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The Application Potential Analysis of Refuse Derived Fuel as an Alternative to Coal -A Case Study of Ningbo, China

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ABSTRACT

Exploring sustainable energy supply and effective solid waste disposal methods is becoming a challenge around the world. Refuse derived fuel (RDF) has been proposed as a potential alternative to coal, natural gas, oil, and coke due to its advantages of higher calorific value than original wastes, uniform composition in both physical and chemical aspects, transportation and storage, simplicity, low emission rate, and less extra air demand during combustion. However, the applicability of RDF in a given region needs to be evaluated by the combination of market analysis and political conditions. Based on the background research of Ningbo, an important industrial city in China, this paper analyzes and evaluates the energy structure, market potential of RDF and its sources in Ningbo, showing that the area has a demand for more than 7 million tons of RDF per year and is suitable for promoting and applying RDF as the alternative to coal.

Keywords: Refuse Derived Fuel, Carbon Reduction, Coal Alternative, Resources Potential, Applicability Analysis.

NONMENCLATURE

Abbreviations	
RDF	Refuse Derived Fuel
Mtce	Million tons of Coal Equivalent

1. INTRODUCTION

The problem of global warming is deteriorating and the core problem is the greenhouse gas emissions. The waste disposal contributes to a considerable amount of greenhouse gas emissions of carbon dioxide equivalent, accounting for 5% of emissions around the world (Kaza et al., 2018, Kristanto and Koven, 2019). The production of solid waste has also surged with the rapid growth of industry, population and economy in recent years. According to a conservative statistical analysis, 3.4 billion tons of waste is predicted to be produced annually by 2050 globally (Karpan et al., 2021). Considering the demand for the alternative to coal and the waste disposal, one of the most advantageous strategies is to treat solid waste by heat to produce RDF.

RDF is transformed from wastes by removing non-combustible parts, reducing the size and moisture content of them, and make the waste homogeneous. The main advantages of RDF over original wastes are higher calorific value, uniform composition in both physical and chemical aspects, transportation and storage, simplicity, low emission rate, and less extra air demand during combustion (Shangdiar et al., 2021). Also, the application of RDF can mitigate the environmental problem due to its capability to replace the fossil fuel. (Poller, 1980, Kaminsky and Rossler, 1992).

There are three main application approaches of RDF. Firstly, the blended combustion of RDF refers to the combustion of RDF blended with other fuels, mainly coal, in proportion as an alternative fuel, to produce steam or electricity. This is the main methods of utilizing RDF in the world today. It is used to replace coal in thermal power plants, and the co-disposal of cement kilns also belongs to this application category (Chatziaras et al., 2014). In 2017, Chinese government issued relevant policies, which aim to coordinate the disposal of agricultural and forestry, garbage, sludge and other wastes based on the centralized pollution treatment

system of coal power plants (National Energy Administration, 2017). Another method is direct combustion. The promotion of it is relatively slow because of the differences in perceptions and understanding of RDF. In recent years, however, the situation has been gradually reversed due to the climate change and energy prices. Also, gasification technology was developed in Europe and US in last few years, to solve harmful substances produced in the treatment of solid waste. Garbage gasification technology includes gasification and melting in both pure oxygen pyrolysis gasification or plasma gasification. First, garbage is gasified at high temperature, producing syngas consisting of hydrogen, carbon monoxide and carbon dioxide. While ash and bottom slag melt at high temperatures, all kinds of solid dioxin are decomposed completely and molten heavy metals are solidified in the glassy slag. The syngas produced by gasification can be used as either fuel or industrial raw material (Šuhaj et al., 2020).

As a potential substitute for coal-like energy, RDF is catching worldwide focus now. In Japan, Scandinavia and Switzerland, 74%, 53%, 27% of the energy in wastes was recovered by transforming the wastes to RDF respectively (Yang et al., 2021). In the UK, RDF is increasingly being accepted as an alternative renewable energy source (Yang et al., 2021). In addition to developed countries, interest in recycling RDF from municipal solid waste has expanded to some developing countries, including Indonesia (Anasstasia et al., 2020, Paramita et al., 2018), Brazil (Paramita et al., 2018), India (Thawani et al., 2020), Thailand (Eaktasang et al., 2019). Indonesia published guidelines to emphasize the proposed facility design for the disposal of RDF of the best quality, rules of feed-in tariffs for RDF treatments and stricter municipal solid waste management law. Governments of India and Thailand implemented waste management and energy-related policies to enhance the conversion of municipal solid waste into RDF as an alternative to coal similarly (Yang et al., 2021, Srisaeng et al., 2017). South Africa relies heavily on coal to meet more than 75 percent of the country's energy demands, which undoubtedly makes South Africa face the problems in energy security and environmental issues (Joshua and Bekun, 2020). Therefore, in response to these crises, a carbon tax was launched by the government in 2019, which aims to reduce carbon emissions from power plants and shift the use of fossil fuels towards renewable energy steadily. Additionally, carbon tax incentives are offered to companies, promoting the growth of the development and application of renewable energy by government. Those facilitate the development of transforming municipal solid waste into RDF, which received more and more attention in the country (Yang et al., 2021).

The promotion and application of RDF should be adapted to local conditions. Ningbo is the city of China discussed in the paper. The city is a famous manufacturing capital. With the promotion of the "246" strategy, a number of industrial clusters have been formed in the city, such as green petrochemical, automobile manufacturing, high-end equipment, key basic parts (components) and new materials. In 2021, the GDP of the region achieved 1459.49 billion yuan, involving 221 million yuan of gross value of industrial output. In terms of the carbon emissions, during 1978 and 2012, China, as a manufacturing powerhouse, witnessed the increase of total carbon dioxide emissions approximately at 550 million tons, accounting for the 75.8% contemporary global growth (Yang and Li, 2017). To successfully meet the global carbon dioxide mitigation goal, China issued that the peak carbon dioxide emissions should be reached by 2030 and achieve carbon neutrality before 2060 (General Office of the State Council, 2021).

This paper explores and analyzes the applicability of RDF in Ningbo, China. The energy structure and trend are analyzed first. The market demand of RDF as the alternative to coal is then discussed based on the main application technologies and the characteristics of energy consumption in the region. Next, the sources of RDF are evaluated. Finally, recommendations for the application of RDF in Ningbo are given. This paper aims to demonstrate that RDF is suitable to be applied as the alternative to coal in Ningbo and make recommendations on the promotion of RDF, which are also expected to provide references for other cities to facilitate the application of RDF.

2. THE ENERGY SITUATION IN NINGBO

2.1 The current structure of energy

Ningbo is a typical industrial city with high energy consumption. In 2020, the total energy consumption of the city was 45.6 Mtce, among which the total energy consumption of the primary industry was 0.7 Mtce. The secondary industry consumed 33.7 million tons of

standard coal. Also, there was 16% of the total consumption in the tertiary industry, as shown in table 1. The composition of the primary energy consumption is shown in table 2. 33.4 million tons of raw coal was consumed, equivalent to 23.9 Mtce, accounting for 35.6% of the total amount. The amount of crude oil and natural gas accounted for 57.6% and 4.6% in standard coal, respectively. It should be noted that the proportion of clean energy in primary energy has not exceeded 2.1% for many years due to the massive energy consumption. Though the government has made a lot of effort in low-carbon target in recent years, the space for the development of photovoltaic and wind energy in Ningbo is limited by the natural endowment (Bureau of Energy Ningbo, 2020).

Table 1

The Energy Consumption Structure in 2020, Ningbo

	Total	Primary Industry	Secondary Industry	Tertiary Industry	Household
Amount (Mtce)	45.6	0.7	33.7	7.3	3.9
Proportion (%)	100.0%	1.5%	73.9%	16.0%	8.6%

Table 2

The Composition of the Primary Energy Consumption in 2020, Ningbo

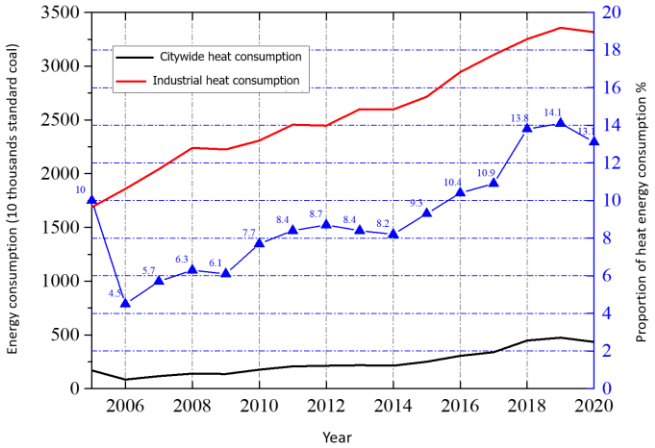
Primary Energy	Consumption amount	Standard coal equivalent (Mtce)	Proportion (%)
Raw coal	33.4 million tons	23.9	35.6%
Crude oil	27.0 million tons	38.6	57.6%
Natural gas	2.6 billion m^3	3.1	4.6%
Renewable energy	-	1.4	2.1%
Total	-	67.1	100.0%

2.2 The trend of energy consumption

The rapid development of industrial economy is dependent on the consumption of large amount of energy. Tremendous consumption of steam is the main feature of the current situation of industry in Ningbo. The proportion of thermal energy consumption in the industrial energy consumption is shown in figure 1 (Bureau of Energy Ningbo, 2020). It is clear that the ratio of thermal energy consumption against industrial energy consumption increased gradually, exceeding 14% in 2019.

Figure 1

The Change of the Proportion of Thermal Energy Consumption in Industrial Energy Consumption in Ningbo

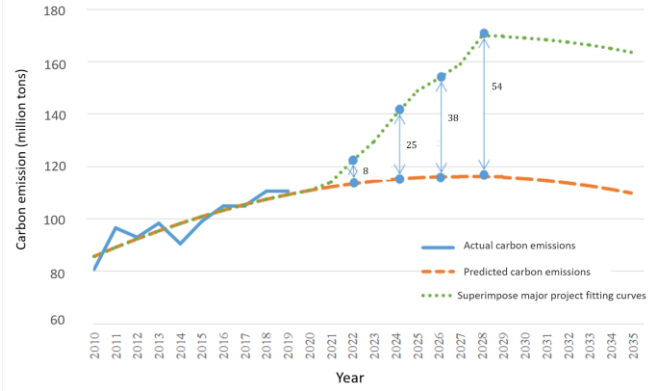


(Bureau of Energy Ningbo, 2020)

There will be a large number of projects in operation during the 15th five-year plan. The trend of carbon emission in Ningbo is shown in figure 2 from 2010 to 2019, followed by the estimation until 2030 (Bureau of Energy Ningbo, 2020). It is shown that there will be a significant discrepancy between the curve based on the past energy consumption and the curve considering the scheduled major projects, with the emission gap predicted to be 54 million tons in 2028.

Figure 2

The Trend of Carbon Emission of Major Projects in Ningbo



(Bureau of Energy Ningbo, 2020)

3. THE POTENTIAL MARKET OF RDF IN NINGBO

3.1 The potential of blending combustion

The boiler types of RDF blending combustion are generally fluidized bed, chain furnace, grate furnace and bubbling furnace, while coal water slurry boiler, pulverized coal furnace and other boiler types are not suitable for RDF blending combustion. According to the survey, the installed output of fluidized bed, chain furnace, grate furnace and bubbling-furnace in Ningbo is 5100 steam tons/hour. There is RDF replacement potential of approximately 1.95 Mtce with a replacement rate of 30%, at running time of 6,500 hours, assuming the calorific value of RDF equal to 80% of standard coal.

3.2 The industrial steam market of RDF direct combustion

Without considering the existing demand of lowering carbon emissions in the steam market, the incremental energy demand brought by the development of economy leads to a carbon dioxide emission index gap of 30 million tons. Specifically, a steam power center of 800 steam tons can be deployed in Zhenhai Chemical Industry Zone, Qingsi Chemical Industry Zone, Daxie East and Chuanbi Road respectively, which also have a market potential of about 4 Mtce according to the distribution of chemical industry in Ningbo.

3.3 Market of RDF hydrogen production

The demand for hydrogen is so strong in Ningbo that the price of hydrogen for coal-to-pipeline soared from 1.4 yuan/m^3 in 2021 to 2.3 yuan/m^3 in 2022. According to the investigation, the demand for hydrogen of general chemical enterprises, such as Bohui, Jinyang, Henghe and Fude, is more than 20,000 m^3/ h, neglecting the hydrogen demand brought by the expansion of Sinopec zhenhai refinery into account. Assuming that four companies have hydrogen requirements on the similar scale, the market potential for RDF is about 1.2 Mtce per year, based on the full refactoring of gasification syngas into hydrogen

As shown in table 3, Ningbo is estimated to have a demand for RDF of more than 7 Mtce a year.

Table 3

The Estimated Demand for RDF

	Blending combustion	Direct combustion	H_2 market	Total
Demand (Mtce/year)	1.95	4	1.2	7.15

4. RDF SOURCES IN NINGBO

RDF raw materials come from a wide range of sources, including general industrial waste, municipal household waste, garden waste and agricultural waste. With the acceleration of urbanization and waste classification in Ningbo, especially the construction of the national "waste free city"(General Office of Zhejiang Provincial People's Government, 2020), the sources of RDF are likely to be promised.

4.1 *Municipal household waste*

In 2021, the annual resident population of the whole city is about 9.4 million (Statistical of Bureau Ningbo, 2021). Based on the waste production of 1.35KG per capita, the daily amount of domestic waste is about 12,000 tons. Assuming that 30% of the produced waste is wet waste and 70% is dry waste, the amount of domestic waste that can be used as raw material for making RDF is about 8400 tons per day. Therefore, Ningbo has a resource potential of around 3 million tons per year.

4.2 Garden rubbish

Garden waste mainly comes from park greening, road greening, residential areas and plant regions, which are mainly divided into two categories, one is plant debris including fallen leaves, grass chips and leaf chips, and the other is larger plant branches. According to relevant data, the total amount of landscaping waste generated in the six districts of Ningbo is 200,000 tons per year (Planning and Design Research Institute Ningbo, 2019).

4.3 General industrial solid waste

General industrial solid waste refers to the part containing calorific value and produced in industrial production activities, such as waste materials of clothing

industry, various packaging materials and so on. It is very difficult to estimate this part because of the industrial structure of the region, for example, some chemical plants only have hazardous waste disposal without general industrial solid waste disposal caused by comprehensive utilization. Also, the industry is still in its infancy, and there is no statistical data yet. According to experience, raw materials of RDF of can be estimated at 5000 tons per day based on the GDP of the city, so that the potential RDF raw material resources in Ningbo is about 2 million tons per year.

The RDF sources in Ningbo are listed in table 4, showing that the region can promise the RDF production of 5.2 million tons per year.

Table 4

The Estimated RDF Sources in Ningbo

	Municipal household waste	Garden rubbish	General industrial solid waste	Total
Amount (Mtce/year)	3	0.2	2	5.2

5. DISCUSSION

Ningbo is a typical industrial city with enormous energy consumption. It is indicated that the carbon emission, or the demand for the fuel, will hardly be reduced in the following several years in Ningbo. Otherwise, the scheduled major projects have to be suspended. With the targets reaching the peak of carbon dioxide emission by 2030 and achieving carbon neutrality by 2060, it is a problem left to be solved by local government that how to attain a balance between the economic development and the carbon emission limit.

Based on the potential large market of RDF of more than 7 Mtce per year in Ningbo, RDF is considered to be a suitable choice as an alternative to the coal. The policy, “new renewable energy and raw materials is not included in total energy consumption control” mentioned on the Central Economic Working Conference provides a policy basis for RDF to replace coal. Energy consumption index may no longer become an obstacle in the development of economy if abundant of RDF is guaranteed to be supplied. Though the sources of RDF in the region may not satisfy the total demand for RDF in Ningbo, the estimated supply of 5.2 Mtce of RDF is likely to mitigate the serious conflict between the economy development and the low carbon targets.

6. CONCLUSION AND RECOMMENDATIONS

RDF is a fuel made from various kinds of waste. The application of RDF is supposed to benefit the environmental protection as an alternative fuel for coal. As an industrial city with the feature of the massive assumption of primary energy, Ningbo shows a large demand for the RDF and is able to supply considerable sources for RDF production. The application of RDF should be actively promoted in order to achieve the goals of "carbon emissions peaked" by 2030 and “attaining carbon neutrality” by 2060, reducing the restraint of the economy development as much as possible.

To enhance the promotion of RDF, supportive policies are expected to be published, including the financial subsidies, quotas, subsidies policy, tax policy, investment and financing policy, land policy, encouraging relevant enterprises to shift excessive RDF resources of other regions to Ningbo. In the meantime, the conception that RDF is a strategic resource related to Ningbo economic development should be established, especially among the government.

Also, it is suggested to encourage more investment in the scientific research funds and the technology introduction. First, trials and demonstrations should be conducted actively. As a new type of fuel derived from waste, RDF needs strong support from relevant government departments in terms of production, transportation and application. Second, the introduction and innovation of RDF clean energy technologies should be promoted. Although there are many RDF gasification projects around the world, they mainly focus on the agricultural waste, especially in China. Gasification technologies of domestic waste and general industrial solid waste are mainly owned by enterprises in Britain, Germany, Switzerland and other countries. It is necessary to enhance the introduction and incubation of relevant technologies. Third, the collaborative mechanism of RDF and low-carbon energy industry chain should be devised to avoid the potential risks of security and supply in the transformation. This should be reflected in spatial planning and energy planning.

Furthermore, it is recommended to increase the research on low-carbon policies. Relevant methodological researches need to be carried out under the framework agreement of the United Nations on the low carbon characteristics of RDF and the impact of carbon footprint certification on the export of related products, especially the research on the path to achieve carbon neutrality in Ningbo and China to further demonstrate the role of RDF in the reduction of carbon emission. The development of low-carbon industry will be achieved through finding new opportunities in international carbon finance, utilizing international low-carbon technology transfer, developing low-carbon investment and low-carbon industry planning.

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