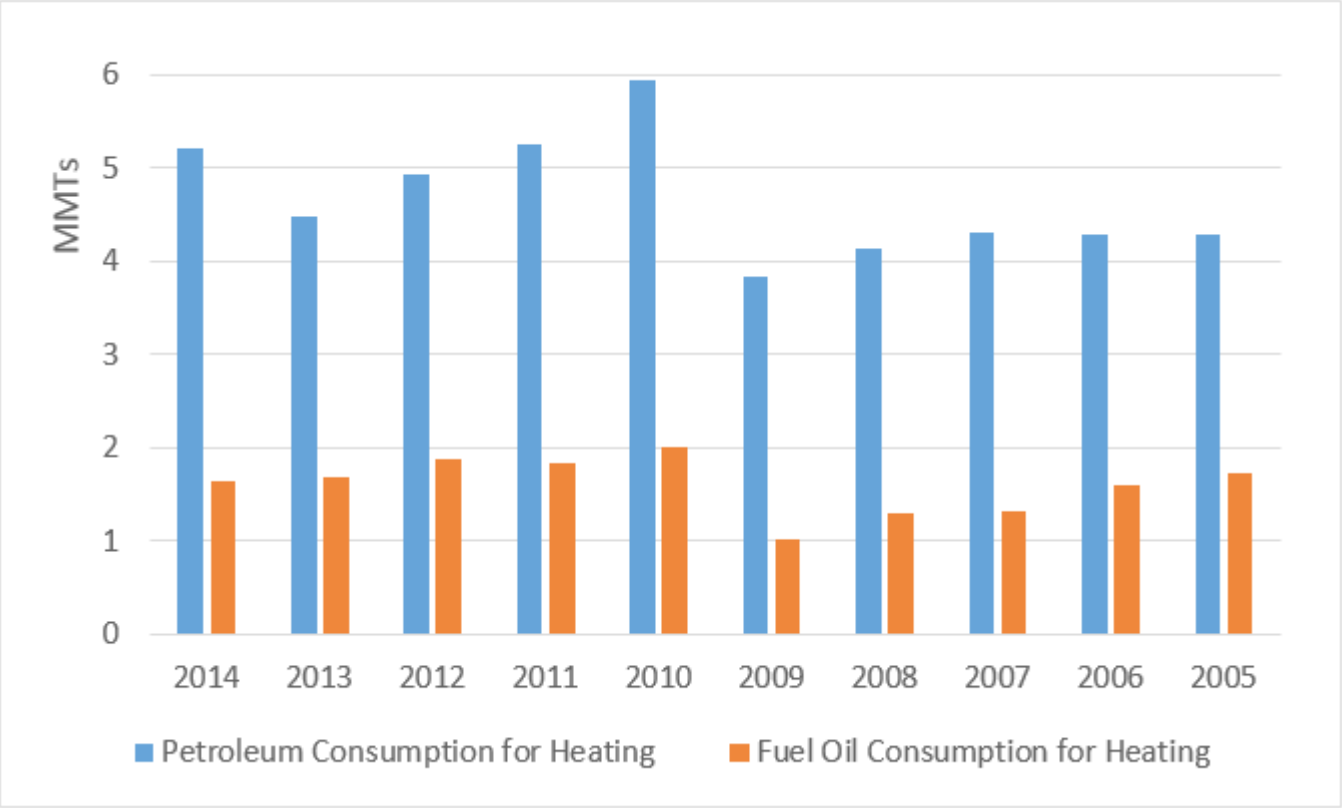


Figure 1-7 2005-2014 Petroleum and Fuel Oil Consumption for Heating

2 METHANOL COOK STOVES

2.1 OVERVIEW OF METHANOL COOK STOVES

A methanol cook stove is a liquid fueled cook stove designed to use methanol fuel dedicatedly. Without any major change in how people use the cook stove, methanol can directly replace existing gas stove, electric stove, diesel stove and liquefied petroleum gas (LPG) stove. The major difference between a methanol cook stove and an ordinary LPG stove is the stove core. The stove core in a methanol cook stove has a gasification chamber which pipes fuel directly into the nozzle before the fuel gets heated to a temperature of around 65°C, and before methanol starts to change from the liquid state to a vapor state, at which point, it will flow back to the combustion to be ignited.

When methanol undergoes combustion in the cook stoves, it competes with other cooking fuels in economics even though its heating value is comparatively lower than LPG, diesel or natural gas. As a liquid fuel, methanol is relatively safe and convenient for use in cooking. Methanol does not leave any residue or sludge, does not carbonize the wok bottom, and it is clean and hygienic. Methanol is replacing LPG and kerosene in the kitchens of hotels, restaurants, schools, company canteens and households.

2.1.1 METHANOL COOKING FUEL

Generally, methanol is blended with water and additives to form methanol cooking fuel or alcohol based liquid fuel. Such fuel used in methanol cook stoves usually consists of at least 80% methanol, approximately 5% additives and water within 15%. The following are two typical and patented formulae for methanol cooking fuel:

1. China Patent Application No.: 200910119005.5

Table 2-1 Ratio of Raw Materials indicated in Patent 200910119005.5

Raw Materials	Ratio (by mass) / %
Methanol	80 ~ 85
Emulsifier	5
Water	10 ~ 15

1. China Patent Application No.: 201210417898.3

Table 2-2 Ratio of Raw Materials indicated in Patent 201210417898.3

Raw Materials	Ratio (by mass) / %
Methanol	86 ~ 88
Combustion stabilizer	0.1 ~ 0.4
Water	11 ~ 13
Essence	0.1 ~ 0.6

Note: Combustion stabilizer is formulated by mixing potassium hydroxide and water based on a ratio of 0.8-0.95:2 by mass and cooling it, mixing sodium hydroxide and water based on a ratio of 0.8-0.95:2 by mass and cooling it, mixing the cooled aqueous solution of potassium hydroxide and the cooled aqueous solution of sodium hydroxide, followed by consecutively adding ethyl acetate that is 4.5-5.5 times of and anhydrous ethanol that is 10 times of the total mass of the original potassium hydroxide and sodium hydroxide, and mixing it until it is consistent.

2.1.2 METHANOL COOKING FUEL ADDITIVE

Methanol cooking fuel additive, also known as combustion improver or emulsifier, is less complicated than methanol fuel additives for automotive use. Methanol is usually added with up to 15% of water supplemented by strong oxidizing chemicals with relatively low flash point (such as potassium permanganate and hydrogen peroxide) mainly to improve combustion. The following are the commonly used additives in the market, as shown in Table 2.3.

1. Methanol-water fuel, which is relatively easy to prepare. The water content in the fuel, can reduce the fuel (mainly methanol) gasification, so the coupled cook stoves need not have complicated stove design to make sure the fuel is burnt effectively. Table 2-3 Emulsifier Formula in Patent 200910119005.5 lists the methanol-water fuel and the corresponding formulae. It's also found in the market that some unscrupulous traders increase the water content to reduce costs.

Table 2-3 Emulsifier Formula in Patent 200910119005.5

Raw Materials	Ratio (by mass) / %
Sodium hydroxide	1 ~ 5
Potassium hydroxide	1 ~ 5
Anhydrous ethanol	40 ~ 70
Ethyl acetate	18 ~ 75
Water	7 ~ 15

2. Methanol-hydrocarbon fuel is mainly refined methanol that is added with 10% of hydrocarbons to increase the heat value of the fuel (many traders reduce costs by replacing refined methanol with crude methanol, leading to lower combustion). The addition of hydrocarbons risks forming a stratified methanol fuel during storage and use, although this can be resolved by appropriately adding a co-solvent to ensure that methanol and hydrocarbons mix uniformly. This type of fuel is commonly used in the market today.

3. Methanol-ether fuel is made by dissolving a large portion of dimethyl ether (DME) in methanol and water in steel cylinders. The pressure in the cylinder forces the fuel flow assisting the gasification, unlike methanol-water or methanol-hydrocarbon fuel from requiring external pre-heating and pressure during the ignition process.

2.1 OVERVIEW OF METHANOL COOK STOVES

2.2.1 STANDARDS

Although methanol cook stoves have gradually been introduced into China since 1983, there was a lack of national standards, provincial and local standards and enterprise standards for product quality and technical specifications. There also was a difference between test methods and specification limits, resulting in a lack of consistency in acceptance criteria at the inspection institutions and raising serious issues in market supervision and control. In terms of domestic cook stoves, China currently takes reference from National Standards such as “Alcohol Base Liquid Fuel (GB16663-1996)” and “Domestic Alcohol Base Cook Stove (NY312-1997)” issued by the Ministry of Agriculture. Below is a brief description of the standards stipulated in NY312-1997 Domestic Methanol Cook Stove.

Table 2-4 Major Standards in Domestic Methanol Cook Stove

Item	Standards
Rated Pressure	According to industry standard, the cook stove should not be greater than 0.2MPa. Since the combustion area of the burner is in direct contact with air, place of use and the operator, higher pressure will cause discomfort to the operator, a longer flame and the inability to completely use the combustion heat.
Burner Load	Based on industry standard, heat load of domestic methanol cook stove should be greater than 10500kJ/h and smaller than 16700kJ/h. This is determined by the scope of use of a domestic methanol burner. Low heat load leads to low thermal efficiency because low fuel supply results in ineffective combustion and low thermal efficiency. High heat load on the other hand, will exceed the power required by the domestic burner and result in energy wastage. On the other hand, in order to obtain a higher heat load, the mass and flow rate of the fuel should be increased. In order to have a good combustion, the design dimensions have to be enlarged or have the fuel pressure increased. These two methods may have practical limitations. The accuracy of a burner heat load is an important indicator for the evaluation of the burner performance. Industry standard stipulates that the deviation between the measured heat load and design heat load of a burner should not be greater than ±10%. When multiple burners are operating, the total heat load of the burner should be greater than 90% of the sum of measured heat load of individual burners when each operates individually under the same conditions. These technical requirements are important acceptance criteria of the burner quality, and guarantee that the burners are able to achieve the basic usage requirements.
Combustion Stability	During combustion, combustion stability is reflected in the relative stability of the temperature, pressure, length of flame, etc. of each part of the combustion region. When there are changes externally, combustion stability is still able to be maintained. Specific requirements include: 1. Burner flame should be uniform and once an orifice is ignited, the flame should spread to other orifices in 4s; 2. Within 0.5-1.5 times fuel tank rated pressure, flame must be stable with no yellow flame, tempering, flame-out and flame lift; 3. Stability of small fire: no flame-out or tempering within 3min; 4. When using rated heat load, thermal efficiency of Class I products should not be lower than 55%, that of Class II products not lower than 50%; 5. If excess air coefficient α=1, the carbon monoxide in exhaust gas of Class I products should not be more than 0.05%, that of Class II products not more than 0.1%; 6. Under 0.5 times fuel tank pressure, burner flame must not return or extinguish when subject to 1m/s wind flowing horizontally across stove surface;
Combustion Exhaust Gas	Methanol burners generally use smaller spaces and burn large amount of oxygen. If ventilation conditions are not demanded for, it will easily cause air quality to drop and threaten user's safety. To avoid causing air pollution and to ensure the safety of methanol burner users, the industry standards stipulates that when a domestic methanol cook stove is being used, the maximum permissible concentration of harmful gases in the kitchen is as follows:

Table 2-5 Maximum Permissible Concentration of Harmful Gases in the Kitchen when using Domestic Methanol Cook Stove

Item	Maximum Permissible Concentration (mg/m^3)
Methanol	≤5
Formaldehyde	≤0.13
NO_x	≤0.5
Carbon Monoxide	≤25
Sulphur Dioxide	≤1

2.2.2 POLICIES

In the past two years, a majority of the provinces and cities in China have adopted clear guidelines on the use of clean fuel as cooking energy, although there is no clear mention of methanol. Tianjin and Gansu are the only provinces that clearly encourage the use of methanol as cooking energy.

Table 2-6 Policies Promoting Methanol Cooking Fuel in Tianjin and Gansu

Date	Location	Policy Document	Main Contents
2010	Tianjin	Notice on Provisional Regulations on Safety Management and Use of Methanol Fuel and Special Burners in Tianjin (No. 61 (2) (2010) of Tianjin Administration of Work Safety)	In order to implement in Tianjin; there is a ban on the use of 50kg liquefied petroleum gas cylinders as the source of heat in restaurants as well as the promotion of methanol and special burners as alternatives. Restaurant businesses that are located in areas not covered by natural gas pipelines and in areas covered by but are not connected to the pipelines (including construction sites, schools, companies and office canteens) are required to install special burners and use methanol.
2013	Gansu	Notice on Pilot Work on the Proper Promotion of Methanol Fuel	Gansu will actively study the introduction of preferential policies to accelerate the development of several methanol cook stove production enterprises, promote and demonstrate in office and company canteens, restaurants and hotels as well as realise the standardisation and large-scale production of methanol stoves, household methanol storage cylinders and packaged delivery cylinders.

Table 2-7 Other Provinces and Cities that Promote Clean Energy Policies for the Restaurant Industry

Date	Location	Policy Document	Main Contents
2013	Cangzhou	Notice by Environmental Protection Bureau	Inspect at least 152 medium-sized service units in urban built-up areas and require them to use natural gas and other clean energy. Before end June 2014, all food service units in urban built-up areas shall use clean energy. Before end June 2015, all food service units in every province (city) shall use clean energy. Cangzhou shall conduct daily supervision and control of food service units to ensure the use of clean energy.
2013	Gansu	Qianjiang District Implementation Plan Banning Coal-fired Facilities and Promoting the Use of Clean Energy (No. 88 (2013) Issued by Qianjiang People's Government)	Ban coal-fired facilities and promote use of clean energy solutions and clarify subsidy scheme. Focus on promoting clean energy to urban catering businesses. Strict approvals, examination, supervision and control by relevant departments to ensure coal-fired issues in urban areas are effectively curbed. Achieve improved level of pollution prevention and control activities in Qianjiang District.
2013	Xi'an	Notice by Environmental Protection Bureau	Full and thorough investigations on medium-sized caterers and canteens, clear and completely ban all illegal open-air barbeque markets and stalls; clear all legal barbeque businesses that fail to use clean energy.
2013	Other major provinces and cities	Notice by Environmental Protection Bureau	Promote the use of clean energy as cooking fuel in catering services, schools and business enterprises.
2014	Henan	2014 Henan Blue Sky Work Plan and Implementation Plan (No. 53 (2014) Issued by Henan People's Government)	Before end June that year, every city under provincial jurisdiction and county (city) government under provincial jurisdiction shall formulate and promulgate relevant administrative regulations and impose deadlines on charcoal stove and other coal-fired facilities in food service establishments, schools and enterprises in the cities (including counties). To transition to clean energy, food service businesses are to install efficient fume purification facilities and there is to be standardisation of open-air barbecue businesses.

2.3 APPLICATIONS AND SUPPLIERS

2.3.1 STOVE CLASSIFICATION

Methanol cook stoves have undergone several generations of development based on commercial applications, and they can be subdivided into household stove, frying stove, large cook stove, steam cabinet, and clay pot stove, among others. Furthermore, the performance of methanol cook stoves has not only been enhanced, its design has also been significantly improved. Methanol cook stoves are developing rapidly and there is a wide range available in the market today. The desired equipment can be purchased in many places – including online via the Internet in China – and many people have started using methanol cook stoves.

1. Household Stoves

Figure 2-1 Mini Pot Stove

Household stoves are mainly divided into two types: mini pot stove and automatic gasifier stove. Mini pot stove usually make use of 600-1000 ml methanol canisters, from which fuel is drawn by a specially-made wick and its firepower increased with the use of finned thermal conductive technology. Single-user hotpot stove of 0-1.0kW heat load and multiple-user hotpot stove of 1.5-2.5kW heat load are equipped with automatic temperature control and patented fire extinguishing technology. In fact, a multiple-user hotpot stove is suitable for many occasions such as household use by a small family of three, police post, fishing boat and picnics.

Figure 2-2 Automatic Gas Stove

By appropriately increasing the dimensions of a mini pot stove, a household methanol automatic gasifier stove can be made. The supply system of this domestic stove is either similar to the integrated design seen in a mini pot stove or one in which the canister and the burner are split. A split design can use a high pressure tank or micro pump, among others for fuel supply. The core components of the burner are divided into six parts: pulse ignition preheating, thermal conduction fins, automatic feed control, full gasification, combustion by mixed gas injection and heat preservation. Its convenience and thermal efficiency are similar to LPG stoves although it is superior in terms of cost savings as a result of not carbonising the bottom of the pot.

2. Frying Stove

Figure 2-3 Single-Frying Stove

In terms of the structural principles and fuel supply system, frying stoves differs in some ways compared to small stoves and domestic stoves, mainly in terms of its higher demand for firepower, which cannot be handled by small stoves and domestic stoves. This large Chinese dish frying stove comes in two types: Type I full gasification stove that does not require a blower and Type II semi-gasification stove that requires a blower. The structure adopted is a large size split fuel and burner unit connected by metal pipes to supply the fuel. The fuel tank is placed in a safe location 1.5m above or any other locations below the burner using a micro pump supply. The core components of the burner are divided as follows: automatic quantitative supply device, automatic ignition device, reinforced fins thermal conduction device, gas mixture ignition and combustion device and heat preservation and isolation device, among others.

Figure 2-4 Single Frying Stove

Figure 2-5 Dual-Frying Single-Heating Stove

Figure 2-6 Dual-Frying Dual-Heating Stove

3. Large Cook Stove

Figure 2-7 Large Cook Stove

There is a difference in combustion methods between large cook stoves, household stoves and frying stoves. A large cook stove primarily transfers the flame in the stove chamber to the surroundings to ensure that combustion is even, complete, energy-saving, and highly efficient. In addition, the large cook stove has characteristics such as durability, stronger heat and firepower, speed, and non-contaminating. From our survey, frying and large cook stoves have the major market in the methanol cook stoves in restaurants and central kitchens for a large number people catering, where fuel cost is a concern.

4. Steam Cabinet

Figure 2-8 Methanol Steam Cabinet

Methanol steam cabinets are widely used for cooking food by steam, like rice and dishes like fish. It does not require a burner head; the entire steamer is fully automated, easy to ignite, and automatically adds water when there is no water. Usually it is installed with an oil pump with an automatic ignition device, has a large heat load, strong firepower, high heat efficiency, and is easy to operate. The methanol steam cabinet usually adopts a monolithic design and has very good sealing, effectively saves energy, and shortens the time for steaming food such as bread, buns, rice cakes and the like.

5. Clay Pot Stove

Figure 2-9 Methanol Clay Pot Stove

The methanol clay pot stove has characteristics such as high efficiency and power, shortening cooking time, and saving energy. The firepower is adjustable; ranging from a weak flame to a very strong flame, which is suitable for use in small and medium-sized restaurants, night market food stalls that serve clay pot dishes such as vermicelli, porridge and so forth.

2.3.2 EQUIPMENT MANUFACTURERS (DISTRIBUTORS)

Currently, there are many methanol cook stove manufacturers (distributors) in China although they lack economies of scale and have limited production and marketing capabilities. In general, these are limited to the local areas and the product quality is inconsistent. Taking into account that the stove core is the main component of a methanol cook stove, some of the larger methanol cook stove manufacturers (distributors) are summarized in the table below.

In our survey of methanol cooking fuel suppliers, methanol is used in densely populated provinces, i.e. the eastern, southern and central part of China. People in these provinces are inclining to have meals in central kitchens, restaurants where food is processed in large volumes efficiently. The clean cooking fuel supply cannot meet the rapid urbanization of China, many buildings are not natural gas pipeline connected, and LPG has limited coverage in many areas, and is more expensive than methanol cooking fuel in some areas. The widely-spread distribution network for methanol enables the efficient supply in almost every province of China. Like Tianjin City, local suppliers estimate the annual consumption of methanol for cooking purpose in this one city is around 500,000 tons.

Table 2-6 Methanol Cook Stove Manufacturers (Distributors)

Hebei Cangzhou Nuoka Gas Co., Ltd.	http: //nuoka66.cn.china.cn/
Shandong Boxing Qiguo Kitchen Industry	http: //bxqgcy.jdzj.com/
Chengdu Jindingfeng Energy Saving Technology Co., Ltd.	http: //denglinggui.1688.com/
Shanxi Chuanfeng Technology Trading Co., Ltd.	http: //www.yqcfkj.com/
Xi'an Tranto Energy Saving Technology Co., Ltd.	http: //www.029kx.com/
Wuhan China Alcoholisation Investment Holding Co., Ltd.	http: //wuhanzchjc.cn.china.cn/

2.3.3 STUDIES IN EMISSIONS AND COAL ALTERNATIVES

According to recent studies[6], residential sector (cooking and heating) contributes to a large proportion to the air pollutions in China, especially in Northern parts of China like Beijing, Tianjin and Hebei (BTH) region. Household emissions from the combustion of solid fuels (coal and biomass) in very low efficient stoves results in 32%, 44%, 71%, 15%, and 4% of the primary PM2.5, Black Carbon (BC), organic Carbon (OC), SO2, and NOx emissions in the BTH region respectively, and is further exacerbated during the cold weather heating season. This fact has been underappreciated for far too long and needs a long-term effort to replace the solid fuel with clean energy/fuels like methanol.

As an alternative fuel for cooking, like other clean fuels, methanol is superior to coal and diesel in air pollutants like SO2, NOx and particle emission. In joint tests conducted by new energy company of Yulin Mining Group and Shaanxi Provincial Transport New Energy Development, Applications and Automobile Key Laboratory have shown that methanol particulate emissions are significantly better than diesel. The use of methanol as energy for cooking is not only able to fundamentally eliminate sulphide emission, but also able to reduce to a large extent PM2.5 contents in the air. The PM2.5 contents in the air that is emitted through methanol combustion is less than 1/10 those of diesel, which is easily accepted by the consumers since the direct impact on the cleanliness level of the operating environment is small.

[6] Tong Zhu, et al. (2016) Air pollutant emissions from Chinese households: A major and under appreciated ambient pollution source, PANS, July 12, 2016, Vol. 113, no. 28, 7756-7761

Table 2-7 Comparison of Emissions by Various Fuels

Fuel	#1 Fuel	#2 Fuel	#3 Fuel	#4 Fuel	#5 Fuel	#6 Fuel
Formula	Methanol	Diesel	95% Methanol + 5% #1 Additive	99.5% Methanol + 5% #2 Additive	99.5% Methanol + 5% #2 Additive	95% Methanol + 5% #1 Additive + 0.5% #2 Additive
CO emission (%)	0.02	0.02	0.02	0.03	0.03	0.01
NO_x emission (ppm)	21	67	12	28	66	17
HC emission (ppm)	45	7	9	38	10	10
PM2.5 (μg/m³)	232	2678	240	237	2508	228
Formaldehyde (mg/m³)	1.82	0.04	1.40	2.21	0.06	1.65

2.4 MARKET ANALYSIS

2.4.1 ECONOMICS

When conducting economic analysis for end users (i.e. catering customers), an indicator of Actual Economics is calculated from the price of fuel, heat value, and thermal efficiency of the related cook stoves. Table 2-11 clearly reflects Shaanxi Yulin catering customers' actual fuel economics in 2014. It can be seen that methanol has greater advantages compared to diesel and LPG.

Table 2-11 Analysis of Customer's Fuel Economics

Fuel	Methanol	Natural Gas	Liquefied Petroleum Gas	Diesel	Coal	Electricity
Price per unit mass	¥3.4/kg	¥1.85/m³	¥9.2/kg	¥8.7/kg	¥0.4/kg	¥0.78/kWh
Price per kcal (¥0.0001/kcal)	6.4	2.2	8.1	8.6	0.8	9.1
Thermal Efficiency	56%	75%	50%	40%	30%	80%
Actual Economics (¥0.0001/kcal)	11.4	2.9	16.2	21.5	2.7	11.4
Fuel economy (¥$^{0.0001}$/kcal)	0	-8.5	4.8	10.1	-8.7	0

Note: 1. Price per unit mass used in this Table refers to current Yulin City catering end customers' actual cost price
2. Methanol thermal efficiency is based on People's Liberation Army Plant 5701 Professor Sun Hongwei's research on methanol values in liquid fuel stoves
3. Liquefied petroleum gas (LPG) price per unit mass is based on 2014 Yulin Pricing Bureau's announcement of average prices in the LPG market

2.4.3 STATE OF THE INDUSTRY

From the joint survey conducted by CGNESS and Yulin Coal Mining New Energy Co., current China domestic methanol participants are mainly divided into methanol cooking technology companies, franchisees (suppliers), and end-use customers. The methanol cooking technology companies generally transfer their methanol formulae together with the supply of cook stoves, with some operating the methanol business. Franchisees generally form the intermediate parties in the industry chain, purchasing from methanol technology companies and supplying the methanol to end customers after processing and preparing the methanol fuel. Since it is not complicated to formulate methanol and the protection of domestic intellectual property rights is relatively weak, many franchisees buy the formula from methanol cooking technology companies to transfer the formula again while selling cooking appliances. End customers are generally the catering (restaurant) business owners who adopt the use of methanol as cooking fuel. Many large-sized end customers (e.g. large-sized catering businesses) will directly buy the formula from methanol technology companies and process it themselves to cut costs.

Methanol cooking fuel franchisees are generally located in counties and villages or in places in the cities where there is no access to natural gas. The current prices of methanol cooking fuel range from a minimum of ¥2700 (USD$405) to a maximum of ¥4500 (USD$675) per metric ton. Product quality is also inconsistent. Based on surveys, the market efficiency of methanol franchisees is acceptable. This is also related to the relatively low coverage of and insufficient availability of natural gas in China. In addition, many cities in China have recently introduced policies to prohibit catering businesses from directly burning coal, thus providing a certain development space for the applications of methanol in cooking.

For end customers, China's current main cooking fuels include natural gas, LPG, methanol, diesel, coal, electricity, firewood and straw, a total of nine types of fuels. In most cities, domestic cooking fuels are mainly methanol, natural gas, LPG, coal and electricity, a total of five types of fuels. In urban fringes and rural areas, the reality is that many types of fuels are used at the same time. Many citizens use each type of fuel based on their own needs.

Based on field studies, methanol for cooking purposes in city areas is competing with natural gas and LPG. Since pipeline natural gas is currently the most economical, the real alternative to methanol is LPG. Compared to LPG, methanol has a price advantage, although it has relatively low heat value compared to LPG. Feedback from cooks indicated that it does not affect cooking applications.

However, compared to LPG which has a more complete set of systems and detailed national standards, methanol still has a huge gap in these two areas.

In rural areas, China is currently promoting rural biogas as the preferred domestic fuel. Bio-methane from agricultural waste is a clean, environmental friendly and renewable energy. Its combustion value is lower than conventional natural gas. However, for ordinary farmers, biogas presents the larger issues of daily maintenance and control of biogas as well as feeding of straws, bio-waste, etc. As such, the market is not receptive and the popularity of biogas in rural areas is less than 30%. Thus, methanol can be developed as the preferred choice of cooking fuel in rural areas.

2.4.3 NATIONWAIDE MARKET ESTIMATION

In domestic cooking fields, the economic and usage performance of methanol is relatively weak in comparison to natural gas. Therefore, methanol in the cooking market will primarily be in areas not covered by natural gas. Based on the population in each province and city that has yet to use natural gas, assume other provinces and cities reach as good a penetration rate as Tianjin's as the benchmark, while also considering local fuel competition and government support, the estimated methanol consumption is adjusted by a provincial support factor. The future potential of methanol cooking fuel market in each province or city is estimated as follows in Table 2-12. **Annual domestic methanol consumption (considering cooking only) in China may reach 8 million tons.**

Table 2-12 Analysis of Customer's Fuel Economics

Province/City	Population (x10,000)	Population not using Natural Gas (x10,000)	Provincial Factor	Estimated methanol used (x10,000 tons)
Tianjin	1413	775.77	1	50.00
Gansu	2578	2325.99	0.5	74.96
Shaanxi	3753	3108.67	0.1	20.04
Beijing	**2069**	**702.15**	**0.1**	**4.53**
Hebei	**7288**	**6306.43**	**0.1**	**40.65**
Shanxi	**3611**	**3026.94**	**0.1**	**19.51**
Inner Mongolia	**2490**	**2142.86**	**0.1**	**13.81**
Liaoning	**4389**	**3432.39**	**0.1**	**22.12**
Jilin	**2750**	**2362.82**	**0.1**	**15.23**
Heilongjiang	**3834**	**3196.38**	**0.1**	**15.23**

Table 2-12 Estimated Methanol Consumption in Each Province or City

Province/City	Population (x10,000)	Population not using Natural Gas (x10,000)	Provincial Factor	Estimated methanol used (x10,000 tons)
Shanghai	2380	1059.10	0.1	6.83
Jiangsu	7920	6176.37	0.1	39.81
Zhejiant	5477	4773.18	0.1	30.76
Anhui	**5988**	**5076.17**	**0.1**	**32.72**
Fujian	**4505**	**4182.04**	**0.1**	**26.95**
Shangdong	**9685**	**7819.41**	**0.1**	**50.40**
Henan	**9406**	**8310.92**	**0.1**	**53.57**
Hebei	**5779**	**4834.00**	**0.1**	**31.16**
Hunan	**6639**	**6076.80**	**0.1**	**39.17**
Guangdong	**10594**	**9439.29**	**0.1**	**60.84**
Guangxi	**4682**	**4495.17**	**0.1**	**28.97**
Hunan	**887**	**782.10**	**0.1**	**5.04**
Chongqing	**2945**	**2010.98**	**0.1**	**12.96**
Sichuan	**8076**	**6693.30**	**0.1**	**43.14**
Guizhou	**3484**	**3429.19**	**0.1**	**22.10**
Yunan	**4659**	**4626.03**	**0.1**	**29.82**
Xizang	**308**	**308**	**0.1**	**1.99**
Qinghai	**573**	**464.58**	**0.1**	**2.99**
Niqxia	**647**	**505.68**	**0.1**	**3.26**
Xianjiang	**2233**	**1685.32**	**0.1**	**10.86**
Nationwide	**134789**	**113581.47**	**0.1**	**837.02**

Note: 1. Tianjin has clear support guidelines, extensive promotion effort, longer developmental time and developed a certain scale, thus provincial factor is assumed to be 1;
2. Although Gansu has clear support guidelines, it has only just started and has not scaled up sufficiently, thus provincial support factor is assumed to be 0.5;
3. Other China provinces/cities currently have other fuel competition and no clear guidelines and policies supporting methanol in cooking although it is used in a small group of end customers. Thus, provincial support factor is assumed to be 0.1;
4. All population figures are adopted from National Statistics Bureau's latest 2012 data;
5. Tianjin's domestic methanol usage is 500,000 tons in 2012 and figures are taken from actual ground surveys.

3 POLICY RECOMMENDATIONS

Methanol working as fuels for industrial boilers and cook stoves are both directly burning methanol in special designed equipment to achieve the balance between economic operational cost and emission reduction. Although the technology is rapidly under development, there are a number of issues that need to be addresses by the government, industry associations, and private companies.

For industrial boilers, it's very promising to see the new regulation and standard change on boiler burner classifications, from oil/gas to liquid/gaseous forms. As a liquid, methanol can be regarded as one of the liquid boiler fuels, hence the local boiler safety inspection authorities have a clear reference. However, a methanol boiler fuel standard is needed to specify the fuel properties to avoid quality variations across different regions. Comprehensive tests and studies are also needed in boiler emissions, especially formaldehyde emissions. At present time, there is no regulation of formaldehyde emissions in the National Boiler Emission Standard. Formaldehyde could also be tested from other boiler fuels like coal, diesel and fuel oil. Formaldehyde emissions also should be researched, forming the bases of related standards if necessary. In addition, in boilers featuring high pressure vessels, best safety practice should be established jointly by private companies along the supply chain and industry associations. As methanol production and application expanding to boarder areas, such safety practice can enhance the technology transfer, into other countries around the world. In the cities with high emphasis on the air pollution from industrial boilers, pilot programs on methanol boilers could be introduced by the government to demonstrate the safety and environment benefits.

For the cook stoves, currently there are two national standards on "alcohol based liquid fuels" in China, but the standards were made in the late 1990s, and new developments of methanol cooking stoves should be reflected in revisions to these standards. Cooking is labor intensive in China, human health issues are the major concern in methanol storage, poisoning, fire risks, formaldehyde emitted after burning methanol. As a result, an update of such standards or new methanol specific fuel and cook stove standards should be developed.

The operators in the methanol cooking fuel supply chain lacks the related knowledge of methanol safety handling and/or not well educated, so that best practices for methanol in cooking application should be introduced in an easy-comfortable method. Trace amount of formaldehyde is emitted in the combustion of methanol in internal combustion engines and boilers. Unlike these applications, formaldehyde is emitted to expelled through exhaust pipes in the open air. Although lack of evidence, formaldehyde may also be generated from cook stoves and accumulate in the indoor air if the air circulation is not sufficient. Formaldehyde emission should also be paid attention especially in the working atmosphere, more work is needed to understand the formation of formaldehyde from methanol cook stoves and a higher standard/regulation should be made and used for government inspection.