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# Discussion on the Feasibility of Industrial Fuel Gas Prepared by Lurgi Gasification Which Used Anthracite as Raw Material

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## Abstract

The long, stable operation of Jinshi and Tianqing programs proved the feasibility of Lurgi gasification by using Jincheng anthracite as raw material. Compared to other types of coal, Lurgi gasification by using Jincheng anthracite as raw material showed advantages including environmental protection, water consumption, effluent disposal, etc. By analyzing the characteristics of Lurgi gasification by using Jincheng anthracite as raw material, we discussed the choice of technical route and confirmed that the route of industrial gas, coal chemical products, and natural gas could exploit the advantage to the full. Finally, techno-economic evaluation of fuel gas prepared by Lurgi gasification with anthracite as raw material was discussed, and the result showed that industrial fuel gas produced by Lurgi gasification with anthracite as raw material could become an alternative to natural gas in industrial fuel gas field.

**Keywords:** fuel gas, Lurgi gasification, anthracite, techno-economic evaluation

## 1. Introduction

As a large corporate group, Jincheng Anthracite Coal Mining Group Corporation Limited (JAMG) mainly deals with the exploitation and sale of anthracite. In the past, when new coal gasification technology had not been industrialized, United Gas Improvement Company gasification (UGI) technology was the major gasification technology in coal chemical industry. Since the beginning of twenty-first century, many types of gasification technology designed for other types of coal has gradually industrialized and matured, such as HT-L gasification technology [1], SE pulverized coal gasification technology [2], GSP gasification technology [3], shell gasification technology [4], opposed multi-burner coal water slurry gasification technology [5], and Texaco coal-water slurry gasification technology [6]. The monopolistic status of anthracite as raw material in chemical industry has been broken. Expanding the application of anthracite has become the key issue for the sustainable development of JAMG.

In China, industrial fuel gas, which was produced by two-stage coal gasification technology and fluidized-bed coal gasification technology, is mainly applied in glass industry, ceramics industry, nonferrous metal industry, etc. However, with the development of society, the mode of production is no longer suitable eager for

transformation and sustainable development. Production mode with characteristics of environment-friendly, supply-stable, and low cost is the development trend of industrial fuel gas [7, 8].

Natural gas, which is recognized as the cleanest fossil energy resource, has been vigorously promoted by the government in industrial fuel gas field. But as the characteristics of resource endowment in China are “rich coal, lack of oil, and less gas,” the supply of natural gas in industrial fuel gas field is far from enough. How to acquire other types of industrial fuel gas which can meet with the development trend has become the key issue for the sustainable development of glass industry, ceramics industry, nonferrous metal industry, etc. [7–9].

In China, the resource endowment is rich in coal and lack of oil and gas. It is a good way to make full use of abundant coal resources to produce industrial fuel gas. According to the movement state of coal and gasifier in the gasifier, coal gasification technology has three kinds: fixed bed gasification technology, fluidized bed gasification technology, and entrained bed gasification technology [10, 11].

Fixed bed gasification technology mainly includes intermittent atmospheric fixed bed (UGI), Lurgi, BGL, etc. Intermittent atmospheric fixed bed is being phased out worldwide because of its high pollution and energy consumption. Lurgi furnace is made of crushed (lump) coal as raw material. The content of effective gas ( $\text{CO} + \text{H}_2$ ) and methane is about 65 and 8–10%, respectively. It is suitable for producing industrial fuel gas. Compared with other kinds of coal, the tar, phenol, and ammonia produced from anthracite are less difficult to treat, and the amount of waste water is also less [10–12].

The representative types of fluidized bed are high temperature Winkler gasification technology and ash fusion gasification technology of Shanxi Coal Chemical Institute. Because the technology has many problems, such as low effective component, high impurity (high carbon content, difficult separation), high activity of coal, and high ash melting point, it is seldom used in China [10, 11].

At present, the entrained flow bed is the main choice for large-scale production. The representative furnace type is shell, space furnace (HT-L), Texaco, etc. Its characteristics are high reaction temperature (1500–2000°C) and high conversion efficiency. Its effective gas composition ( $\text{CO} + \text{H}_2$ ) is as high as 85–92%, while  $\text{CH}_4$  composition is very low or almost no, and its calorific value is relatively low, so it is not suitable for the production of industrial fuel gas [10, 11, 13].

So, the application as an industrial fuel gas by taking Lurgi gasification, which used anthracite as raw material can expand consumption field of anthracite, simultaneously, offers a sustainable alternative choice for industrial fuel gas industry [7, 8, 13].

## **2. Feasibility of producing industrial fuel gas from anthracite**

### **2.1 Status of industrial fuel gas in China**

Fuel gas mainly includes natural gas, biogas, liquid gas, coke-oven gas, blast furnace gas, producer gas, and so on, which is widely applied in glass processing industry, ceramics production, non-ferrous metal smelting and melting, steel rolling, refractory production, etc. The source of fuel gas is multifarious and specification is complicated, but the market capacity is broad.

From the development of industrial fuel gas, many types of fuel were applied in industrial fuel gas, such as coal, electricity, heavy oil, coke oven gas, blast furnace tail gas, syngas, and natural gas. At present, the proportion of syngas (producer gas) is the largest. However, with the increasing pressure of environmental protection and publication of coal to natural gas policy, the proportion of producer gas

is gradually decreasing and the proportion of natural gas is gradually increasing. **Table 1** shows specifications of fuel gases that are produced by different production technologies and with different raw materials.

The development of fuel gas derived from coal is shown as follows: first of all, UGI gasification technology, which was introduced in China in the 1930s, became the earliest technology for fuel gas derived from coal and the most widely applied technology for industrial fuel gas; because of its best adaptable to UGI gasifier, anthracite became the favorite raw material. Then, with the rise in price of anthracite, many enterprises transformed one-stage gasifier to two-stage gasifier and used low-rank lump bituminous coal as raw material to reduce production cost; simultaneously, fluidized-bed gasification technology sprung up and gradually promoted in industrial fuel gas, which led to occupy a certain proportion of the market. Now, with the development of society and improvement of environmental consciousness, Chinese government vigorously advocates the application of natural gas in fuel gas field, for its properties of being green, having low carbon, and being recognized as the cleanest fossil energy resource.

At present, problems such as low efficiency and high pollution generally exist in coal gasification technology in operation and the projects face with elimination. Many local governments require fuel gas industry to switch to natural gas, but downstream industries prefer to fuel gas derived from coal through our research. The reasons are shown as follows:

1. For its high price and unstable supply, the quantity of natural gas cannot be guaranteed at the peak of consumption.
2. For its high calorific value, high local temperature during combustion results in high content of nitrogen oxides, and the cost of denitrification is 1–3 times higher than that of coal gas.

Considering all aspects, stable supply, friendly environment, and low price are the future development directions of industrial fuel gas.

## **2.2 Choice of technical route by taking Lurgi gasification which used anthracite as raw material**

In JAMG, the product of anthracite is primarily divided into two varieties, lump coal having particle size over 13 mm and slack coal having particle size below 13 mm [16]. Lump coal is widely used in ammonia synthesis and slightly used in civil combustion. In 2016, the sales of lump coal in coal chemistry were  $1058 \times 10^4$  MT, which accounted for 80% of anthracite lump coal sales in JAMG. When new coal gasification technology has not been industrialized, anthracite lump coal was the high-quality raw material for chemical plant. For its scarcity and monopoly, anthracite lump coal had much higher price over other kinds of coal, which formed core competence for JAMG.

Since the beginning of twenty-first century, many types of gasification technology designed for other types of coal has gradually industrialized and matured, such as HT-L gasification technology, SE pulverized coal gasification technology, GSP gasification technology, shell gasification technology, opposed multi-burner coal water slurry gasification technology, and Texaco coal water slurry gasification technology. The monopolistic status of anthracite as raw material of chemical industry has been broken. Simultaneously, the gradual withdrawal of UGI furnace from chemical industry market has become a general trend and is difficult to reverse for its own technical defects. If we cannot expand new application fields, anthracite lump coal will face the market risk of falling volume and price.

Fuel gases derived from different sources		H <sub>2</sub> (%)	CO (%)	CH <sub>4</sub> (%)	C2 (%)	C3 (%)	C4 (%)	C5+ (%)	Calorific value (kcal/Nm <sup>3</sup> )
Natural gas		—	—	97	1.5	0.5			8200–8700
Heavy oil		—	—	—	—	—	—	—	10,000–11,000 kcal/kg
Liquefied petroleum gas (LPG)	Beijing	—	—	1.5	1.0	13.5	80.2	3.8	10,800–12,000 kcal/kg
	Daqing	—	—	1.3	0.2	22.4	61.7	12.6	
Gas from oil	Catalytic cracking	58.1	10.5	16.6	5	—	—	—	4500
	Thermal cracking	31.5	2.7	28.5	26.4	5.7	—	—	10,000
Syngas from coal	Coke oven gas	59.2	8.6	23.4	—	—	—	—	4000–4500
	Converter gas	2–3	60–70	—	—	—	—	—	2000–2200
	Blast furnace tail gas	1.5–3	25–30	0.2–0.5	—	—	—	—	800–950
	One-stage gasification	7–10	23–27	1.5–3	—	—	—	—	1250–1400
	Two-stage gasification	11–15	27–31	1.5–3	—	—	—	—	1450–1600
	Oxygen enrichment gasification	30–35	30–35	1.5–2	—	—	—	—	1600–1800
	Lurgi gasification with anthracite as raw coal	35–40	25–27	75–95	—	—	—	—	2400–2600
	Fluidized-bed gasification	39	29	—	—	—	—	—	1300–2000
	Dry-pulverized gasification	19.9	66.3	—	—	—	—	—	2450–2650
	Coal water slurry gasification	35–36	44–51	—	—	—	—	—	2100–2400

*Note: fuel gas derived from coal to syngas refers to crude syngas at the outlet of gasifier without any treatment.*

**Table 1.**  
*Specifications of fuel gases produced by different production technologies and with different raw materials [14, 15].*

The 13th Five-Year Plan of JAMG pointed out: till 2020, JAMG will build a 100 million MT coal production base and anthracite raw coal output will reach 80 million MT per year. With the gradual operation of a series of integrated coal mines, the output of anthracite lump coal will increase year by year. The mismatch between continuously increasing output of anthracite lump coal and shrinking consumption of anthracite lump coal is becoming the main contradiction, which perplexes the development of JAMG. Actively exploiting application field of anthracite lump coal has become the key to solve the above contradiction. Application as industrial fuel gas by taking Lurgi gasification, which used anthracite as raw material positively, responds to the above proposition.

The long-term, stable operation of Jinshi and Tianqing projects proved the feasibility of Lurgi gasification by using anthracite as raw material. Compared to other types of coal, Lurgi gasification by using Jincheng anthracite as raw material showed advantages including environmental protection, water consumption, effluent disposal, etc. By analyzing the characteristics of Lurgi gasification which used Jincheng anthracite as raw material, the choice of technical route was discussed and confirmed that the route of industrial gas, coal chemical products coupled with natural gas could exploit the advantage to the full.



Industrial analysis (%)				Element analysis (%)					$Q_{gr,ad}$ (MJ/kg)	$Q_{net,ad}$ (MJ/kg)	Characteristics of char residue (CRC)	Caking index (GRI)
$M_{ar}$	$M_{ad}$	$A_{ad}$	$V_{ad}$	$C_{ad}$	$H_{ad}$	$O_{ad}$	$N_{ad}$	$S_{t,ad}$				
6.12	2.46	18.98	6.54	71.78	1.90	1.92	0.52	2.44	26.92	25.53	1	0

**Table 2.**  
*Analytic index of no. 15 anthracite.*

2.2.1 Operational aspect of Lurgi gasification by using anthracite as raw material

Jinshi project had a total ammonia production capacity of  $30 \times 10^4$  MT per year, which equipped with four Lurgi gasifiers (three open, one standby). Lurgi gasifiers were Mark-IV type, which were designed by Saiding Engineering Co., Ltd. Gasifier's specification was  $\Phi 4000 \times 12,500$  mm and operation pressure was 3.0 MPa. The designed dry syngas output of gasifier was  $38,000 \text{ Nm}^3/\text{h}$ , and designed raw material was no. 15 anthracite (coal quality data are shown in **Table 2**).

It was the first time in China to produce synthetic ammonium feed gas, which used Lurgi gasification technology with anthracite as designed raw material. The project started in March 2008 and implemented the whole process in May 2014. Through two-and-a-half-year operation, the feasibility of long-term and stable operation of Lurgi gasifier with anthracite as raw material was proved. When the ratio of steam to oxygen was 5.1, the components of crude syngas were shown as follows: CO 27.8%,  $\text{H}_2$  38.4%,  $\text{CH}_4$  7.5%,  $\text{CO}_2$  24.8%,  $\text{O}_2$  0.2%, and others 1.3% and feed consumption was as follows: 0.53 MT raw coal/ $\text{kNm}^3$  crude syngas, 550 kg steam/ $\text{kNm}^3$  crude syngas, and  $169 \text{ Nm}^3 \text{O}_2/\text{kNm}^3$  crude syngas.

Based on the Jinshi project, JAMG founded Tianqing company in Qinyang city, Henan province and implemented a project that had ammonia production capacity of  $30 \times 10^4$  MT and 500 million cubic meters of natural gas per year. The project equipped with six Lurgi gasifiers (five open, one standby). Lurgi gasifiers were Mark-IV type, which were designed by Saiding Engineering Co., Ltd. Gasifier's specification was  $\Phi 4000 \text{ mm} \times 13,000 \text{ mm}$ , and operation pressure was 4.0 MPa. The designed dry syngas output of gasifier was  $42,000 \text{ Nm}^3/\text{h}$ , and designed raw material was no. 15 anthracite.

Since coming into operation in November 2014, the project has achieved long-term and stable operation. When the ratio of steam to oxygen was 4.1, the components of crude syngas were shown as follows: CO 23.6%,  $\text{H}_2$  42.3%,  $\text{CH}_4$  8.3%,  $\text{CO}_2$  24.2%, and others 1.6%, and feed consumption was as follows: 0.45 MT raw coal/ $\text{kNm}^3$  crude syngas, 566 kg steam/ $\text{kNm}^3$  crude syngas, and  $166 \text{ Nm}^3 \text{O}_2/\text{kNm}^3$  crude syngas.

On the basis of implementation of two above projects, JAMG set up a scientific and technical program which named "research and industrial demonstration of pressurized movable bed gasification technology for anthracite." The research and development mainly focused on gasifier structure, cooling process from chilling process to waste boiler process, and coal gas water treatment system. The program aimed to reduce project investment, reduce operation cost, improve energy efficiency, and enhance market competitiveness of Lurgi gasifier with anthracite as raw material.

2.2.2 Characteristics of Lurgi gasification by using anthracite as raw material

Compared with other types of coal, Lurgi gasification by using anthracite as raw material has the following advantages:

1. Because of high hardness, crush ratio and value loss are lower than that of other types of coal while transporting.

2. Because of low content of volatile, there are fewer refractory organic wastes such as tar and phenol in crude syngas than that of other types of coal. Some tar and phenol separation devices in traditional Lurgi gasification technology can be removed, and the investment can be reduced. There are almost no organic impurities such as tar and phenol detected in coal gas water of the outlet gasification section; the  $\text{NH}_3\text{-N}$  and COD contents in waste water are 200 and 400 mg/L, respectively [17], which induced the easiness of waste water treatment and reduction of processing cost.
3. Because of high ash melting point, the process point of gasifier is higher than that of other types of coal. Although the oxygen consumption is slightly higher than that of low-rank coal, gasification efficiency can be greatly improved. The coal gas yield of anthracite is the highest; the effective gas (which is consisted by  $\text{CO}$ ,  $\text{H}_2$ , and  $\text{CH}_4$ ) content ranges from 73 to 75%; and the calorific value of crude syngas is about  $2500 \text{ kJ/Nm}^3$ .

With the increase of gasification temperature, the ratio of steam to oxygen can be decreased greatly and coal gas water treatment capacity can be reduced. Simultaneously, the content of organic compounds in coal gas water will decrease and waste water will be easier to treat.

The above advantages make Lurgi gasifier with anthracite as raw material to show obvious competitiveness over that of other types of coal in environmental protection, water consumption, effluent disposal, etc.

Certainly, compared with other types of coal, Lurgi gasification by using anthracite as raw material has the following disadvantages:

1. Because of low volatile content, the content of  $\text{CH}_4$  in crude syngas is lower than that of other types of coal.
2. Because of low volatile content, the by-products, such as tar, middle distillate, phenol, and naphtha, are lower than that of other types of coal, which lead to low economic benefits.

The above disadvantages, to a certain extent, reduce the economy of Lurgi gasification device with anthracite as raw material. So, to get advantaged position in the fierce market competition, Lurgi gasification with anthracite as raw material needs to optimize the choice of technical route and identify its own position.

### *2.2.3 Choice of technical route by taking Lurgi gasification with anthracite as raw material*

As indicated by research findings [18], the cost of large-scale project of coal to natural gas, which takes Lurgi gasification by using anthracite as raw material, is higher than that of other types of coal, such as Datang and Qinghua projects. Under current international and domestic energy landscape, the project of anthracite coal to natural gas is basically not profitable.

Under current economic development background, technical route of Lurgi gasification with anthracite as raw material has the following choices:

1. Syngas obtained from Lurgi gasification with anthracite as raw material has advantages such as higher calorific value, better environment protection, and cheaper price than natural gas, so as to expand its application in industrial fuel gas fields, such as glass industry, ceramics industry, and nonferrous metal industry.

- 2. Syngas obtained from Lurgi gasification with anthracite as raw material has unique component characteristics, which should give full play and take product route of coal chemical products coupled with natural gas. Coal chemical route should take methane and ethylene glycol as products; natural gas should be sold as a high-priced non-civil product such as vehicle fuel and industrial gas in accordance with the national guidelines for the development of natural gas distributed energy.

2.3 Techno-economic evaluation of fuel gas prepared by Lurgi gasification with anthracite as raw material

2.3.1 Process flow

Through optimized design for anthracite, mainly on gasifier structure, cooling process from chilling process to waste boiler process, and coal gas water treatment system, Lurgi gasification by using anthracite as raw material can exploit the advantage and enhance market competitiveness to the full. The flow chart is shown in **Figure 1**.

2.3.2 Process index

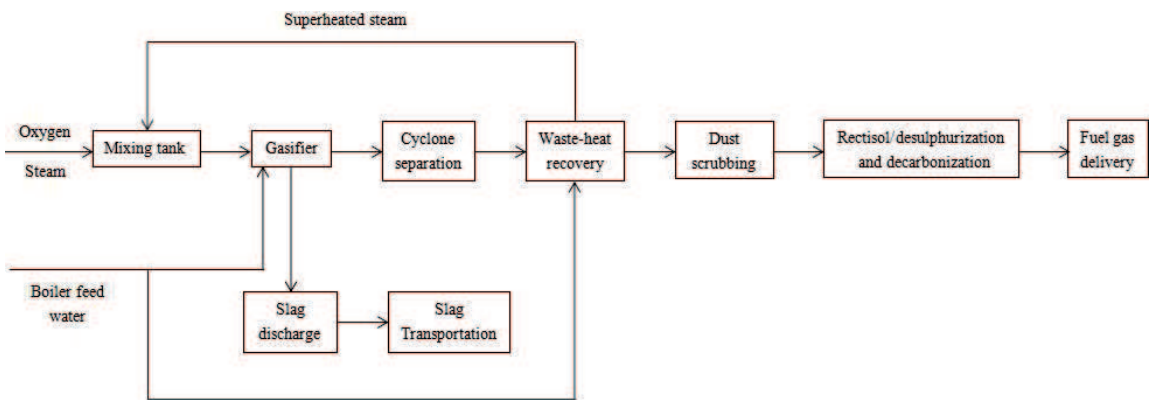
The key factors affecting the gasification process are particle size, cohesion, mechanical strength, operating pressure, and temperature of the gasifier (**Table 3**, the process date of Jinshi and Tianqing projects).

2.3.3 Techno-economic evaluation

Based on the average price of raw material in the past 3 years (shown in **Table 4**), the economics of industrial fuel gas, which was produced by Lurgi gasification with anthracite as raw material, is discussed (shown in **Table 5**). Production capacity of crude syngas is  $10 \times 10^4 \text{ Nm}^3/\text{h}$ . In response to this, production capacity of refined syngas is  $7.4 \times 10^4 \text{ Nm}^3/\text{h}$ .

The result shows that total production cost of crude syngas is  $653.5 \text{ ¥/kNm}^3$ , which is equivalent to  $2.56 \times 10^{-4} \text{ ¥/kcal}$ .

Correspondingly, total production cost of refined syngas is  $960.5 \text{ ¥/kNm}^3$ , which is equivalent to  $2.78 \times 10^{-4} \text{ ¥/kcal}$ . Simultaneously, the average price of domestic pipeline natural gas is  $2.6 \text{ ¥/Nm}^3$ , and the equivalent cost is  $3.06 \times 10^{-4} \text{ ¥/kcal}$ . Therefore, fuel gas produced by Lurgi gasification with anthracite as raw material shows certain advantages over natural gas in cost.



**Figure 1.**  
Flow chart of Lurgi gasification by taking anthracite as raw material.



Name of process index		Value of process index
Type of gasifier		Mark-IV
Reactor temperature		900°C
Residence time		1 h
Process pressure		4.0 MPa
Capacity of single gasifier		500 MT/d
Particle size of raw coal		6–50 mm
Gasification agent		Oxygen and steam
Coal consumption		450 kg/kNm <sup>3</sup> crude syngas
Oxygen consumption		166 kNm <sup>3</sup> /kNm <sup>3</sup> crude syngas
Steam consumption		402 kg/kNm <sup>3</sup> crude syngas
Composition of crude syngas	CO	25
	H <sub>2</sub>	40
	CH <sub>4</sub>	9
	CO <sub>2</sub>	24
Calorific value of crude syngas		2550 kcal/kNm <sup>3</sup>
Calorific value of refined syngas		3450 kcal/kNm <sup>3</sup>

**Table 3.**  
*Process index of Lurgi gasification by taking anthracite as raw material.*

Raw material	Free on board (FOB)	Freight	Average price
Anthracite	800 (¥/MT)	150(¥/MT) (vehicle distance < 300 km; train distance < 750 km)	950 (¥/MT)
Fuel coal	450 (¥/MT)	150(¥/MT) (vehicle distance < 300 km; train distance < 750 km)	600 (¥/MT)
Electricity	–	–	0.5 (¥/kwh)

**Table 4.**  
*Average price of raw material in the past 3 years.*

Furthermore, fuel gas produced by Lurgi gasification with anthracite as raw material has incomparable advantages over natural gas in terms of stable supply and environment friendliness (hydrogen sulfide content is less than 1 mg/Nm<sup>3</sup>), which fully correspond to the future development direction of industrial fuel gas industry.

*2.3.4 Industrial application of fuel gas produced by Lurgi gasification with anthracite as raw material*

Shahe city is the capital of flat glass in China, where production capacity of flat glass accounts for about 20% of the total production capacity in China and a lot amount of industrial fuel gas is consumed yearly. Currently, the production mode of industrial fuel gas in Shahe city basically is shown as follows: each company has its own production device of industrial fuel gas, which produces hot coal gas with calorific value of about 1500 kcal/Nm<sup>3</sup> by taking two-stage coal gasifier with low-rank coal as raw material. This production mode will induce serious environmental pollution for technical defects and scattered allocation. Under the background of

Index	Crude syngas as product	Refined syngas as product
Consumption of anthracite (t/kNm <sup>3</sup> )	0.51	0.69
Cost of anthracite (¥/kNm <sup>3</sup> )	484.5	655.5
Consumption of fuel coal (t/kNm <sup>3</sup> )	0.12	0.2
Cost of fuel coal (¥/kNm <sup>3</sup> )	72	120
Consumption of electricity (t/kNm <sup>3</sup> )	50	100
Cost of electricity (¥/kNm <sup>3</sup> )	25	50
Cost of accessories (¥/kNm <sup>3</sup> )	5	15
Variable cost (¥/kNm <sup>3</sup> )	586.5	840.5
Labor cost (¥/kNm <sup>3</sup> )	10	14
Depreciation and repair costs (¥/kNm <sup>3</sup> )	25	40
Financial cost (¥/kNm <sup>3</sup> )	35	56
Selling expenses management cost (¥/kNm <sup>3</sup> )	7	10
Fixed cost (¥/kNm <sup>3</sup> )	67	120
Total cost (¥/kNm <sup>3</sup> )	653.5	960.5

**Table 5.**  
*Economics of industrial fuel gas that was produced by Lurgi gasification with anthracite as raw material.*

increasingly stringent environmental policies, a large-scale, centralized industrial fuel gas production project is planned to construct, which can supply the need of flat glass production in Shahe area and meet with the need of environment protection.

Through investigation and demonstration, Zemag Slagging Gasification (BGL) technology and Lurgi gasification technology with Shenfu coal as raw material are rejected and Lurgi gasification technology with anthracite as raw material is applied in Shahe project, which validates the technical and economic feasibility of producing industrial fuel gas by Lurgi gasification with anthracite as raw material. The scale of project is 1.6 billion Nm<sup>3</sup> per year, and annual consumption is 1.9 million tons of anthracite and 0.6 billion of fuel coal, respectively, which can broadly expand the utilization of anthracite. Now, the project construction is proceeding in an orderly manner.

Furthermore, our group has established extensive contacts with many projects to produce news types of fuel gas, such as glass production base located in Dezhou, Shandong province, ceramics production base located in Linyi, Shandong province, and economic development zone located in Cangzhou, Hebei province. When the conditions are ripe, our group will follow up rapidly.

### 3. Conclusions

Compared to natural gas, industrial fuel gas produced by Lurgi gasification with anthracite as raw material has the same environmental friendliness, while stable supply and cost are dominant, which has outstanding technical and economic feasibility. The implementation and promotion of Shahe, Dezhou, and other projects have also proved the above feasibility in practical applications.

Under current resource endowment of “rich coal, lack of oil and less gas” in China, development of industrial fuel gas produced by Lurgi gasification with anthracite as raw material has shown outstanding technical and economic feasibility, which can become an alternative to natural gas in industrial fuel gas field.

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## Conflict of interest


We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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