Case studies of biomass co-firing in full-scale pulverized coal-fired (PC) power plants in China

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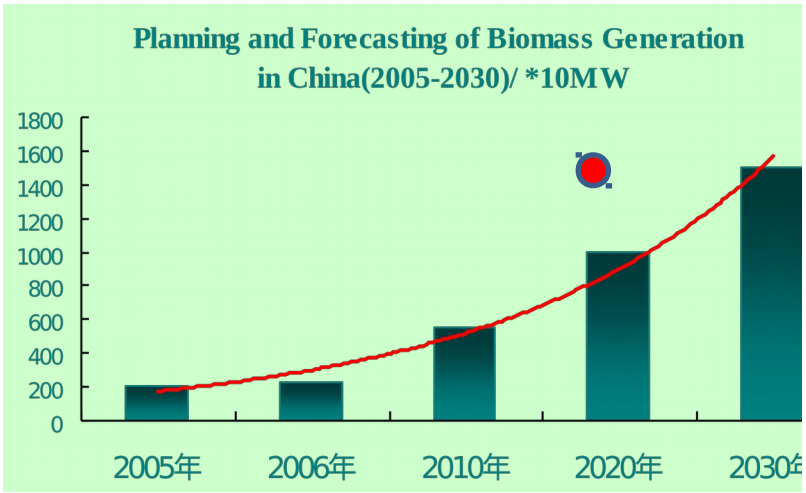
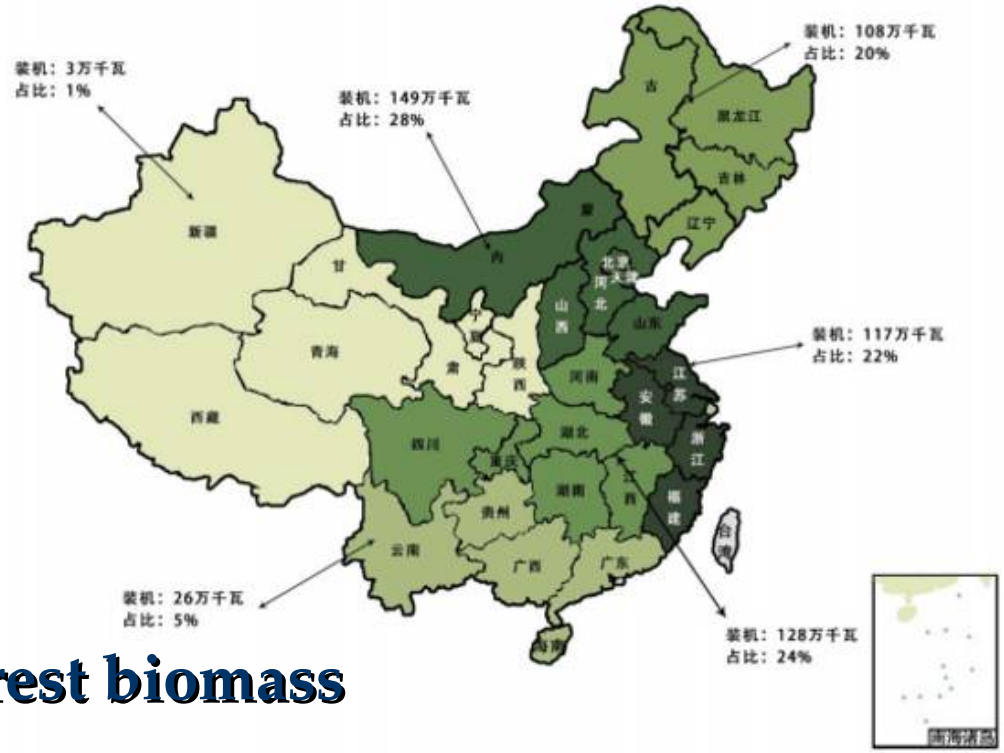
7TH INTERNATIONAL CONFERENCE ON SUSTAINABLE SOLID WASTE MANAGEMENT
26-29 June 2019, Heraklion, Crete Island, Greece

1. Background and motivation.

Biomass-fired power plants in China





- **Actual: >16 GW(2019)**
  - **Half: agriculture and forest biomass**
  - **Half: municipal waste**

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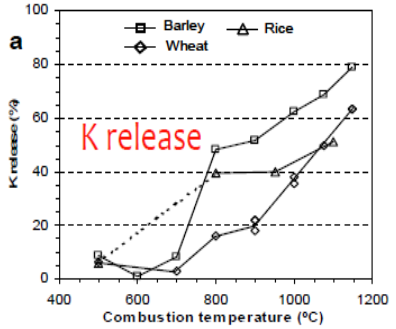
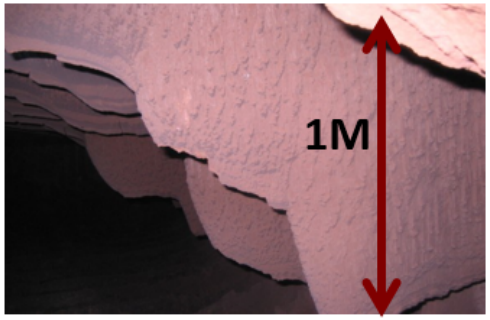
Problems of biomass-fired furnace

Ash deposition, corrosion.





Ash deposition

Corrosion

Low combustion and generating efficiency

UBC in ash > 35%
Generating efficiency < 30%

Biomass co-firing ^_^

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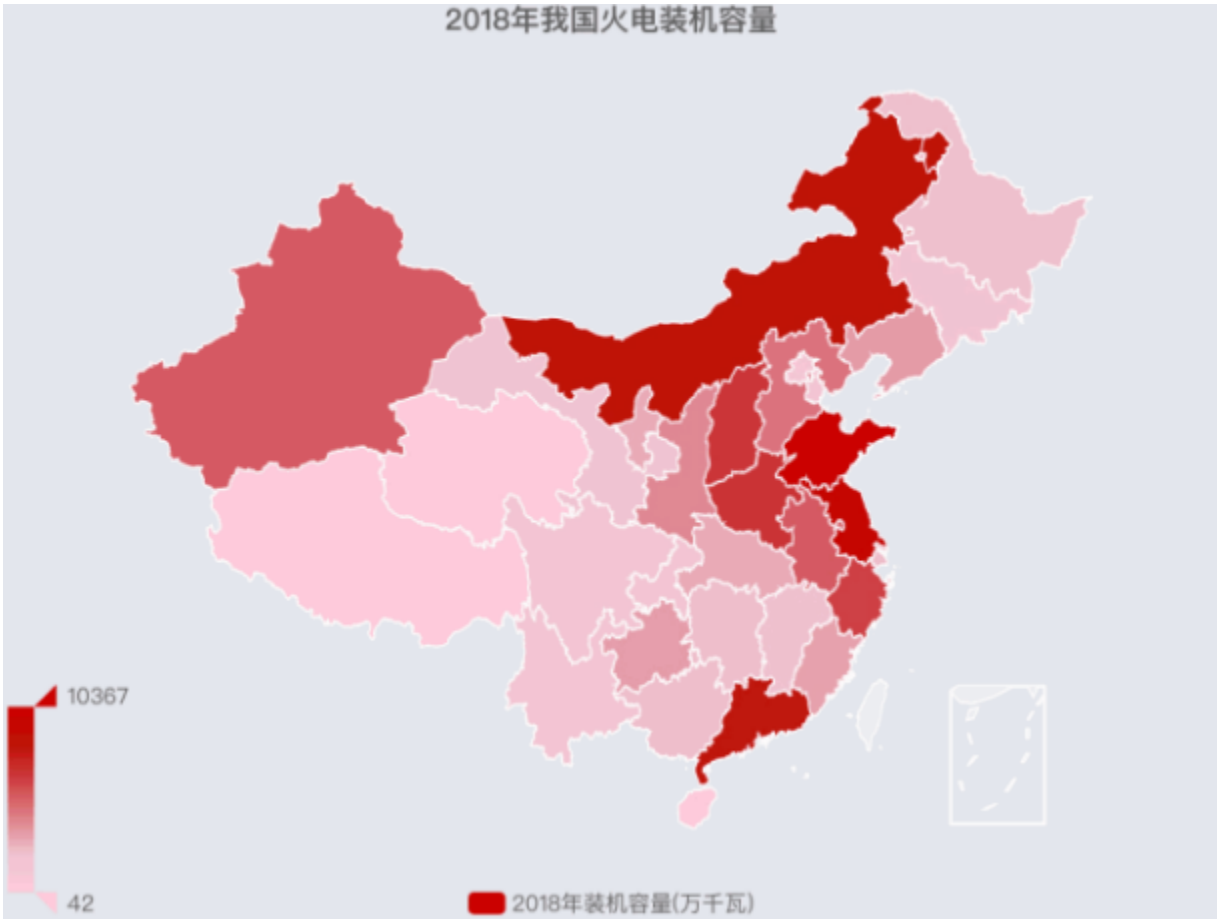
Coal-fired power plants in China



- Total capacity: 1144 GW
- Ultra-low emissions

NOx<50 mg/m3

SOx<35 mg/m3

PM<5 mg/m3

- Near-zero emissions

NOx<25 mg/m3

SOx<10 mg/m3

PM<1 mg/m3

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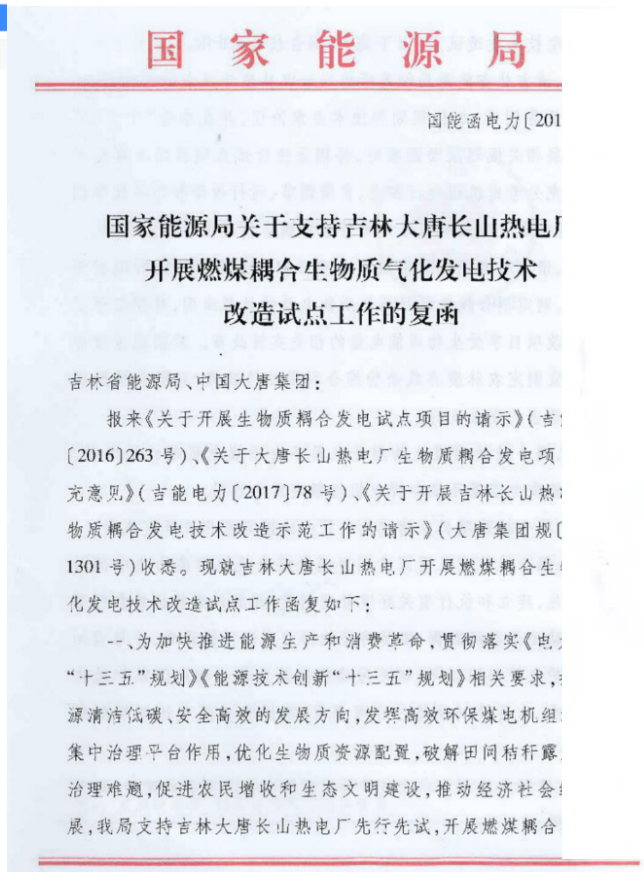
2. Current situation of biomass co-firing in pulverized coal-fired power plants in China

“Biomass co-firing ” → “biomass coupling generating”


国 家 能 源 局

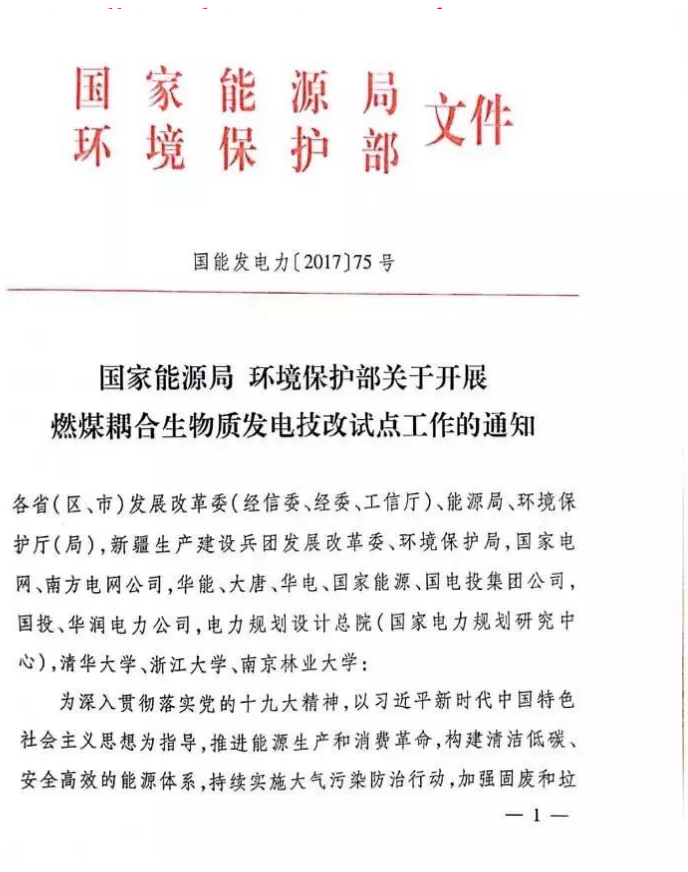
国能函电力〔201

国家能源局关于支持吉林大唐长山热电厂
开展燃煤耦合生物质气化发电技术
改造试点工作的复函

吉林省能源局、中国大唐集团：

报来《关于开展生物质耦合发电试点项目的请示》（吉
〔2016〕263号）、《关于大唐长山热电厂生物质耦合发电项
充意见》（吉能电力〔2017〕78号）、《关于开展吉林长山热
物质耦合发电技术改造示范工作的请示》（大唐集团规〔
1301号）收悉。现就吉林大唐长山热电厂开展燃煤耦合生
化发电技术改造试点工作函复如下：

--、为加快推进能源生产和消费革命，贯彻落实《电
“十三五”规划》《能源技术创新“十三五”规划》相关要求，
源清洁低碳、安全高效的发展方向，发挥高效环保煤电机组
集中治理平台作用，优化生物质资源配置，破解田间秸秆露
治理难题，促进农民增收和生态文明建设，推动经济社会
展，我局支持吉林大唐长山热电厂先行先试，开展燃煤耦合


国 家 能 源 局
环 境 保 护 部 文件

国能发电力〔2017〕75号

国家能源局 环境保护部关于开展
燃煤耦合生物质发电技改试点工作的通知

各省（区、市）发展改革委（经信委、经委、工信厅）、能源局、环境保护厅（局），新疆生产建设兵团发展改革委、环境保护局，国家电网、南方电网公司，华能、大唐、华电、国家能源、国电投集团公司，国投、华润电力公司，电力规划设计总院（国家电力规划研究中心），清华大学、浙江大学、南京林业大学：

为深入贯彻落实党的十九大精神，以习近平新时代中国特色社会主义思想为指导，推进能源生产和消费革命，构建清洁低碳、安全高效的能源体系，持续实施大气污染防治行动，加强固废和垃

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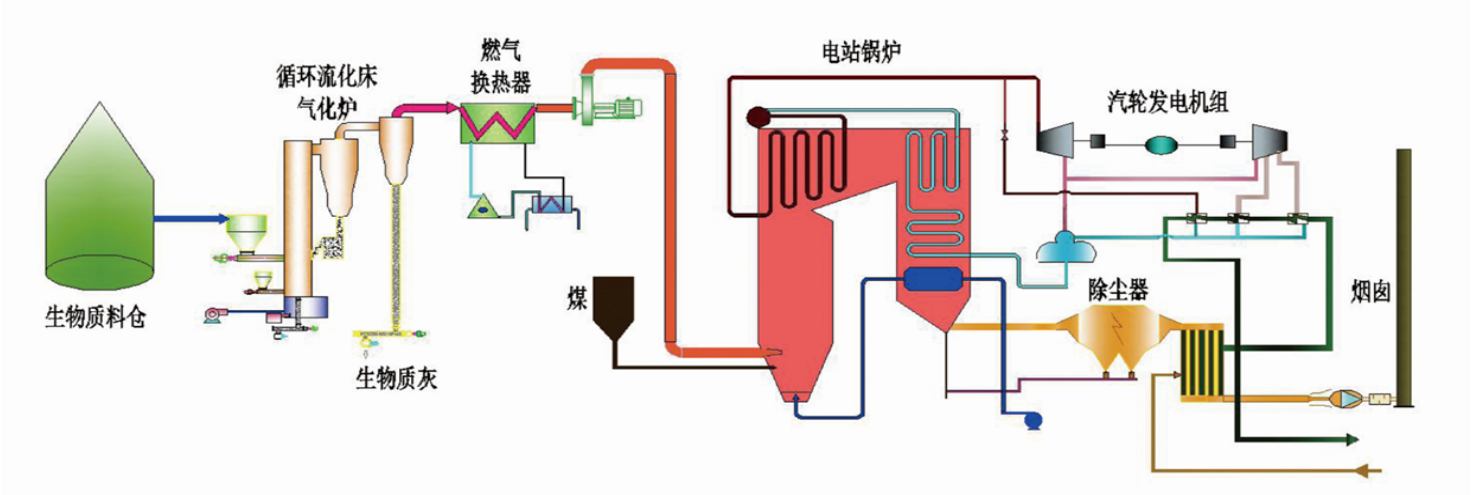
Biomass (gasification) coupling generating in large-scale PC power plants



Biomass gasifier + **Coal-fired power plant**

The only one case of "biomass gasification coupling": Guodian Changyuan Jinmen Power Plant

- Biomass: 8-10 t/h.
- CFB gasifier.
- 600 MW coal-fired unit.
- Commercially operated since 2012.11.
- 0.75 RMB/kwh.
  - Other in Hubei, +0.081RMB/kwh.

Advantages and questions of "biomass gasification coupling"

Advantages：

From a supporting report.

1.Gas transporting temperature >400°C, avoid tar condensation in pipelines.

2.Able to on-line measure the gas composition, heating value, and flux, thereby obtain the feed-in subsidy price: 0.75 RMB/kwh.

Questions (2018.5)：

1.Avoid coal-blending?

2.Tar in gasifier?

3.High investment： 60,000,000 RMB (8-10t/h, 10 MW).

4.Complex system, need to retrofit the coal-fired furnace.

5.Coal gasification? (effective monitoring?)

6.Inherent operating problems of CFB boilers/gasifiers.

7.Fouling in gasifier's heat exchanger?

8.Gasification efficiency?

9.Bio-char market?

News: no subsidy for "biomass coupling generating" from the State Level-2018.6

- The subsidy (0.75 RMB/kwh) for the only project obtaining the subsidy from the State Level was canceled, since 2018.6.
- Whether subsidy or not depends on the local government.

浙江省发展和改革委员会
Zhejiang Provincial Development and Reform Commission

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据悉，此次发布的补贴目录共包含97个生物质发电项目。其中，农林生物质发电项目26个，垃圾焚烧发电项目50个，沼气发电项目21个。在《可再生能源电价附加资金补助目录更正表（可再生能源发电项目）》中特别强调，暂停对第五批目录中“国电长源荆门掇刀秸秆、稻壳气化工业示范10.8MW生物质发电工程”进行补贴拨付。换言之，在此前公布的多批次补贴目录中，燃煤生物质耦合发电项目仅涉及国电长源荆门一例。此前，该项目和农林生物质发电项目享受同样的0.75元/千瓦时的标杆电价。

Another mode of biomass co-firing: “Huadian Shiliquan” , the first one in China since 2005.

Coal fired furnace: 400t/h, tangential combustion.
Fuel: wheat straw and corn straw.
Designed straw capacity: 105000 t/year, accounting for 18.6% energy input.
Time: put into operation since 2005. 12.

上图：秸秆料仓。
右上：秸秆原料输送。
右下：秸秆原料入锅炉
（三根加料管中，中间的为秸秆，上下均为燃煤）

The problems of "Huadian Shiliquan Mode" co-firing.

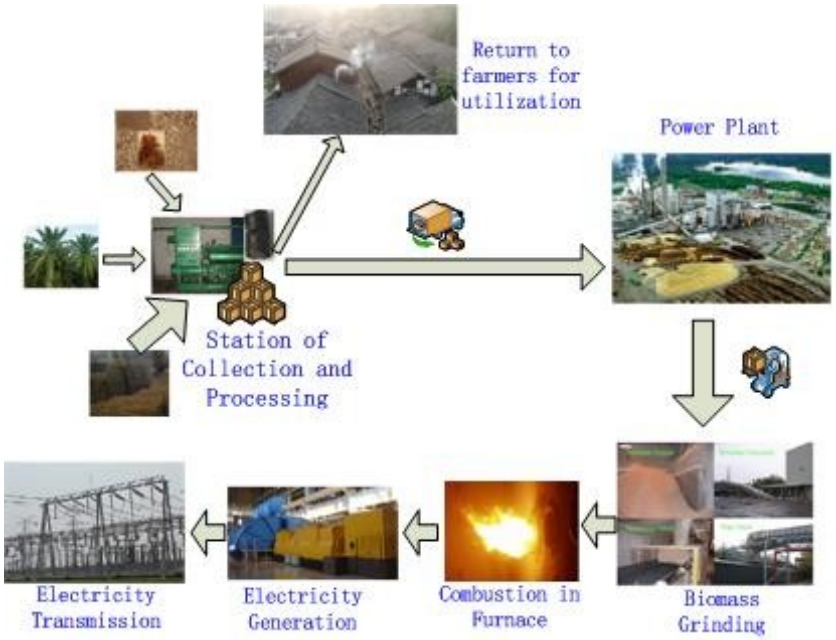
Technical：

1. **The imported equipment for fuel treatment and combustion, huge investment >85,000,000 RMB.**
2. **The uncontrolled biomass price: 200 RMB/t → 500 RMB/t.**
3. **The equipment for fuel treatment can only cut straw.**
4. **Straw supplying is not enough: the actual co-firing ratio is only ~5%.**

Policy:

1. **State government: no subsidy for biomass co-firing.**
2. **Local government: obtain the additional subsidy of 0.08 RMB/kwh.**

XJTU-Bao'er mode: briquette biomass co-firing

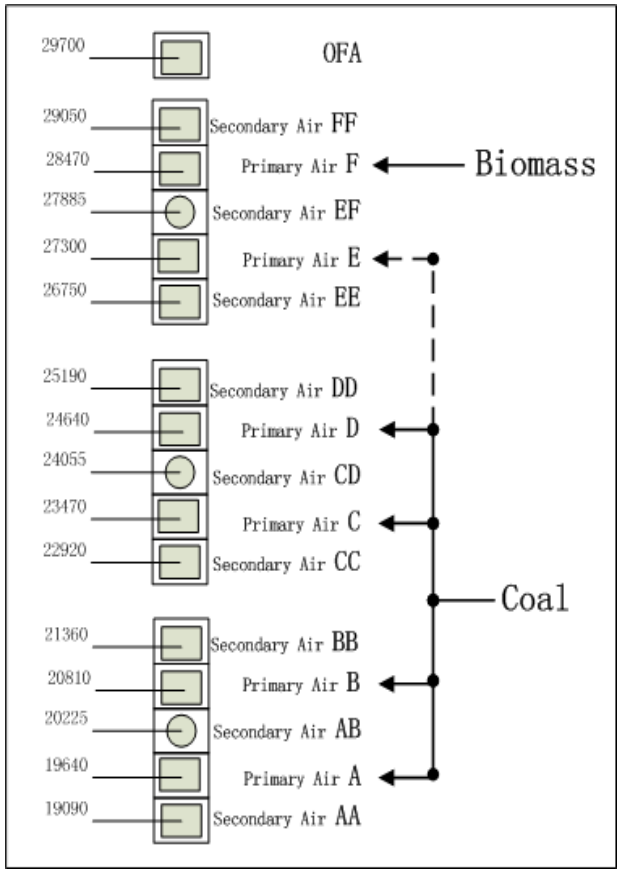


Additional benefits：

- ✓ Zero investment for power plant
- ✓ Long commercial chain, increasing job positions
- ✓ Decrease transporting cost
- ✓ Larger co-firing amount

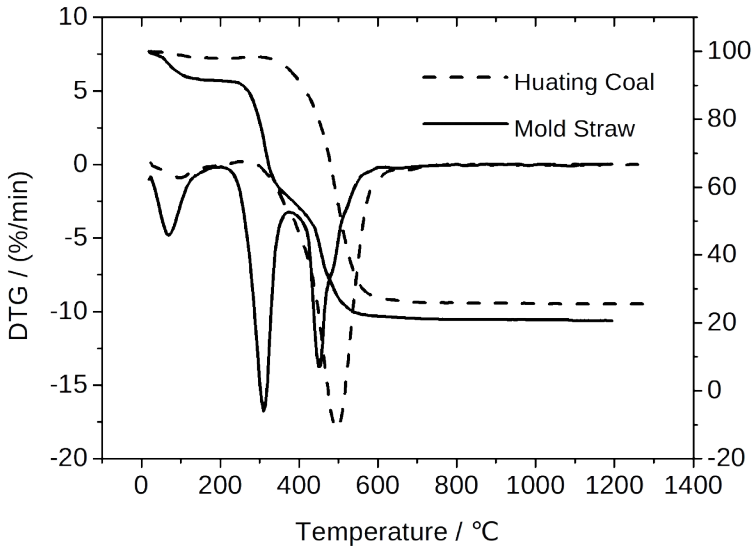
Tested Furnace and Biomass Feeding

- Furnace Parameters
  - 300MW， 1025t/h
  - Tangentially fired furnace
  - A-F, 6 layer combustors
  - Medium-speed roller mill
  - Direct-blow coal powder system
- **Position of Biomass Feeding**
  - **F bunker (standby one)**



Fuel Characteristics

Fuel	$Q_{net,ar}$/ MJ.Kg^{-1}	Proximate analysis			Ultimate analysis				
		M_{ar}	V_{daf}	A_{ar}	C_{ar}	H_{ar}	O_{ar}	N_{ar}	S_{ar}
Huating Coal	**18.7**	**18.5**	**35.5**	**17.6**	**57.9**	**3.03**	**9.96**	**0.51**	**0.64**
Straw pellets	**12.2**	**12.6**	**79.3**	**28.3**	**34.4**	**3.08**	**30.6**	**1.50**	**0.32**



- The straw pellets is prepared by compressing and extruding a mixture of biomass (straw) and a binding agent (local soil).
- The mold biomass pellets are 34mm in diameter and less than 65mm in length, with a density of 1.18g/cm3.

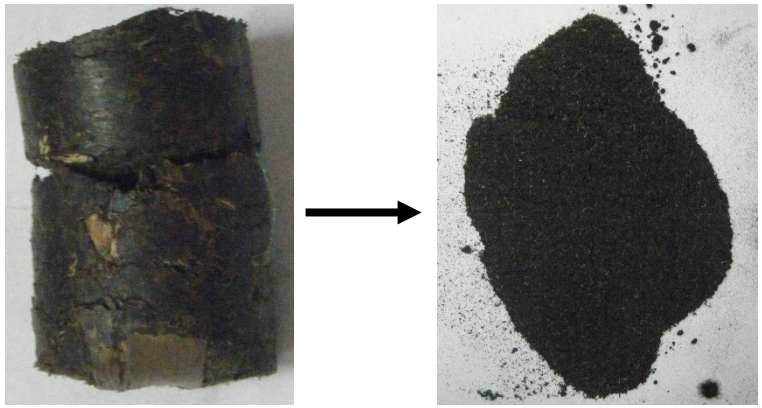
Test Conditions

Condition No.	0	1	2	3	4
Unit Load / (MW)	250	250	250	250	250
Biomass Quantity / (t/h)	-	12	24	24	30
Primary Air of Mill F / (m^3/s)	-	21.74	19.37	15.99	18.70
Inlet Temperature of Mill F / (C)	-	78	83	86	84
Outlet Temperature of Mill F / (C)	-	48	43	42	43
Ratio of Primary Air / (%)	25.1	30.7	30.3	29.2	32.1
Overall Furnace equivalence ratio / (1)	1.184	1.191	1.183	1.180	1.195

Target Characters

- Practicality and safety of the mill operation;
- Furnace temperature and efficiency;
- Pollutant emission;
- Ash availability in cement industry.

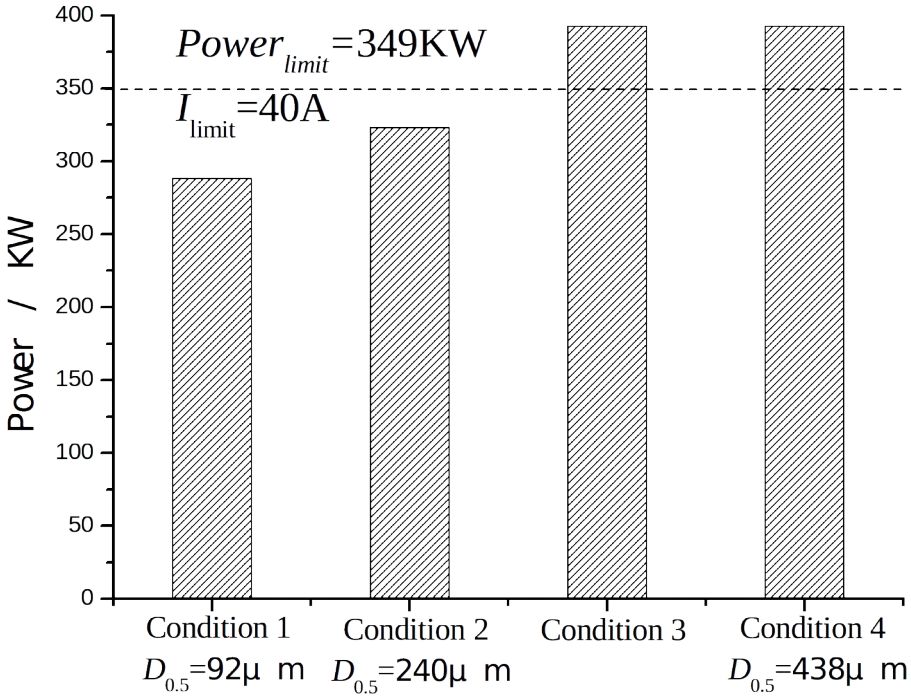
(1) Practicality of biomass grinding & Safety of mill operations



To avoid current overload and blockage of the mill.

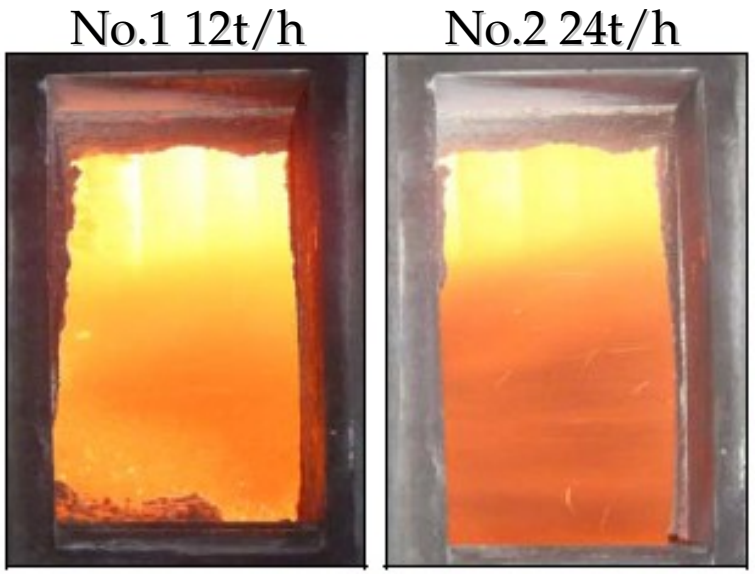
- Biomass feed rate should not be too high
- Carrying airflow rate should be adequate

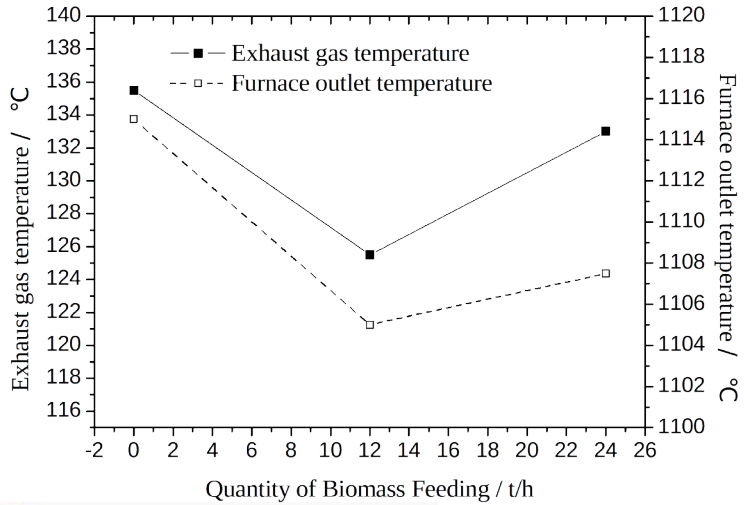
- The roller mill can be used for pulverizing the mold biomass pellets.

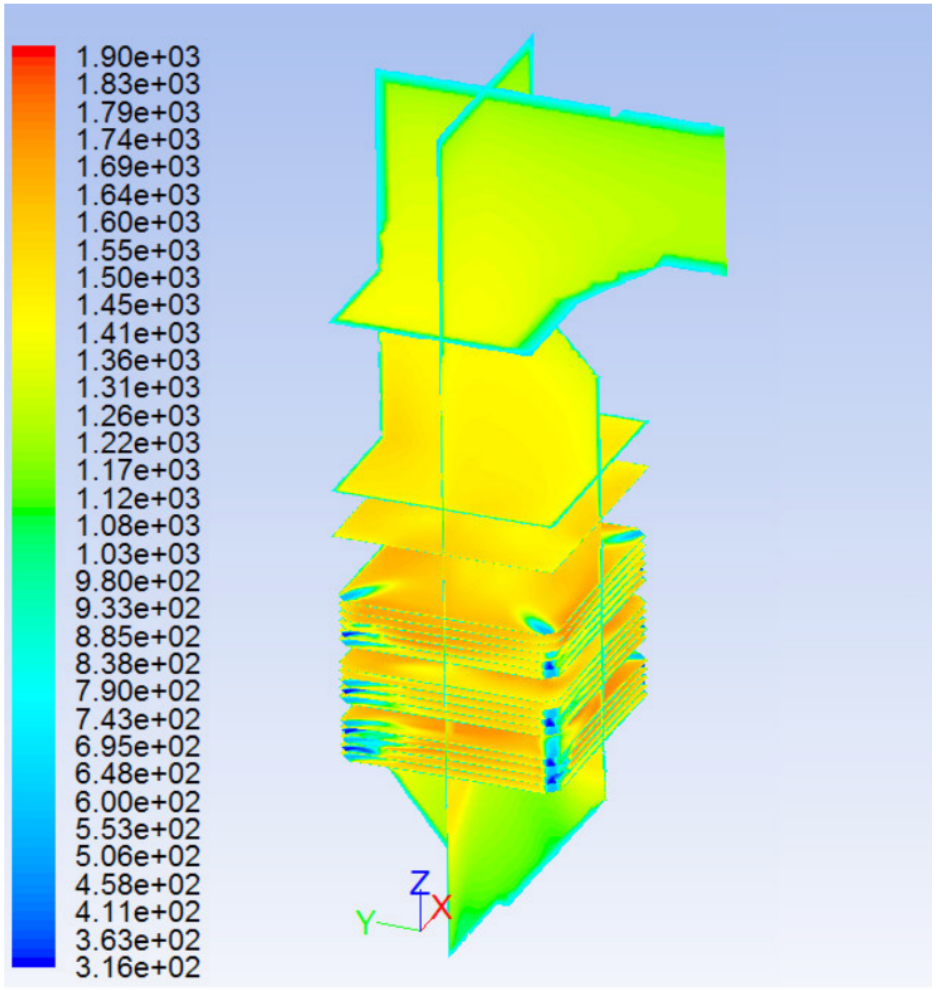


Effect of biomass feed rates & primary air flow rate

(2) Flame & Temperature profiles







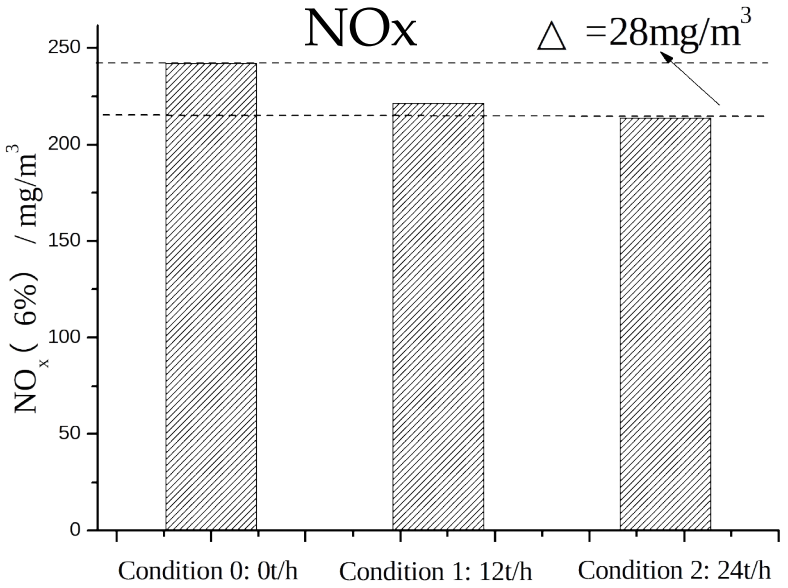
Temperature (K)

(3) Unburned carbon & Furnace efficiency

Test conditions	0	1	2
Quantity of biomass feed (t/h)	0	12	24
Inlet temperature of upper mill (℃)	229	78	83
Content of unburned carbon in fly ash (%)	0.179	0.474	0.519
Content of carbon in slag (%)	1.393	1.438	1.269
Exhaust temperature (℃)	135.5	125.5	133
Furnace efficiency (%)	94.673	94.481	94.149

- Under the conditions of biomass co-firing, the content of unburned carbon in the fly ash is higher :
  - The furnace efficiency decreases by about 0.192%, when the biomass quantity increases from 0t/h to 12t/h.
  - The furnace efficiency decreases by about 0.524%. when the biomass quantity increases from 0t/h to 24t/h.
- Reasons :
  - Temperature of biomass feeding; feeding position of biomass.

(4) Emissions of NOx



- With an increase in the biomass input, the NOx emissions are gradually reduced.
- When the quantity of the biomass feed reaches 24t/h, the NOx emissions have been reduced by about 10%.

Condition No.	0	1	2	3	4
Overall Furnace equivalence ratio / (1)	1.184	1.191	1.183	1.180	1.195
Overall equivalence ratio before OFA / (1)	1.01	1.07	1.03	1.04	1.09
Equivalence ratio of burners A-D / (1)	1.02	0.99	0.96	1.04	1.02

Mainly due to much more air is feed from layer F (the same overall air ratio)

(5) Ash availability in cement industry

Chinese standard GB/T1596-2005.

Key parameters of mortars :

(1)Water demand ratio;(2)Expansion;(3)Flexural strength;

(4)Tensile strength at 7 days and 28 days;(5)**Activity index**.

Source of fly ash	None (used as standard)	Condition 0	Condition 1	Condition 2
Water demand ratio, %	100	91.15	88.50	88.50
Expansion, mm	0.50	1.25	1.75	1.75
Flexural strength (7 days), MPa	6.40	4.90	4.95	5.05
Tensile strength (7 days), MPa	36.70	25.30	23.55	22.30
Flexural strength (28 days) , MPa	8.70	8.95	8.95	8.60
Tensile strength (28 days) , MPa	49.6	39.95	37.95	37.45
Activity index	100	80.55	76.50	75.50

>75% √

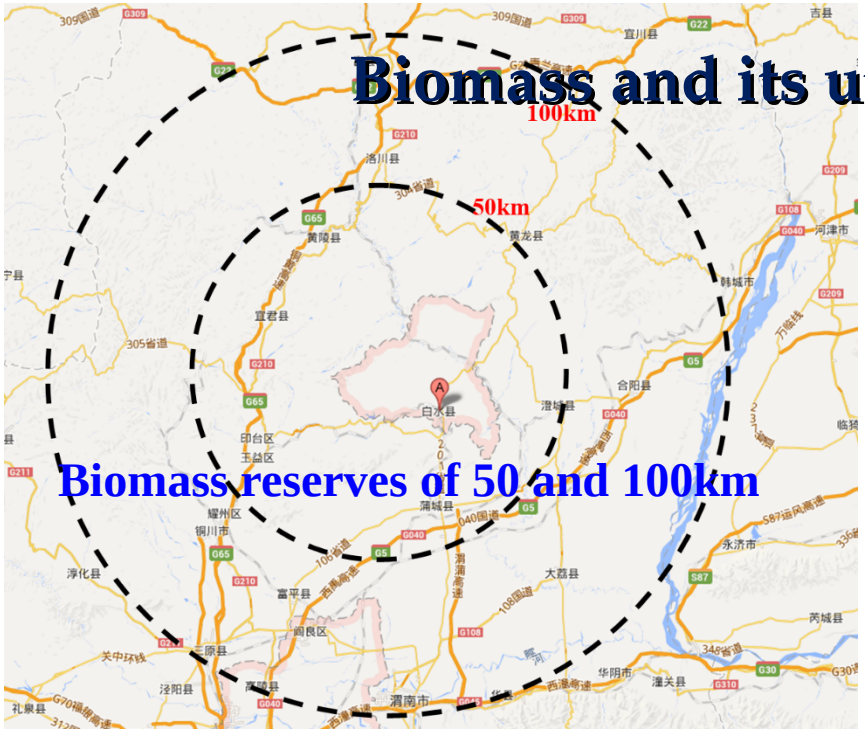
The commercial operating of "XJTU-Bao'er mode"

1. Power plant fostered some fuel suppliers (FSs).
2. The crushed biomass was dried and then briquetted in briquetting station.
3. 0.8-1 t/h, per equipment, moister content <25%.
4. FSs "buy one machine, get one machine".
5. We have built 19 briquetting stations with 50 briquetting, machines.
6. Year-2011: 10,000 ton biomass were burned.

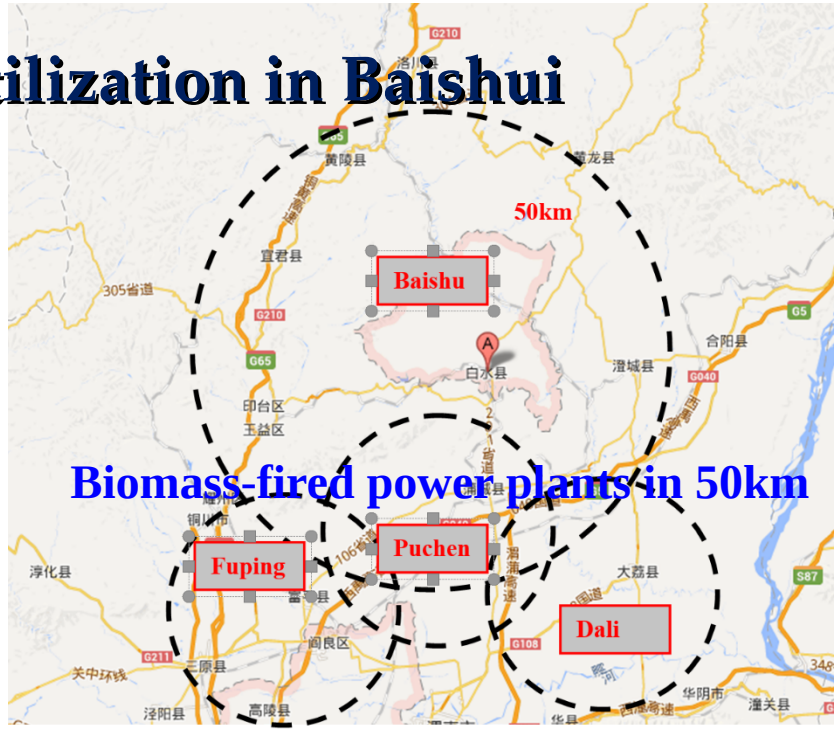
341RMB/t=213(raw fuel)+50(transport)+78(process)

4. XJTU-Baishui mode: biomass powder co-firing in a 55 MW PC furnace.

Biomass and its utilization in Baishui



Biomass reserves of 50 and 100km



Biomass-fired power plants in 50km

- 100KM: 4.25 million tons.
- 50KM:1.53 million tons.
- 40-50% is fruit branches.

- Three biomass-fired unit planded .
- None running.
- Enough fuels.

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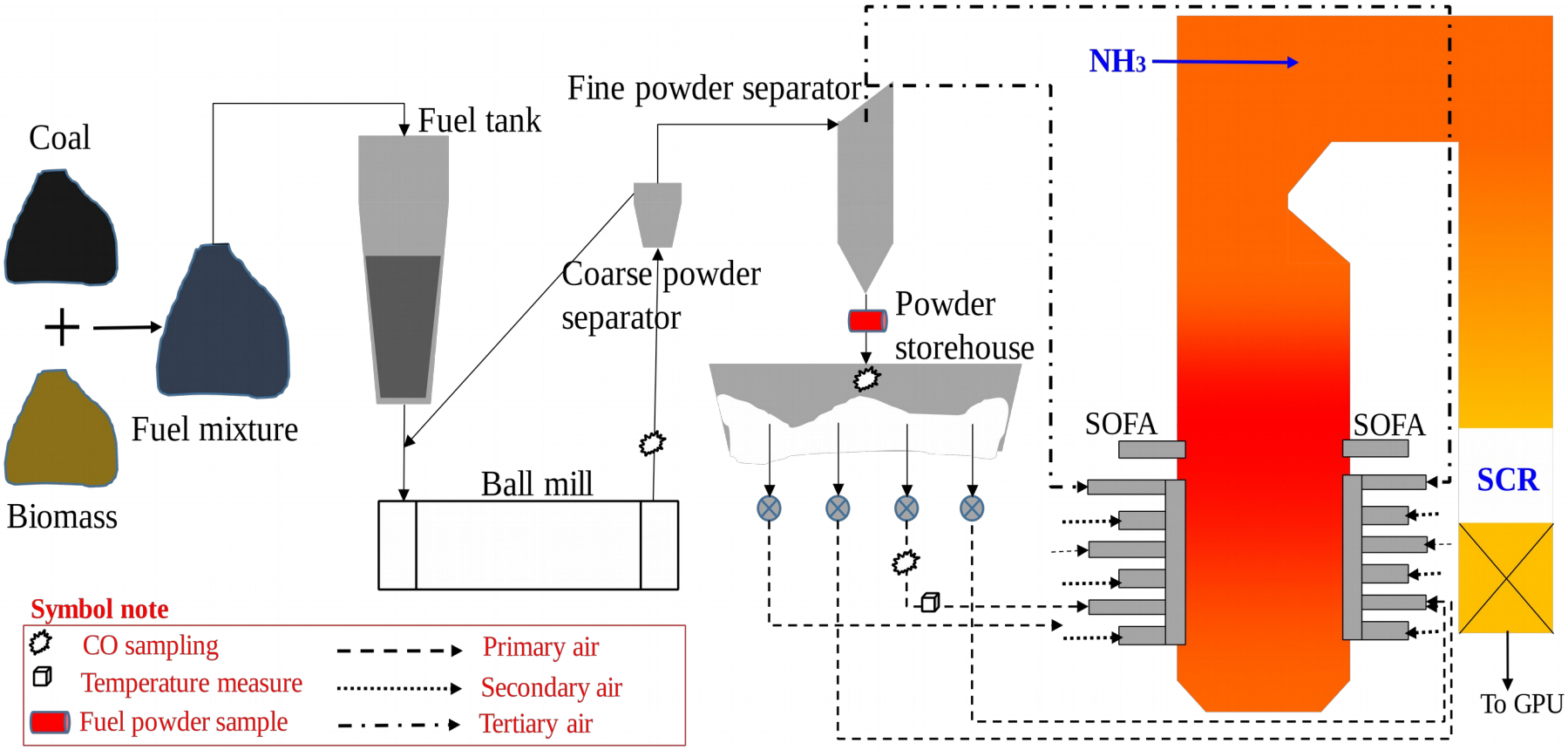
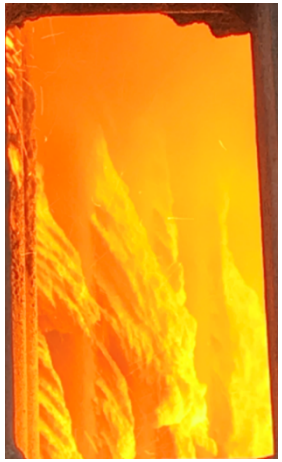
Biomass powder pretreatment

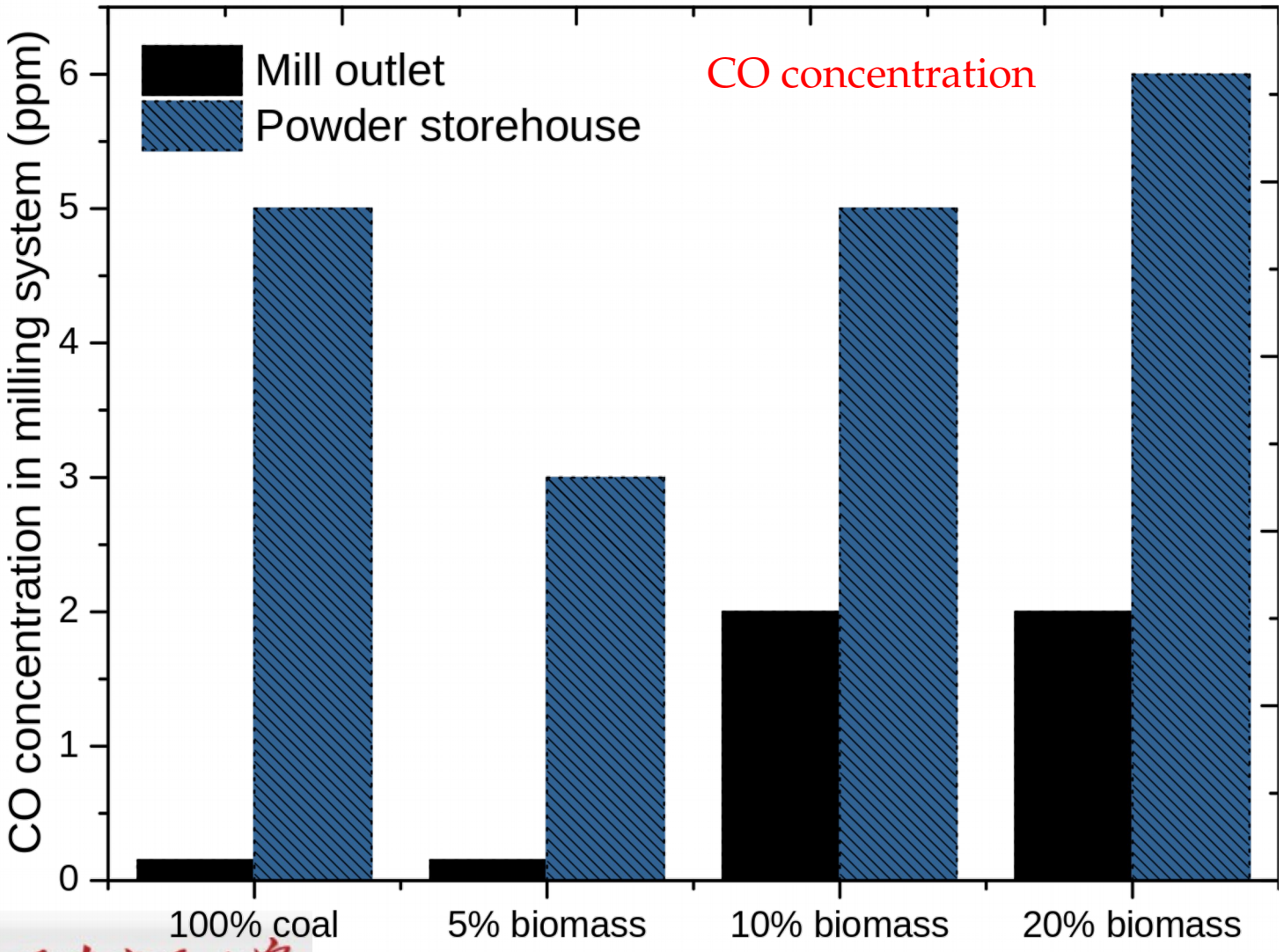
Co-firing experiment (2018.6)



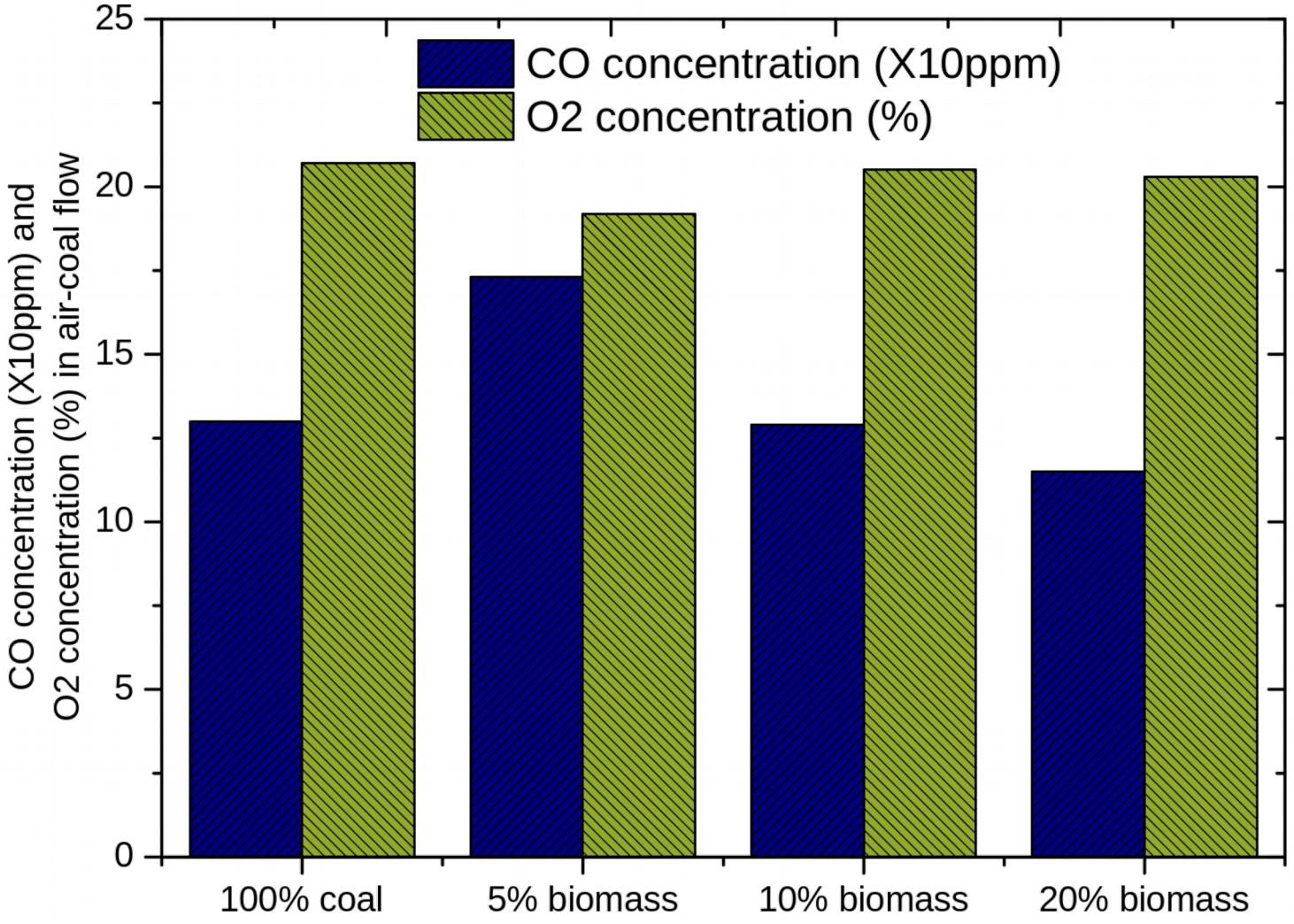
Co-firing experiment (2018.6)



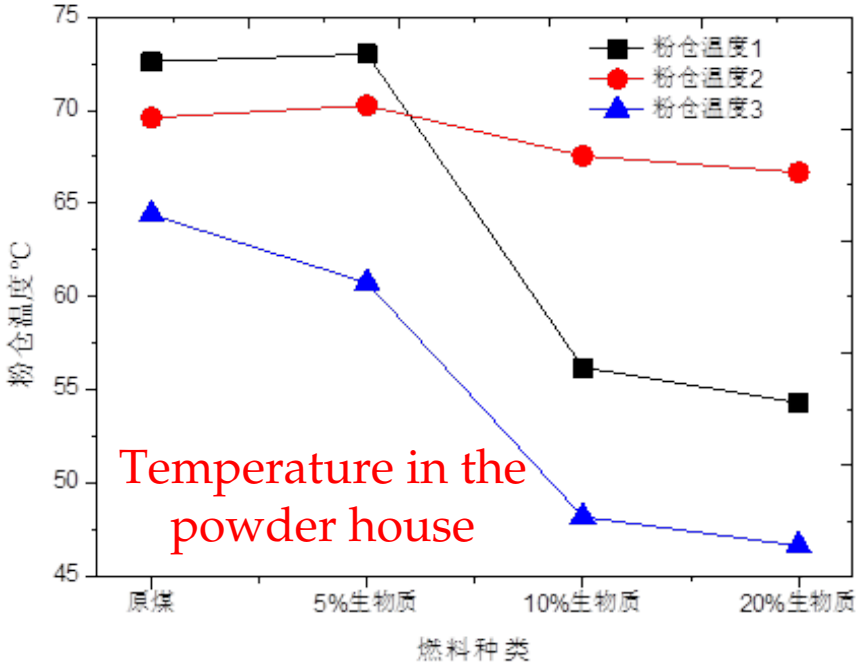
Safety of biomass powder milling and storage

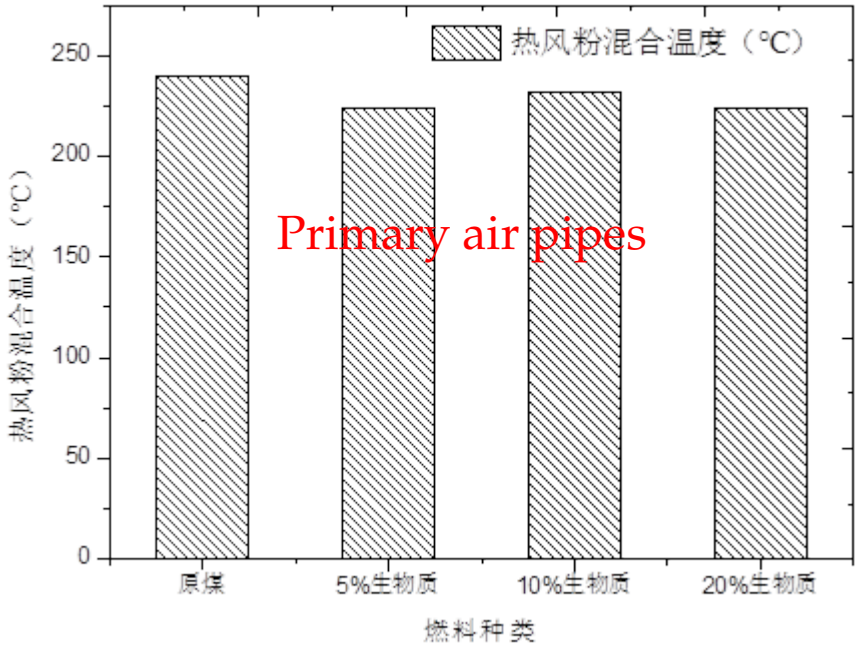


Safety of biomass powder transport in primary air pipe

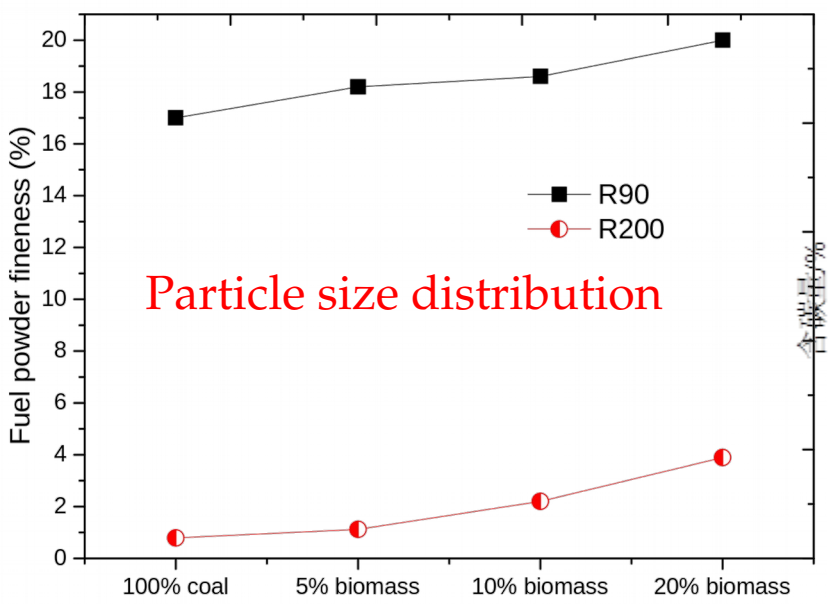


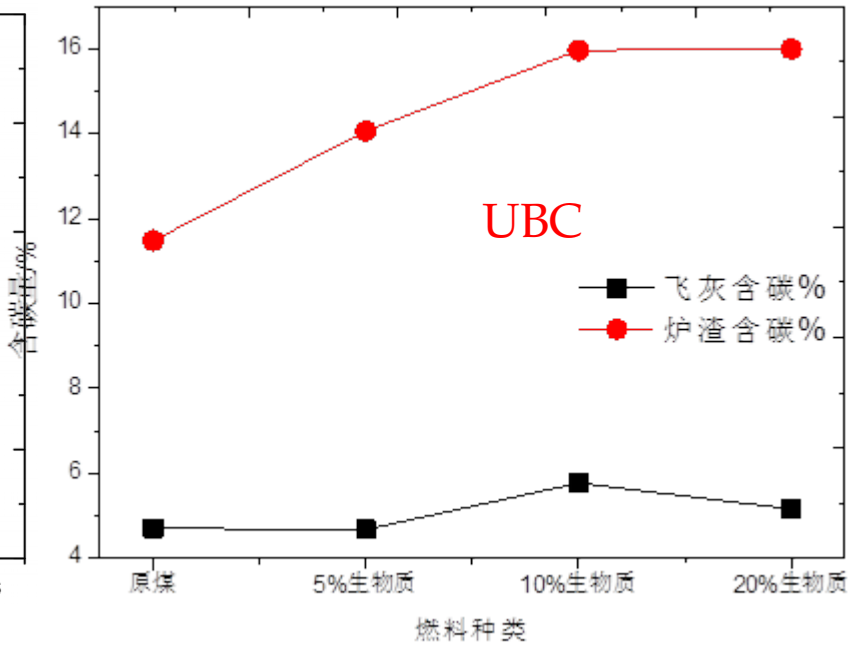
Temperatures in storage house and primary air pipe





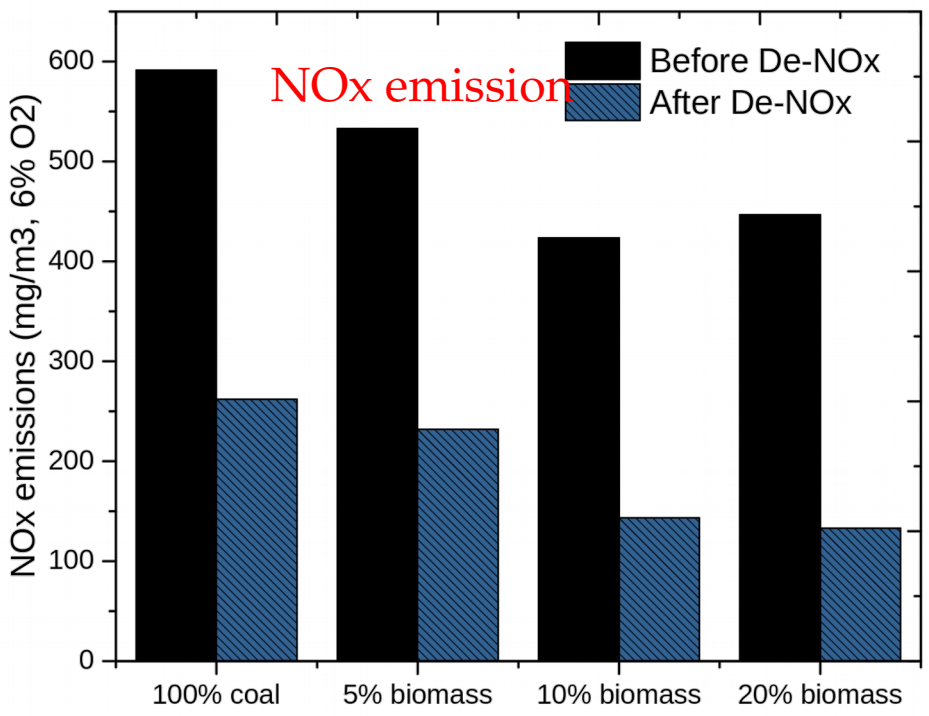
Particle size distribution, unburned carbon (UBC), and efficiency

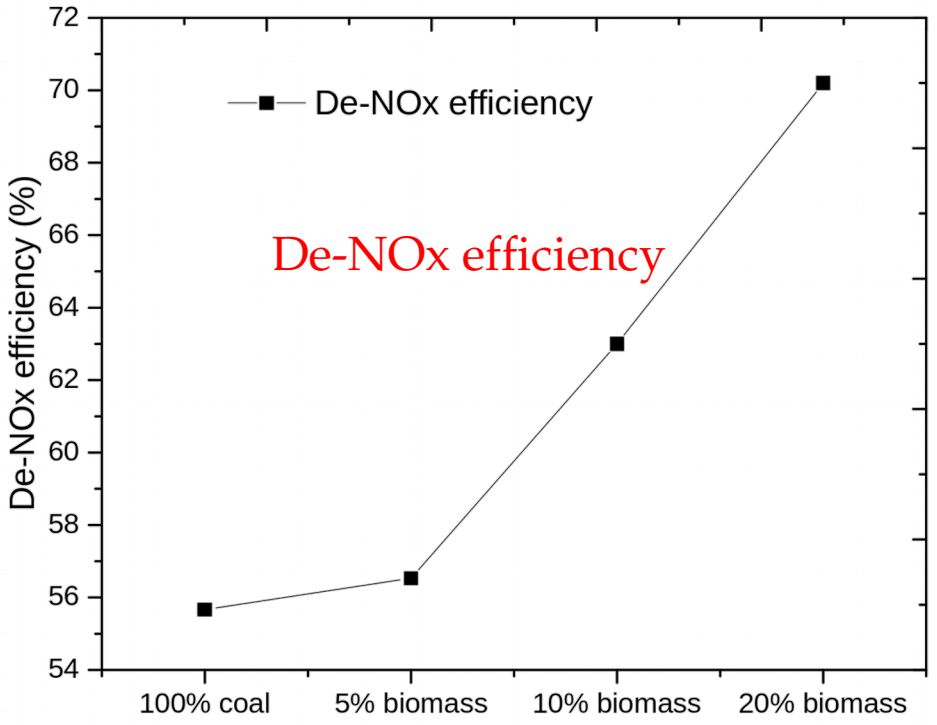




Cases	Qnet (MJ/kg)	UBC in ash (%)	UBC in slag (%)	Efficiency (%)
Pure coal	22.67	4.706	11.479	***90.88***
5% biomass	22.370	4.676	14.063	***90.82***
10% biomass	22.069	5.769	15.960	***90.09***
20% biomass	21.468	5.161	15.992	***90.11***

NOx emission and De-NOx efficiency





Economic analysis for 2×55 MW unit

- One-time investment: 3,350,000 RMB
  - Field storing biomass 1,900,000 RMB
  - Controlled transport and weight system 450,000 RMB
  - Powder machine 1,000,000 RMB
- Fuel price (15 MJ/kg): 397 RMB/ton (can be lower)
  - Raw fuel 350 RMB/ton
  - Electricity 10 RMB/ton
  - Labor 25 RMB/ton
  - Depreciation 12 RMB/ton
- Low sulfur coal price (21.8MJ/kg): 510 RMB/ton
- High sulfur coal price (18.9MJ/kg): 300 RMB/ton
- Cost reduction in De-NOx and De-SOx

5. Summary

1. Biomass co-firing is promptly developed in China.
2. "Biomass gasification coupling co-firing" is under demo-stage, and there are concerning problems in technical and economics.
3. Biomass direct co-firing in PC power plants: (1) "Shiliquan", (2) "XJTU-Bao'er" and (3) "XJTU-baishui".
4. Direct co-firing:
   - Approved safety of system and powder transport system.
   - Slight decrease in efficiency, because of moisture and primary air temperature.
   - Lower NOx emission and higher De-NOx efficiency.
   - Ash availability in concrete industry.
5. Economic analysis: biomass direct co-firing can be competitive at a comparatively higher coal price, like now.

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