Electrostatic Precipitators, Bag Filters and Emission Standards for Coal-fired Power Plants in China

Wang Liqian Zhang Dexuan Yang Xiuyun

Chinese Society of Electrostatic Precipitation
43, East Beijing Road, Nanjing 210008, Jiangsu Province

Abstract
From 1980 to 2003, power installed capacity in China grown from 65,869 MW to 384,500 MW, near 6-foldes increased. By the end of 2003, coal-fired power increased to 285,640 MW, thus induced continuosly increased air pollutions. Accompanying the emission standards from tolerant to stringent, high efficiency dust collectors gradually played dominative role. From 1955, precipitators went into Chinese power plant and by 2003 it already shared 82% of the total coal power capacity. For precipitators, very difficult coals and rather favorable coals were encountered. In 2001, first “successful” bag filter put into operation, after that, it grown very rapidely. From January 2004, new coal power emission standard of 50mg/m^3 implements, considering the big variety of Chinese coal, the choose between precipitator or bag filter will be worth considering. An primary economic coparison is given.

The Progress of Chinese Power Industry and the Using of Precipitators and Bag Filters

Chinese power industry grows rapidly. In 1949, the total installed thermal power capacity was only I,850 MW. Thirty-one years later, in 1980, it became to be 45,600MW. Since then, China began to reform and open. Another twenty-three years passed, in 2003, it increased to 285,640MW, ranked world second. Table 1 listed the installed capacities of total power units, thermal power units (almost entirely coal-fired units) and of which equipped with electrostatic precipitators and bag filters.

Table 1. Total Power Capacity, Coal Power Capacity and That Having Precipitators and Bag Filters

Year	Total Power Capacity MW	Thermal Power Capacity MW	Capacity of Thermal Power Units Having ESP		Capacity of Thermal Power Units Having BF MW
			MW	%	
1949	1,850	1,850	0	0	0
1980	65,869	45,600	11,305	24.8	300*
1990	137,890	76,011	25,840	34.0	77*
1995	217,224	116,127			0
2000	314,000	220,000	190,000*	86.4	0
2001	338,000	240,000	209,800*	89.3	200
2002	353,000	258,000	227,400*	88.1	400
2003	384,500	285,640	253,940*	88.9	1,100*
2010	600,000 [1]	438,530			
2020	900,000 [1]	657,790			

* Closly approximate value.

Brief History of Precipitator Application in Chinese Power Plant

The first electrostatic precipitator for Chinese power industries was bought from former Soviet Union, installed behind a 230t/h boiler of Jilin Heat Power Plant in 1955. Also in this year, Baoding Heat Power Plant had precipitators bought from former East Germany for its three 200t/h boilers. This is the first round of using precipitators in Chinese power plants.

Nineteen years later, in 1974, a third power plant, Shaowu Power Plant in Fujian Province, had precipitators designed and manufactured firstly by Chinese engineers and workers. From that time, precipitators really went into Chinese thermal power Industry. But till 1980, only ten power plants, totally 11,305MW of twenty generating units, about $^1/_4$ of whole China's thermal power capacity (45,600 MW), have operated with precipitators (Table 2). The slow steps were not limited by techniques but by economics. Precipitator's efficiencies were designed only of 98% to 99%, corresponding a very tolerant national emission standard,

Table 2. Precipitators in Chinese Power Plant by 1980 [2]

No	Power plant	Unit MW	Boiler t/h	Gas flow $1000m^3/h$	ESP flowing area m^2	Fields	SCA s/m	Design Eff %	Actual Eff. %	Year of operation
1	Jilin		230	471.6	4x22.9	2	31	92	66-80.5	1956
2	Baoding		3x200	3x396	3x55	3	32.2	95	83-90	1956
3	Shouwu		75	172	2x20	2	38.7	--	91	1974
			75	121.77	30	4	53.6	97	99	1979
4	Hancheng	2x75	2x300	2x540	2x3x40	2	40.8	98	88.2-97.2	1976
	Hancheng	2x125	2x400	2x786	2x3x60	2	34.3	98	85.4-87.4	1978-1979
5	Yongan		220	339	150	2	88.5	96	90.1	1979
6	Yuanbaoshan	200	921	1910	2x173	3	52.1	99.5	99.4	1979
7	Minhang		2x400	3x700	3x60	3	52.7	98	92-95	1979
8	Yangshupu		3x220	3x340	3x2x40	2	42	98	94-96	1979-1981
9	Shougang		3x50	3x120	3x40	2	59.5	98	94.4	1980
10	Handan		75	186	2x22.5	2	-----	97	95.4-97.0	1980
	Total	11305	5206	9820.37						

In 1979, the first Chinese environmental protection law promulgated. Since then, large scale using of precipitator was under consideration. From the beginning of 1980s, favored by the reforming/opening and environmental protection policies, coal-fired power units and precipitators both developed very rapidly. Low efficiency fly ash collectors, such as multi-cyclones, wet scrubbers or venture-scrubbers, which have been the dominators in past thirty years, almost disappeared in new Chinese power plants; instead them were precipitators.

Till the end of 20 century, Chinese precipitator industry equipped new precipitators for 190,000 MW generation capacities approximately, while the total coal units was 220,000 MW. Table 3 is an incomplete statistics till the end of 1999.

Nevertheless, in most time of this period, the emission standard of power industry (GB13223-1996) was rather tolerant. For new power plants, it stipulated an allowable emission of 150~600 mg/m^3 from 1996 and even more tolerant before 1996 (GB 13223-1991). Hence, again, the design collection efficiencies were not high. Based on incomplete statistics that have:

Collection efficiencies ∗ 99%, share 75.98%

Collection efficiencies =99.1%~99.3%, share 13.2%

Collection efficiencies/99.6%, share10.82%

However, large scale using of precipitators gave a primary control of particulates emission in power industry. Should these old precipitators be rebuilt to meet 100 mg/m^3 emission by pure enlarge SCA, 3000 million Yuan YMB will be necessary.

Around year 1980, five small power plants have built glass fiber cloth bag filters. In 1995, Shanghai Yangshupu Power Plant built a bag filter using foreign technology. All of them failed for normal operation and dismantled finally, switched to precipitators.

From 2001, authorities of electric power stimulated a 100-200mg/rn'[3] emission limits for new coal-fired power plants, although this was not the national standard, it was obeyed commonly. Precipitators with collection efficiencies of 99.3% to 99.7% were designed. In the first three years (2001-2003), newly built coal units was 27,640 MW, among which about 1100MW units was selected to use bag house. Another 26,540 MW units still use precipitators, In Hohhot Power Plant, the first bag filter for a 200MW unit was successfully put into operation in December of 2001. Selecting bag filter was due to the extra high Al_2O_3 content of 47% in fly ash that conducted big difficulty for ESP

Table 3. Precipitators in Chinese power plants built in the period of 1981 to 1999* [3]

Unit capacity MW	Less than 50	50~60	100~142	200~250	333~360	600~660	Total
Unit numbers	251	230	221	145	228	25	1100
Total capacity, MW	6076	11945	25839	29110	70510	15240	158720
ESP flow area, m^2	13818	55959	54824	48636	110316	19914	303467

* Incomplete statistics, not including many small precipitator installations.

By the end of 2003, the total installed capacity of coal-fired units was 285,640MW. Among which 253,940MW have precipitators, 1100MW have bag filters and another 30,600MW small units were still using low efficiency particulates control equipments. Almost all of them were domestic made.Fig.1 shows the gas flow of total coal power units, gas cleaned by precipitators, bag filters and low efficiency dust collectors respectively.

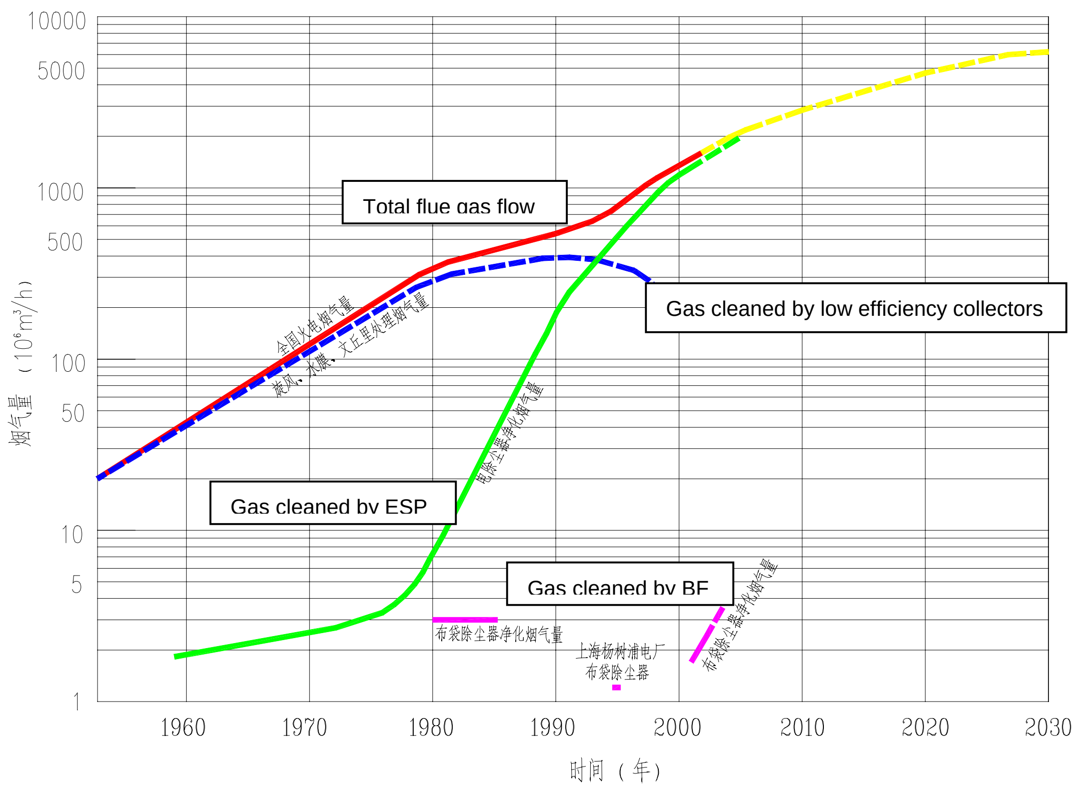

Fig.1 Total Flue gas flow, gas cleaned by precipitators, low efficiency collectors and bag filters [4]

From January 1 of 2004, the new "Emission Standard of Air Pollutants for Thermal Power

Plants "(GB 13223-2003) was carried out instead of GB33223-l996. The new allowed particulates emission for new coal-fired power plants is 50 mg/m^3 (for those new power plants in none “Two-control Zone” of west China and burn coal of sulfur content less than 0.5%, is soften to 100mg/m^3). New standard will definitely promote the using of bag filters, especially for power plants bum difficult coal.

Table 4 summarized all the previous and new particulates emission standards for Chinese coal-fired power plants.

Table 4. Previous and current particulates emission standards

Date and National Standard	Classification	Received base coal ash content %						
		∗10	∃10~[20	∃20~[25	∃25~[30	∃30~[35	∃35~[40	∃40
By Aug.1992	All conditions	200	300	500	600	700	800	1000
Aug.1992~Dec.1996 GB13223-1991*	Boiler bigger than 670 t/h or at county city and above	150	200	300	350	400	450	600
	Boiler smaller than 670t/h or at the district under the county	500	700	1100	1300	1500	1700	2000
Jan.1997~Dec.2003 GB13223-1996*	Boiler at county and above	200						
	Boiler at the districts under the county	500						
	Boiler at county and above, before Aug.1992	600						
2000~2003 (Informal regulation)	Large Boiler	100~200						
Jan.2004~ GB13223-2003	New boiler	50						
	West China, Power plant near coal mine	100						
	Gangue-fired Boiler	200						

- These two emission standards were so tolerant that have been refuted by personalities of various circles.

Difficult and Favorable Chinese Coals for Precipitator

The composition of Chinese power coals and their fly ashes vary widely, such as for coal: heat value10~26 MJ/kg, ash content 10%~58%, sulfur content 0.14%~5.3%, water content 0.8%~9%; For ash: SiO_2 68,2% max (Mudanjiang coal), Al_20i_3 55.7% max(Zhunger coal), SiO_2+Al_2O_3 91.73% max(Mudanjiang coal), SiO_2 /A_2O_3 ratio 0.84(Zhunger coal), Fe_2O_3 0.4% min(Xuzhou coal), Na_2O 0.02 min(Shizuishan coal), K_2O 0.05% min(Hequ coal). CaO 1.1~50%(Dawukou coal and Xiaolongtan coal respectively). Extreme conditions make precipitator working badly, while some coals combined beneficial factors give smooth operation and high performance. Table 5 listed the typical difficult and favorable power coal for electrostatic precipitation.

We experienced very high ash Al_2O_3 content of approximately 50% in Hohhot, Zhunger and Tuoketuo Power Plants that all burn Zhunger coal. Combined with SiO_2/Al_2O_3 ratio less the 0.9~0.65, these means very high percentage of kaolinite clay predominates, which generally appears as very fine, sticky powder and giving high resistivity as well as heavy reentrainment, hence Zhunger coal conducted to the most difficulty conditions to precipitators in China. This is the reason that bag filter was selected instead of precipitator for Hohhot Power Plant's new 200MW unit, which burnt Zhunger coal dominantly. so much advantages concentrated in one coal is seldom among variety Chinese coals.

Table 5. Some typical Chinese power coal for precipitator

Coal	**Zunger**	**Xuanwei**	**Dawukou**	**Zhengzhou**	**Dongsheng**	**Shenmu**	**Jinbei**
	Difficult				**Favorable**		
Mine location	Inn.Mongo.	EastYunnan	Ningxia	Henan	Inn.Mongo.	Shanxi	Shanxi
Carbon %	43.21	49.41	54.1	51.35	50.84	59.34	58.56
Sulfur %	0.43	0.38	1.18	0.36	0.82	0.33	0.63
Water %	10	6.2	3.9	8.3	20.07	12.3	9.61
Volatile %	40.87	27.96	22.35		35.86	37.77	32.31
Ash %	31.7	35.1	32.35	30.1	14.14	13.31	19.77
Heat value MJ/kg	16.29		21.47	19.68		22.363	22.44
Ash							
SiO2 %	38.22	58.89	50.26	57.26	23.04	46.1	58.41
Al2O3 %	51.72	22.43	40.48	26.43	2.24	17.84	15.73
Fe2O3 %	1.38	(FeO)8.97	3.14	4.47	19.46	8.49	23.46
CaO %	1.36		0.73	3.63	19.99	18.06	3.93
Na2O %	0.02	0.16	0.63	0.41	1.67	0.6	
K2O %	0.43	0.57	0.19		0.39	1.66	2.33
SO3 %	1.75		1.28	3.22	26.12	4.4	2.05

Zhunger coal is fully deserves the most difficult coal in China for its especially high Al_2O_3 (51.72%), especially low $SiO_2/A1_2O_3$ ratio (0.74), very low Fe_2O_3 and Na_2O (1.38% and 0.02% respectively). This leads to a very large SCA of 149.3 $m^2/m^3/s$ (300mm spacing) for getting an emission of 110 mg/m^3 (99.4% collection efficiency) in Zhunger Power Plant [5].

Precipitators in Dawukou, Xuanwei and Zhengzhou Power Plants were encountered coal difficulties also. As contrary examples, Table 5 also listed two kinds of most favorable China power coals, i.e. Jinbei power coal and Dongsheng Wanli coal. Both are famous power coal with huge reserves

Yunnan Xuanwu coal is difficult because the Fe appears mainly in the form of Fe_3O_4. Unlike other forms of Fe easy to melt hence giving coarser ash, Fe_3O_4 conducted very fine brown fume with bad electric conductance and heavy reentrainment. This is a unique example in China. So, Fe poses dual nature. To divide Fe_3O_4 composition from total Fe seems necessary.

Ningxia Dawukou coal is difficult because its high ash (53.0%), high Al_2O_3 (39.52%), low water (0.79%) and especially low heat value (11.82MJ/kg), in spite of other compositions seem acceptable. Rather high sulfur (1.75%) was counteracted by high ash. Low sea level attitude (barometric pressure only be 666mmHg) and bone-dry weather gave the precipitators additional troubles. In recent years, coal quality has improved and precipitators were retrofitted, situation already turns better.

It is not very clear why Zhengzhou coal gave precipitators bad operation. Relatively low sulfur (0.37%) and high SiO_2 (57.96%) may not be the key factors. This coal is very easy to grinding to fine powder and burns rapidly. In recent rebuilding of one 200MW unit, precipitator was retrofitted to bag house.

Dalate Power Plant is the first big thermal power plant of totally 6000MW. From Table 5, we can see that its fuel Dongsheng (Wanli Mine) coal concentrated many beneficial factors that seldom seen in China, such as: low ash (14.14%), high water (20.07%), very low SiO_2 (23.04%), especially low $A1_2O_3$ (2.24%), high Fe_2O_3 (19.46%) and high Na_2O (1.67%). so much advantages concentrated in one coal is seldom seen among variety Chinese coals. So, from the first beginning of put into operation more than ten years ago till nowadays, precipitators worked very satisfyingly, a series of clear chimneys stand by.

It is rather strange that Dongsheng ditrict is only about 100 kilometers far from Zhunger district, while these two famous, huge reserves and neighboring coalmines product so different coals.

Jinbei (means North Shanxi province) power coal is very famous by its high quality. The best North Shanxi coal, Datong coal, is used only for metallurgy industry and other special important purpose. Jinbei power coal occupy low ash (14.14%), low Al_2O_3 (15.73%), high Fe_2O_3(23.48%) and high Na_2O + K2O (totqly 2.33%). It is no wonder to have a clear sky for many power plants.

We mentioned that Dongseng coal and Jinbei power coal are all low sulfur coal, but they are low ash also. So, coal sulfur/ash ratio may be a useful index besides coal sulfur only for the judgment of precipitator operation.

Economic Comparison between Precipitator and Bag House

In 1979~1981, China have been five small power coal plants using bag house with fiber glass cloth, treated by silicon oil and graphite [6]. Their longest working life was one or three years only. In 1993, Shanghai Yangshupu Power Plant tried to use bag house again. Although foreign techniques was used, but wrong design made it abandoned one year later.

In 2001, viewing its very difficult Zhunger coal and low efficiency precipitators, Hohhot Power Plant decided switching to bag filler on its new 200MW unit. By using Lurgi technology and engineering designed by Australia and Chinese technicians mutually, this bag filter was put into operation in December of 2001 [7]. Till now, it worked well with an emission of 30 mg/m3. Since then, bag filter expanded us use very rapidly in China. More than 1100 MW new or retrofitted unit equipped with bag filter successfully.

Almost at the same time, Zhunger Power Plant persists in using precipitator for its new 330MW unit with a very big SCA of 149.3 m2/m3/s, 99.4% efficiency and 110mg/m3 [8] was obtained as mentioned above.

Beginning with 2004, China implements new emission standard of $50mg/m^3$ for new coal-fired power plants. Hence, to select precipitator or bag filter is a problem must be taken into consideration.

Based on the real data of 200MW unit of Hohhot Plant and 330MW unit of Zhunger Plants, the author made an economical comparison between precipitator and bay filter as Table 6. In which column B and C are the first hand data gathered directly from plants, column D and L convert these data to same bases, i.e. 330MW and $50m/m^3$. Using Deutsch formula to convert necessary SCA for pure enlarge precipitator so to get $50mg/m^3$ emission. Column E is used for reference, it showed first hand data from Xiamen Power Plants that bum high quality Jinbei power coal. From the comparison we can have the following ideas:

- Even for most difficult Zhunger coal with very big SCA (~150m2/m3/s), the capital cost of bag filter is about 50% expensive than precipitator. For good coal as Jinbei, more than three folds expensive.
- Operating costs are basically the same for bad coal, or bag filter is 70% expensive the precipitator for good coal.
- Of course, bag filter is safer than precipitator to achieve $50mg/m^3$ emission. Actually, in Hohhot Power Plant, it gave $30mg/m^3$ approximately.
- Fabric material is imported Ryton. At present, Ryton is expensive in China. It can resist high temperature of utility flue gas, but is dangerous for high gas oxygen that occasionally may occur in power plants. So, precipitator can give more safe operation.

Table 6. Economical comparison between Precipitator and bag filter [4]

	First hand data from power plants	Convert to same base	For reference

Collector	Bag filter	Precipitator	Bag filter	Precipitator	Precipitator
Power Plant	Hohhot 200MW	Zhunger 330MW	Hohhot 330MW 50mg/m3	Zhunger 330MW 50m 50mg/m3	Xiamen 300MW
Coal	Difficult coal 70% Zhunger 30% Haibowan	Very difficult coal 100% Zhunger	Difficult coal 70% Zhunger 30% Haibowan	Very difficult coal 100% Zhunger	Favorable Jinbei power coal
A	B	C	D	E	F
Gas flow m3/h	1,730,000	2,218,930	2,218,930	2,218,930	1,819,580
Gas temperature C	138	130	130	130	133.5
Gas velocity	1.13m/min	0.71m/s	1.13m/min	0.57m/s	1.143
Gas/cloth or SCA	$67.8m^3/h/m^2$	$149.3m^2/m^3/s$	$67.8m^3/h/m^2$	$186.6.3m^2/m^3/s$	$61.3m^2/m^3/s$
Cloth or plate area m2	25,600	92,044	32,835	115,055	30,992
Collector code	4chambers .8units.	2 chambers 5 fields		2 chambers 5 fields	2 chambers 4 fields
	Ryton fabric 8000 bags	2 units @431.6m2	Ryton fabric 10260 bags	3 units @360.0m2	2 units @221m2
Actual efficiency %	>99.84	99.63	>99.84	99.84	99.57
Emission mg/m3	<50	111.4	<50	50	59
Gas pressure drop Pa	600-900	<100	600-900	<100	~260
Total power capacity, kw	Install. 249kw In use 124kw	2352KVA 275.84kw	------- In use 320kw	2496KVA 315.84kw	1152KVA 213kw
Among which:	Roots blower 90kw	T/R 12x108KVA		T/R 12x120KVA	T/R 16x72KVA
	Dampers 8x1.5kw	T/R 16x66KVA		T/R 16x66KVA	364 Top rappers ~5kw
	Motors 8x0.37kw	Rapping 32x0.37kw		Rapping 32x0.37kw	
	Ash unloading 9x0.75kw	Ash unloading 20x2.2kw		Ash unloading 20x2.2kw	Ash unloading 16x2kw
	Instruments 5x1kw	Hopper heating 20x8kw		Hopper heating 20x10kw	Hopper heating 16x10kw
	Illuminating 5kw	Corona heating 20x3kw		Corona heating 20x3kw	Corona heating 16x1kw
Capital cost 10000 Yuan RMB	2050	1813.1	3383	2270	925
Among which:	Mechanical and Control 1451	Mechanical 1571.5	Mechanical and Control 2615	Mechanical 1964.4	Mechanical 787
	Cloth 599	Electrical and Control 241.6	Cloth 768	Electrical and Control 305.6	Electrical and Control 138
Operation cost* 10000 Yuan RMB	409.4	446.5	536.5	545.3	312.2
Among which:	Fan power 178.5	Fan power 32.4	Fan power 228.9	Fan power 32.4	Fan power 61.03
	Other power** 31.2	Other power** 69.5	Other power 51.5	Other power 82.1	Other power** 53.7
	Bag (3 year life) 199.7	Corona*** 344.6	Bag (3year life) 256.1	Corona 430.8	Corona**** 197.4

* Operation costs was calculated based on: Pressure loss of bag filter 800Pa, precipitator 125Pa; Induced fan efficiency 0.7; Power transmission efficiency 0.95; Annual operation time 7000h; Electricity price 0.45Yuan RMB/kwh;

** Coefficient of simultaneously working 0.8;
*** According to operation records, actual input corona power was 1094.0kw;
**** According to operation records, actual input corona power was 626.8kw;

In China, there is a strong tendency to greatly enlarge the use of bag filter for utility mainly due to the new stringent emission standard. China decided to build FGD installation in most new power plant also beneficial to bag filter. However, make careful comparison is necessary.

Future Aspects of Particulates Control for Chinese Coal-fired power Plant

We estimate coal power will be increased to 438,530 MW and 657,790 MW in 2010 and 2020 respectively. If 50 mg/m^3 and 30 mg/m^3 emission standard implemented, the total cost to build precipitators or bag filters is roughly calculated as Table 7. In other words, about 40,000 million Yuan RMB can make a never so clear sky for Chinese new power plant.

Considering precipitator or bag filter will be needed for FGD systems, which will be a indispensable part of new power plant located in the so-called “Two Control Zone”, the above cost should increased additionally.

Table 7. Particulates control costs needed for future two decades

Year	Coal power Capacity MW	Increment MW	Emission standard mg/m^3	Capital cost 10^8 Yuan RMB	
				Using ESP	Using BF
2010	438,530	152,890	50	138.0	157.7
2020	657790	219,260	30	Don’t use	223

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