Industrial waste heat (IWH) resources and utilization

Jianjun Xia
Building Energy Research Center, Tsinghua University

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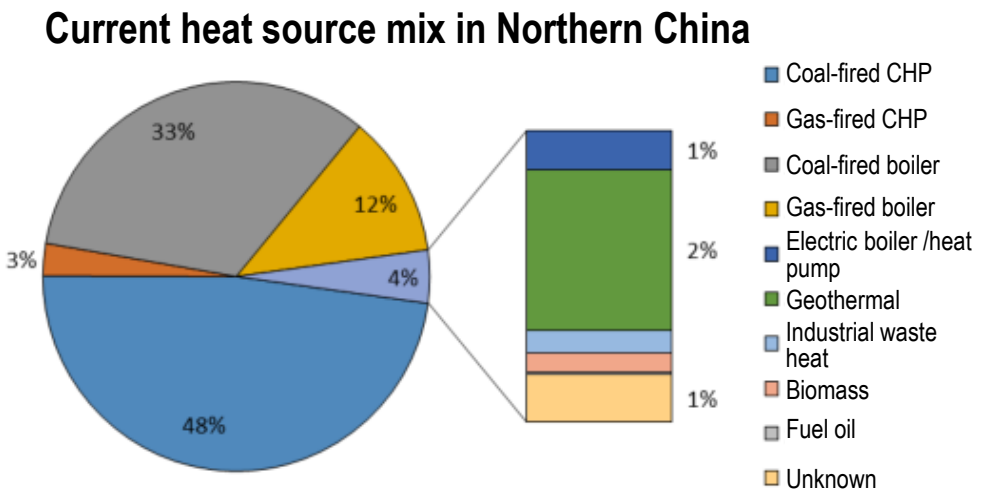
Background

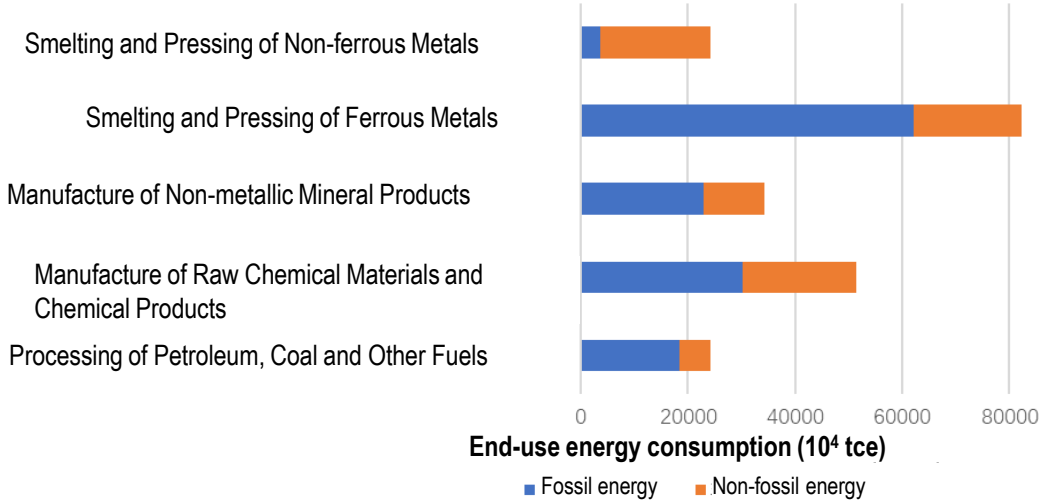
Growing demand for heating in Northern China and current heat source mix will result in significant CO_2 emissions

- **Growing winter heating area and heat demand**
  - By the end of 2019, the floor area in urban heating regions in Northern China reaches 13.7 billion m^2
  - The heating area will reach 20 billion m^2 in the future with a heat demand of 4.2 billion GJ
- **High proportion of low efficiency and highly polluting heat sources**
  - Causing serious energy waste
  - Important cause of winter haze
  - 45% of heat is provided by coal and gas-fired boilers, directly causing 1 billion tons of CO_2 emissions



Low-grade industrial waste heat is a high-quality heat source for district heating

- **China's industrial sector accounts for about 70% of the total energy consumption of the whole society**
  - The industrial structure is dominated by secondary industries and high energy-consuming industries
  - Higher energy consumption per unit of product than the international advanced level
  - Industrial waste heat is not fully reused, causing low energy use efficiency (about 33%)
- **The five most energy-intensive sectors account for 70% of the total industrial end-use energy consumption**
  - The combustion of fossil energy will produce a large amount of waste heat, which is concentrated and of relatively high grade, with great potential for utilization



1 Background

Incentive policies related to IWH utilization

☐ *Industrial green development plan (2016-2020)*

- To popularize medium- and low-grade waste heat/pressure power generation, heat supply and recycling; to actively promote the utilization of low-grade waste heat from industries including steel and chemicals to supply heat to urban residents, and to promote the integration of industry and city.

☐ *14th Five-Year Plan for circular economy development*

- To promote the comprehensive use of waste; the graded use of energy; the recycling of water resources; the recycling of industrial waste heat, pressure, water, gas and liquid as useful resources; the green, low-carbon and circular development; and centralized gas and heat supply.

☐ *General plan for energy conservation and emissions reduction during the 14th Five-Year Plan period*

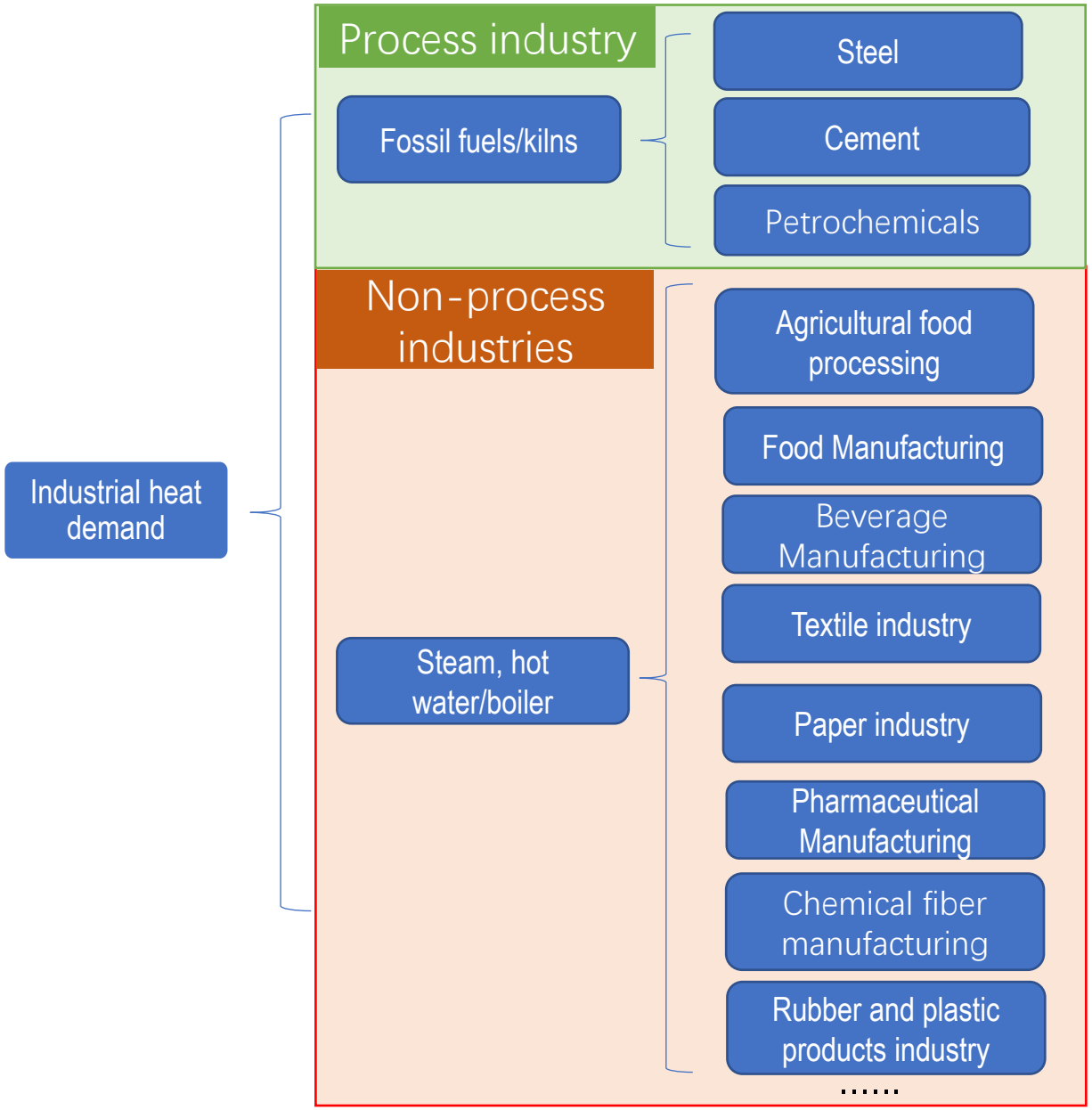
- To promote clean heating in Northern regions in accordance with local conditions, and to accelerate the large-scale utilization of industrial waste heat and renewable energy in urban heating;
- To step up the elimination of outdated coal-fired boilers and small-scale coal-fired CHP, and to promote the substitution of coal for heating (steam) by industrial waste heat, power plant waste heat and clean energy.

☐ *Action plan for stringent energy efficiency constraints and promoting energy conservation and carbon reduction in key petrochemical industries (2021-2025)*

- To encourage the use of technologies such as heat pump, thermal pinch point and thermal combination to strengthen the recovery of waste heat/pressure in the process and to achieve graded use of energy.

1 Background

■ Estimated heat demand by industry



Process industry: The industry that produces basic raw materials, including steel, cement, petrochemical and other industries. The process industry needs to consume a large amount of fossil fuels in the production process, with **rich industrial waste heat resources**.

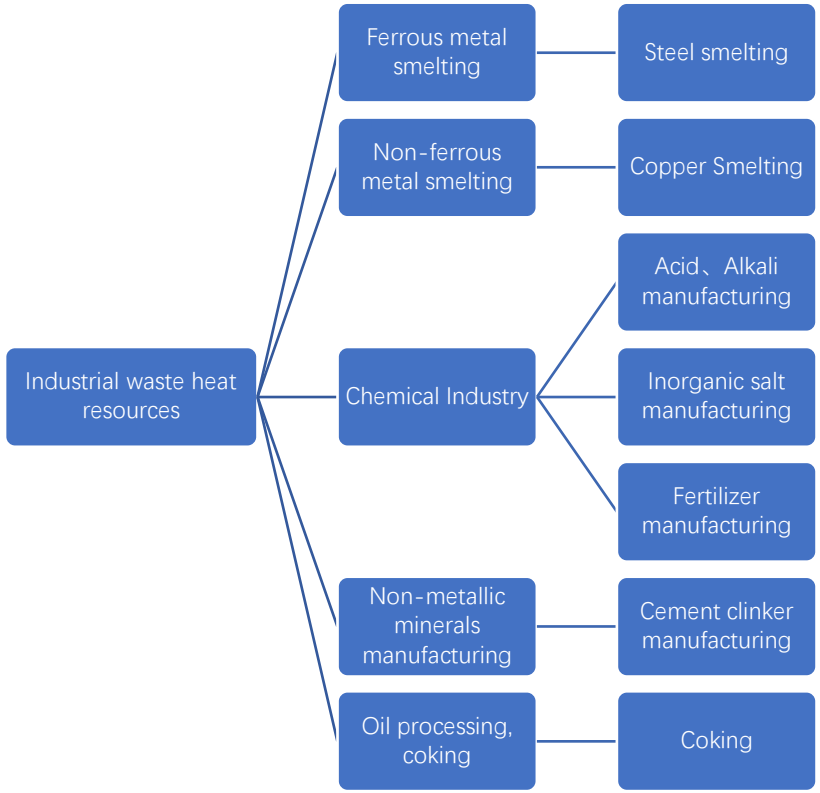
Non process industry: The industry that uses agricultural products or basic industrial raw materials to produce consumer goods, including food manufacturing, beverage manufacturing, textile and other industries. Non-process industries usually have a large amount of **heat demand for medium and low temperature**

☐ Total heat consumption of non process industry: 148 Mtce

- Heat consumption of 8 major non-process industries: 105 Mtce (**3.08 billion GJ**)

Current Resource Research

- **Data source**
  - ✓ Statistical Yearbook: Geographical Data
  - ✓ Business Directory: location of resources, available potential
- **Estimation of available heating potential based on literature and actual projects**



Future potential forecast

- **Influencing factors**
  - ✓ Energy structure transformation, industrial restructuring
  - ✓ Population change and urban development
- **Estimating the potential and distribution of clean heating resources in the future**

- **Bottom-up search for specific production, process, and location based on company directory**
- **Checking with statistical data**

Industry	Main Products	Statistics (million tons)	Enterprise query data (million tons)	Coverage
Ferrous metal smelting	iron	88897.61	73949.52	83.2%
	Crude steel	106476.68	100330.78	94.2%
Non-ferrous metal smelting	Copper	1002.51	977.66	97.5%
Chemical Industry	Sulfuric acid	9238.18	5803.80	62.8%
	Caustic soda	3673.87	1955.14	53.2%
	Calcium carbide	2791.89	2410.22	86.3%
Non-metallic minerals manufacturing	Clinker	156133.13	151130.3	96.8%
Oil processing, coking	Coke	47116.12	42570.54	90.4%

- For the **ferrous metal, nonferrous metal and cement industries**, when the per capita stock reaches the peak, the production will gradually decline, and **the energy consumption will also decline**; At the same time, the improvement of energy efficiency and the recovery of waste metals will further reduce the energy consumption of the industry;
- In the chemical industry, the use of chemical fertilizer will gradually decline, the consumption of plastic will gradually increase, the utilization rate and energy efficiency will gradually improve, and the energy consumption will eventually **remain basically unchanged**;
- With the improvement of people's living standards, the consumption of machinery manufacturing, light industry and food industry will gradually increase, while the energy intensity will also gradually decline. According to the current level of developed countries, it is predicted that the proportion of energy consumption and electricity will **increase significantly** by 2050

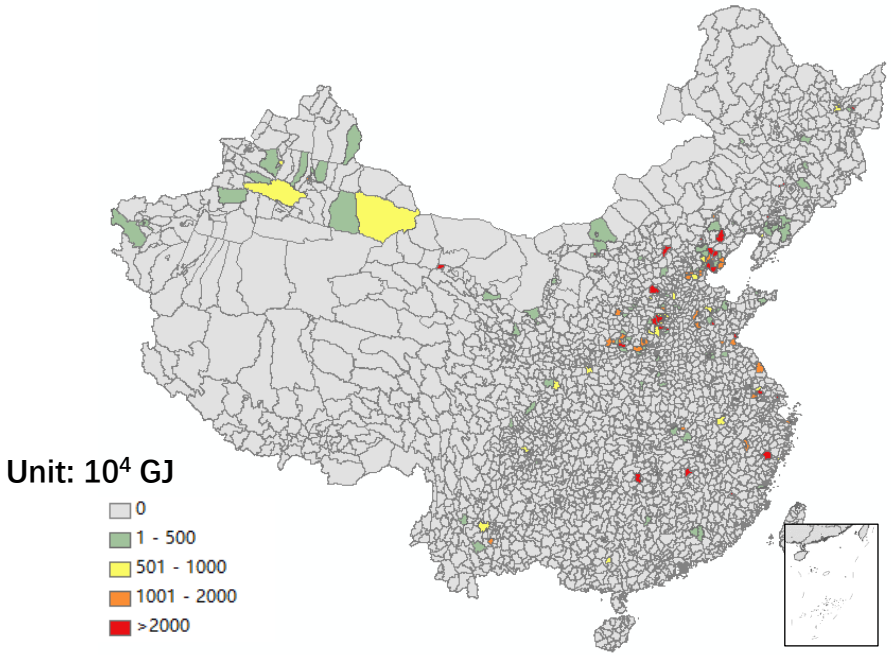
	Industrial energy per capita (kgce/person)		Energy use per unit of added value (tce/million USD)		Fossil fuels	raw material	Electricity	Fossil energy substitution
	Current Situation in China	Average in developed countries	Current Situation in China	Average in developed countries	10^4 tce	10^4 tce	10^8 kWh	
ferrous metal	429	239	23.7	7.55	1.97		3318	Coke is the main fossil fuel used and can be replaced by hydrogen energy
nonferrous metal	79	28	23.7	7.55	825		3232	Small amounts of steam used in the copper electrolysis process can be replaced by electricity or biomass boilers
Building Materials	193	81	11.4	4.20	7961		562	The fossil fuels required for cement can be replaced by using alternative waste
Chemical	358	856	8.9	6.23	23000	9157	7577	Ammonia and methanol, which account for the bulk of energy consumption for the production of raw materials, can be replaced by hydrogen; fossil fuels can be replaced by hydrogen or electricity
Machinery Manufacturing	75	117	1.1	0.37	4420		9052	Fossil fuel consumption can be replaced by hydrogen or electricity
Light Industry	64	160	3.0	3.55	15113		5016	Fossil fuel consumption can be replaced by hydrogen or electricity
Food Industry	39	96	1.4	1.46	8414		3583	Thermal demand accounts for the major portion of fossil fuel consumption and can be replaced by hydrogen or electricity
Other	70	89	12.3	3.76	6668		4224	Fossil fuel consumption can be replaced by hydrogen or electricity
Total	1300	1667	6.62	2.42	66400	9157	36560	

2.2 Distribution of IWH Resources and Prediction – Steel

☐ Current situation investigation

- ✓ The survey covers a total of 290 steel smelters in China, with a total waste heat potential of **130,000 MW and 3.72 billion GJ**
- ✓ Mainly in Tangshan, Handan, Baotou, Anshan, etc.

Waste heat distribution of steel enterprises



☐ Future Forecast

- ✓ Scholars predicted[1,2] that China's total steel production will be about 500-700 million tons in 2050
- ✓ Take 600 million tons as a reference value, 50% of of which is electric furnace steelmaking
- ✓ **49,800 MW** of low-grade waste heat from the steel industry will be retained in the future, which can supply **1.42 billion GJ of** heat

Country	US	Japan	UK	Germany	France	China
Peak steel production per capita (kg/a)	690	1098	509	858	515	712
Peak per capita consumption of steel (kg/a)	711	802	-	660	517	670
Year of peak production	1973	1973	1970	1974	1974	
Urbanization rate	76%	75%	-	80%	70.4%	60.6%

[1] 张超,王韬,陈伟强,刘刚,杜欢政.中国钢铁长期需求模拟及产能过剩态势评估[J].中国人口·资源与环境,2018,28(10):169-176.
[2]汪鹏,姜泽毅,张欣欣,耿心怡,郝诗宇.中国钢铁工业流程结构、能耗和排放长期情景预测[J].北京科技大学学报,2014,36(12):1683-1693.

2.2 Distribution of IWH Resources and Prediction - Coke

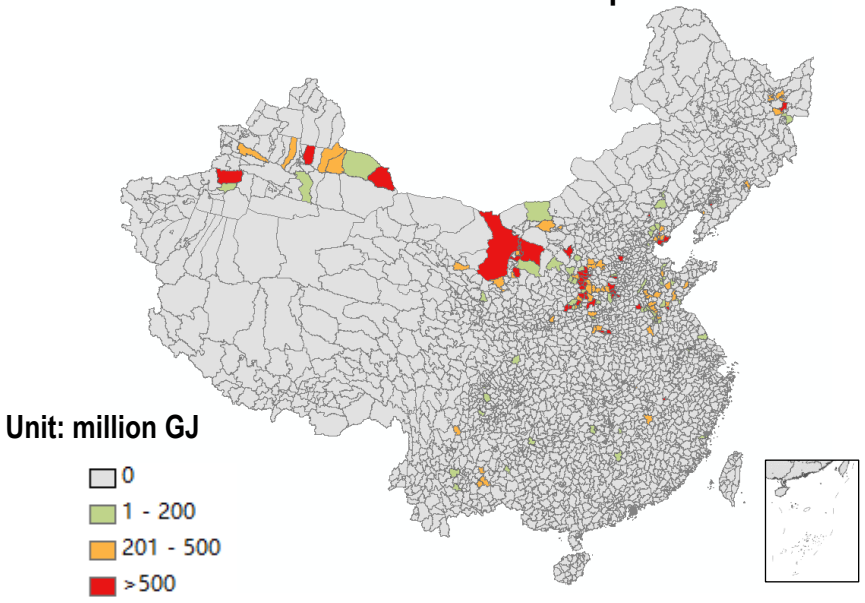
☐ Current situation investigation

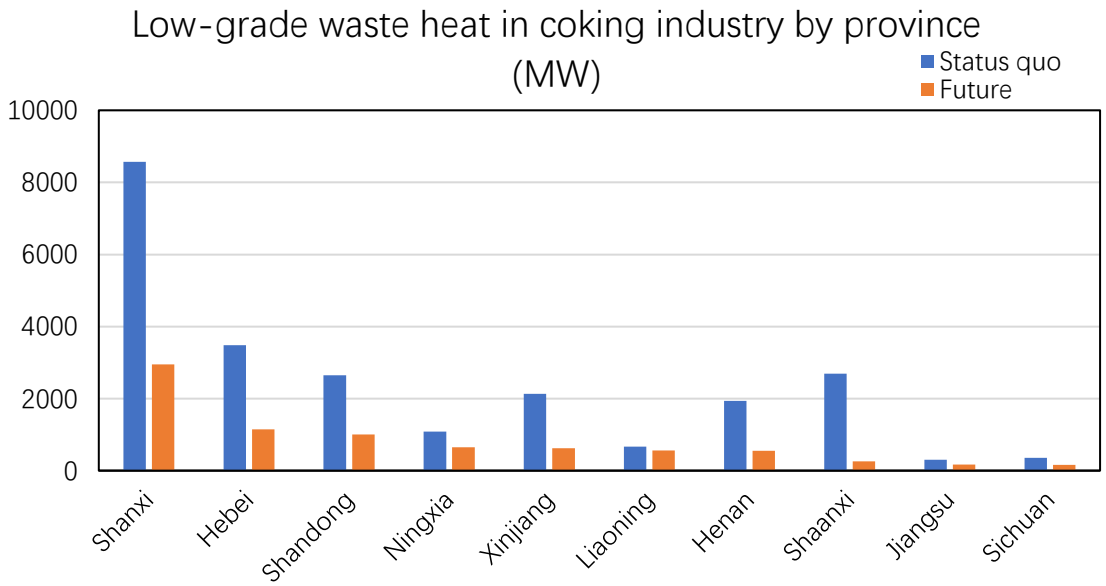
- ✓ The survey covers 394 coking enterprises in China, with a total coke production of about 426 million tons, corresponding to a waste heat potential of **30,900 MW** and **0.88 biliion GJ.**
- ✓ Around the coal resources gathering distribution, Shanxi, Hebei, Shandong, Inner Mongolia

☐ Future Forecast

- ✓ The main use of coke is steel smelting, and the trend of coke production change can refer to the steel trend
- ✓ Take 127 million tons as a reference value
- ✓ **16,800 MW** of low-grade waste heat from the coking industry will be retained in the future, which can supply about **0.48 biliion GJ of** heat

Waste heat distribution of coke enterprises



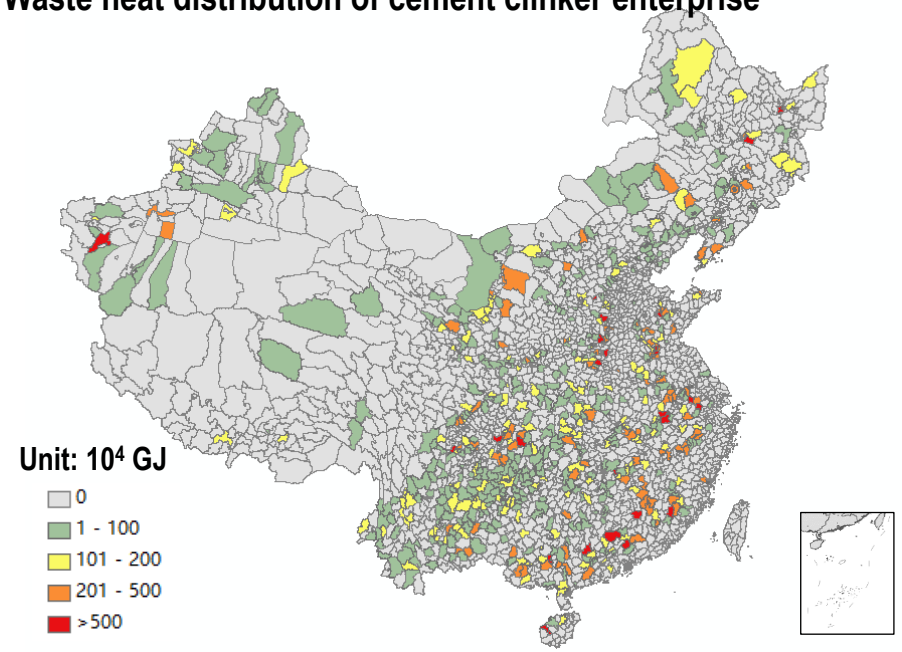


2.2 Distribution of IWH Resources and Prediction – Cement

☐ Current situation investigation

- ✓ The research covers 1046 cement clinker manufacturing enterprises in China, with a total output of 1.89 billion tons, corresponding to a total waste heat recovery potential of **32,600 MW** and **0.93 billion GJ**
- ✓ Clinker enterprises are geographically dispersed, and their geographic location is generally closer to where the product is demanded rather than where the raw materials are provided

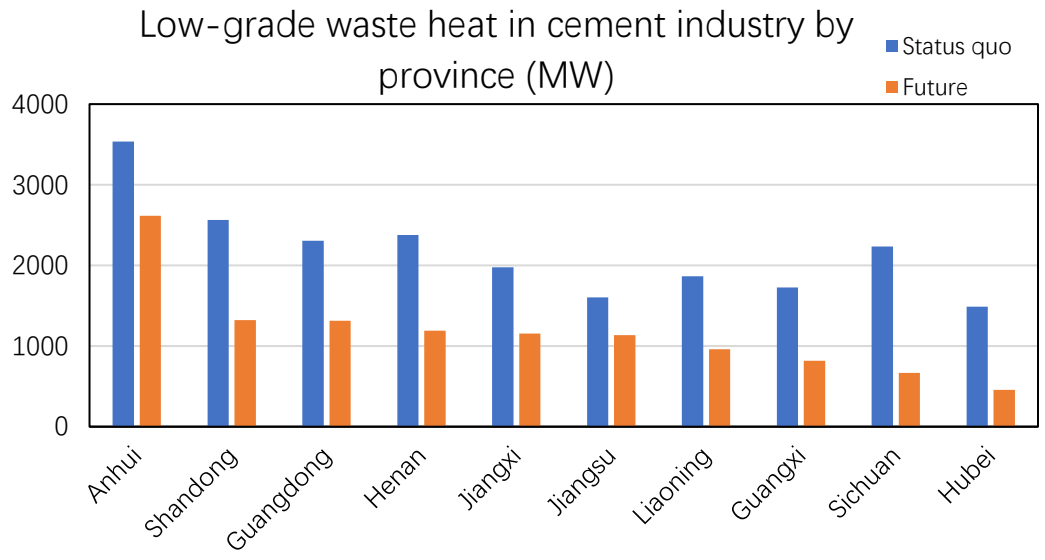
Waste heat distribution of cement clinker enterprise



☐ Future Forecast

- ✓ Scholar[1] predict that China's cement production expected to drop to 750 million tons by 2050
- ✓ **15,800 MW** of low-grade waste heat from the cement industry will be retained in the northern region in the future, which can supply **450 million GJ of** heat

Country	US	Japan	Western Europe	Germany	France	Korea	China
Peak cement production per capita (kg/a)	432	715	600-700	800	566	1000	1664
Urbanization rate	76%	75%	97%	80%	70.4%	90%	60.6%



[1] Gao, Changming. Development forecast and outlook of the world and Chinese cement industry in 2050 [J]. New Century Cement Herald,2019,25(02):1-3+6

2.2 Distribution of IWH Resources and Prediction - Copper

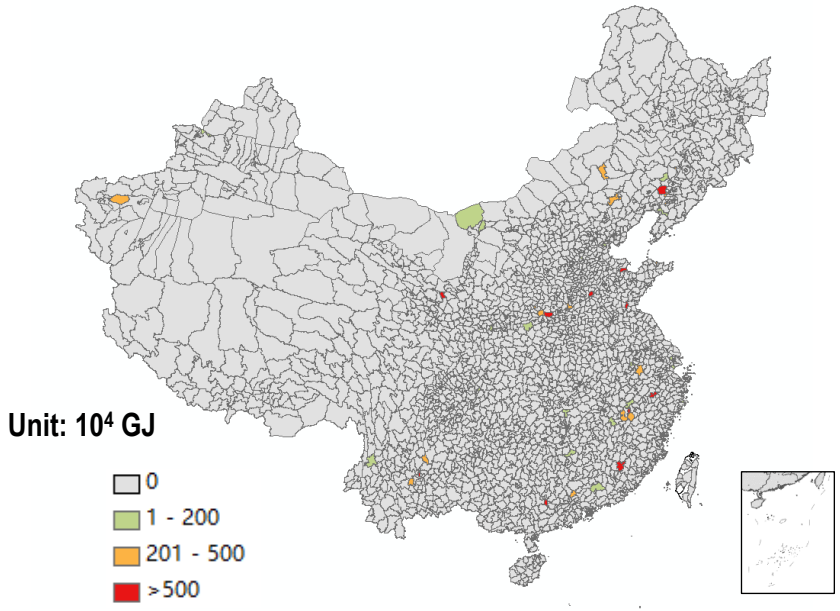
☐ Current situation investigation

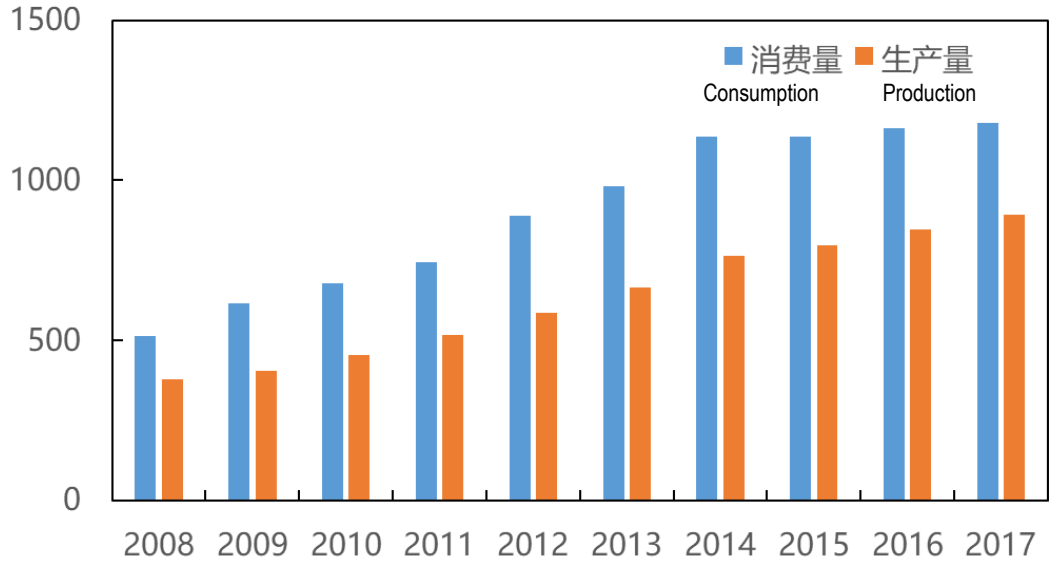
- ✓ The waste heat potential is **10,200MW** and **0.29 billion GJ**, which is a relatively small volume of waste heat compared to ferrous metal smelting
- ✓ China's copper smelting enterprises are mainly located in Yunnan, Shandong, Hubei, Guangxi and other provinces

☐ Future Forecast

- ✓ The scholar [1] predicted that the copper consumption in the future would be 12 million tons. Taking into account the future demand for copper and the recovery of scrap copper in various sectors of China, as well as the reasonable range of copper in use per capita,.
- ✓ The prediction result is not much different from the current situation. **3858MW of** low-grade waste heat is retained, which can supply **0.11 billion GJ of** heat

Waste heat distribution of copper smelting enterprises





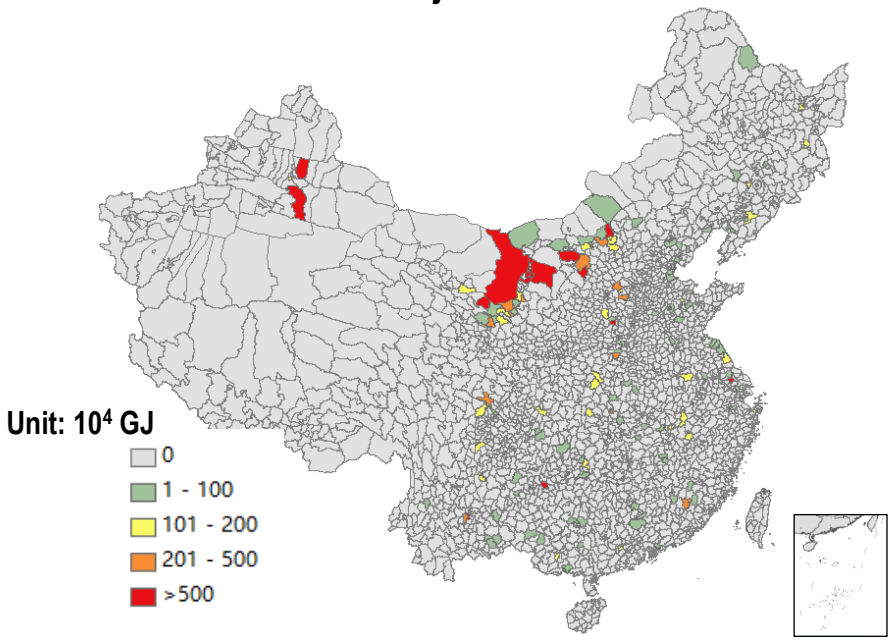
[1] Ling Z , Cai Z , Yang J , et al. The future of copper in China-A perspective based on analysis of copper flows and stocks[J]. Science of the Total Environment, 2015, 536(dec.1):142-149.

2.2 Distribution of IWH Resources and Prediction - Chemicals

☐ Current situation investigation

- ✓ There are many types of chemical industries and complex production processes, several representative chemical industries (sulfuric acid, caustic soda, calcium carbide) were investigated
- ✓ A total of 291 enterprises are covered, with a total waste heat potential of **13,700 MW** and **0.39 billion GJ.**

Waste heat distribution of major chemical industries

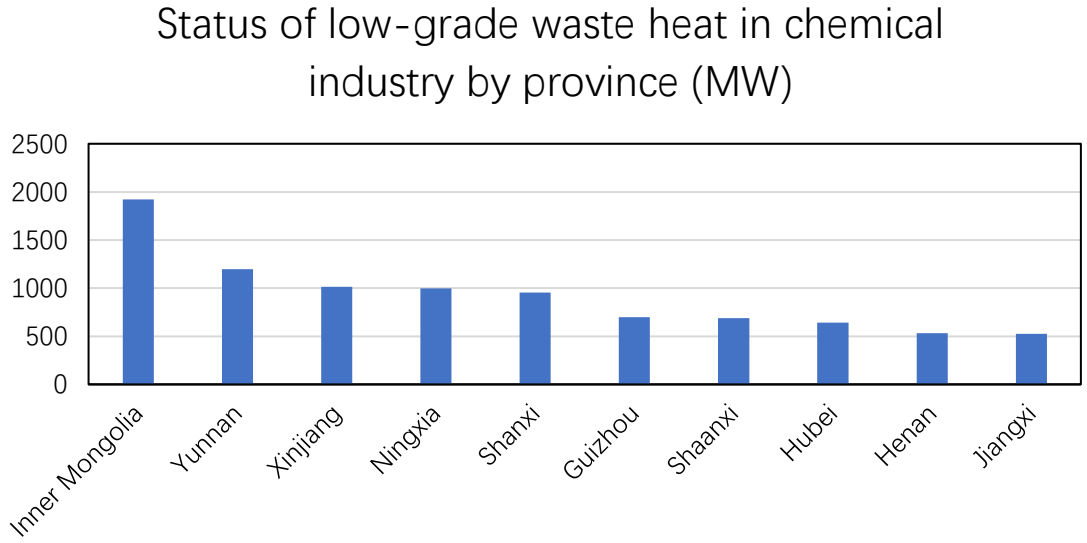


☐ Future Forecast

- ✓ Scholars[1] predicted production of 3 major chemical industry.

Chemicals	Current annual production (10^4 tons)	2050 forecast annual production (10^4 tons)
Methanol	5654	6700
Caustic soda	3459	4200
Calcium carbide	2800	2500

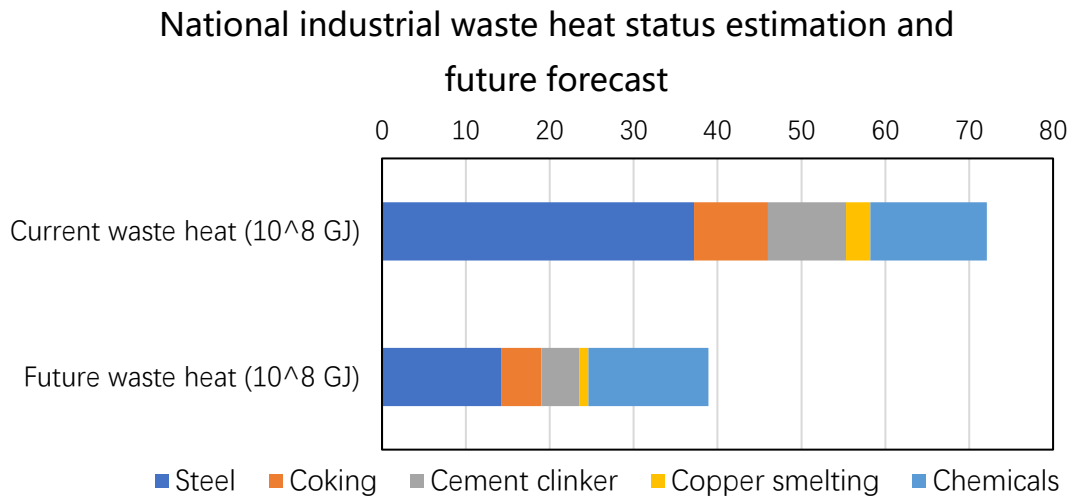
- ✓ The three sub-sectors will have **15,100 MW** of low-grade waste heat in the future, which can supply **0.43 billion GJ of** heat
- ✓ Other chemical sub-sectors can supply about **1 billion GJ of** heat



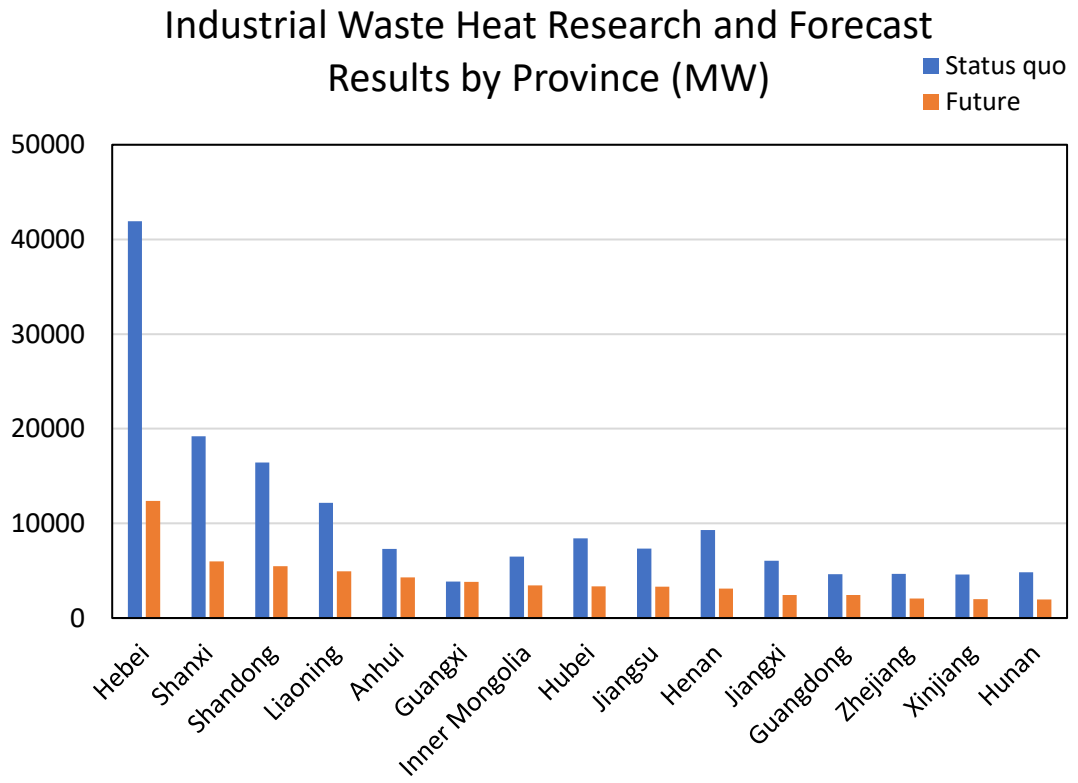
[1] Energy Transition Commission, Rocky Mountain Institute, China 2050: A Zero Carbon Vision for a Fully Modernized Nation

2.2 Distribution of IWH Resources and Prediction - Summary

- ✓ **IWH Resources : 253,000 MW, 7.21 billion GJ**
- ✓ **Prediction in 2050： 136,000 MW, 3.89 billion GJ**
- ✓ Hebei, Shanxi, Shandong and Liaoning have more industrial waste heat



	Current waste heat (billion GJ)	Future waste heat (billion GJ)
Steel	3.72	1.42
Coking	0.88	0.48
Cement clinker	0.93	0.45
Copper smelting	0.29	0.11
Chemicals	1.39	1.43



2.3 Power Plant Waste Heat Resource - Thermal & Nuclear

■ Forecast of future heating potential of power plants

✓ **Forecast results: Future power generation structure in China**

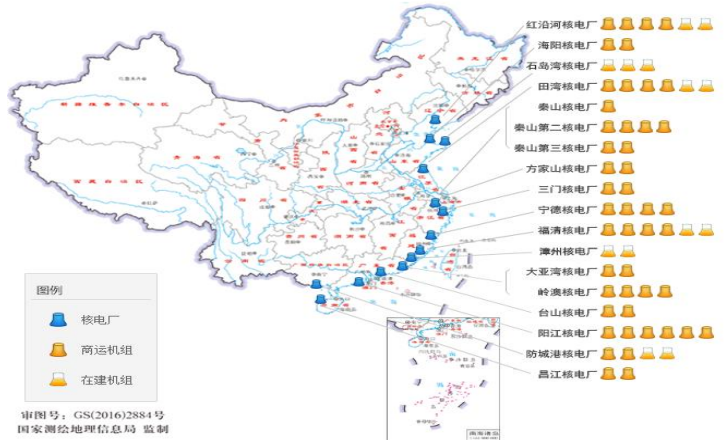
- 840 million kW of thermal power plants will be needed in the northern part of the country in the future, mainly for peaking and to supplement hydropower in winter.
- 200 million kW of nuclear power will be needed in the future

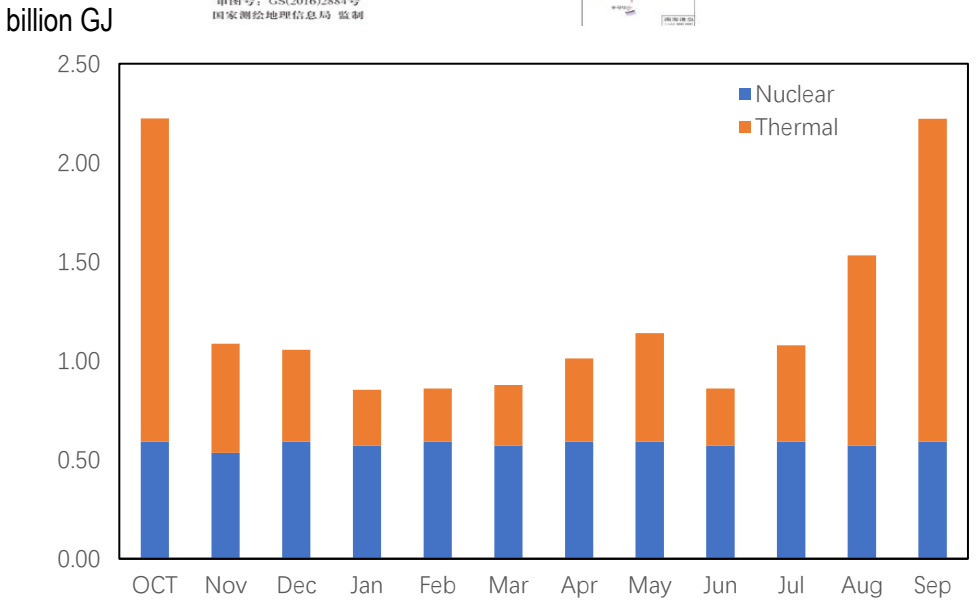
✓ **Heating potential**

- Thermal power： 840 million kW, with 1985h of generation hours， waste heat potential **7.83 billion GJ**;
- Nuclear power： 200 million kW, with 7,500h of generation hours, waste heat potential **7 billion GJ**

Power generation method	Installation (million kW)	Electricity generation (Trillion kWh)	Heat supply (billion GJ)
Thermal power generation	840	1.67	7.83
Nuclear Power	200	1.54	7

Distribution of nuclear power plants in mainland China (as of October 2019)





2.4 Data Center Waste Heat Resources

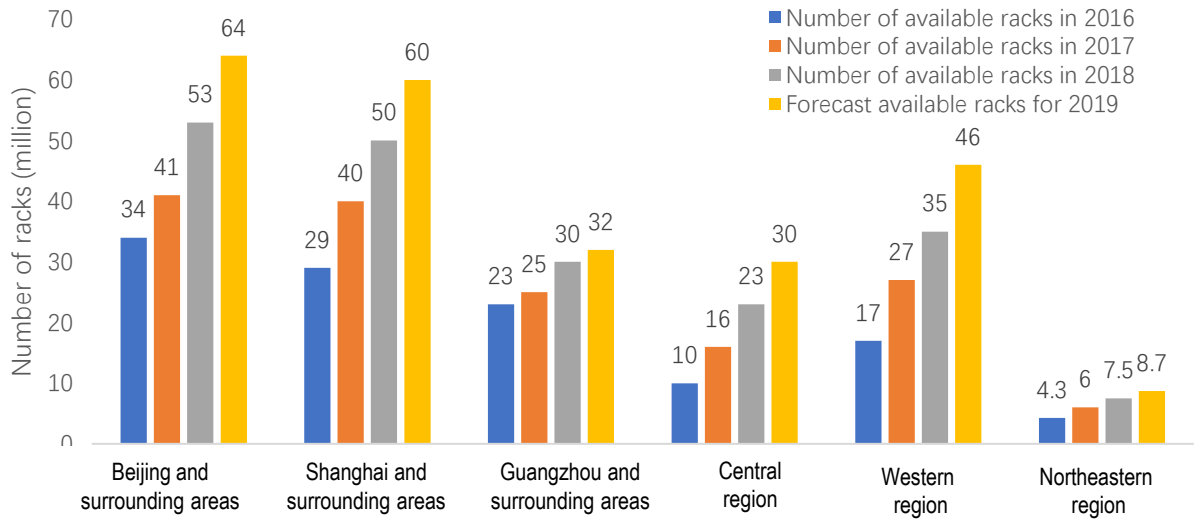
■ Data Center Waste Heat Estimation

☐ Data center electricity consumption in China

- In 2019, the total electricity consumption in China exceeded **130 billion kWh**, accounting for about 2% of the total social electricity consumption[1]
- Total electricity consumption of data centers in China was estimated at **160.8 billion kWh** in 2018, accounting for 2.35% of China's total social electricity consumption (PUE estimated at 2.07)[2]

☐ Estimation of data center waste heat resources

- Takes 2019 data center electricity consumption to be **130 billion** kWh, with total annual heat emissions of approximately **470 million GJ**, with future growth projected to 300 billion kWh and **1.08 billion GJ of** heat emissions
- Data centers are now mainly located in Beijing, Shanghai, Guangzhou, etc.



[1] Ministry of Industry and Information Technology
[2] North China Electric Power University, Research on energy consumption and renewable energy use potential of China's data center

2.5 Urban Sewage and Garbage Waste Heat Resource

Utilization method

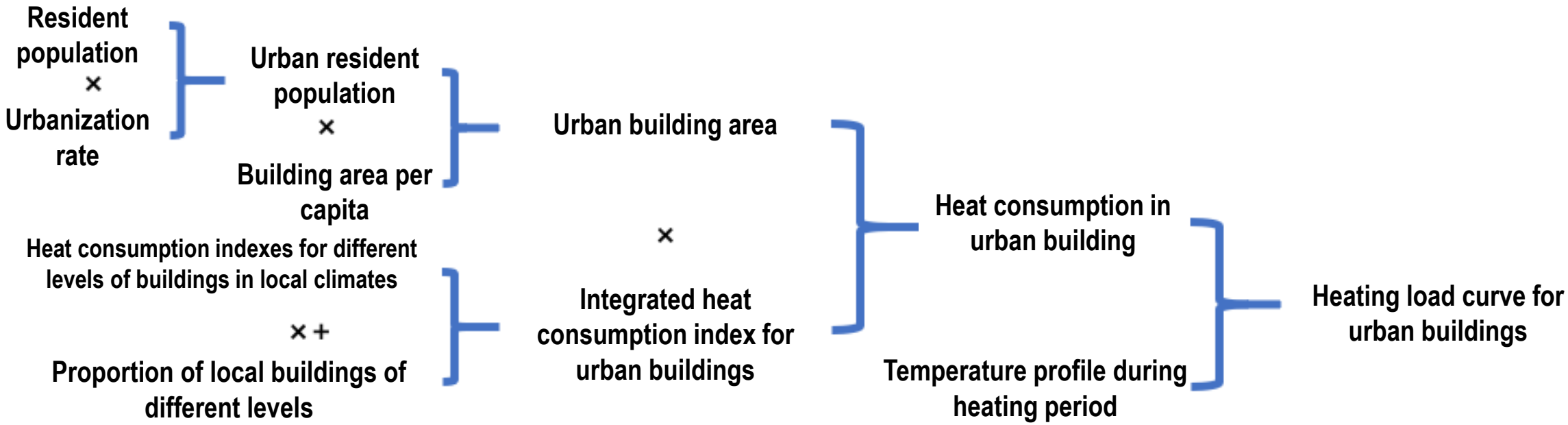
- Municipal garbage: combustible materials in waste can be used for winter heating in towns through cogeneration, which is being gradually implemented in the north of China.
- Municipal sewage: a high-quality low-temperature heat source for the heating season, which can be efficiently heated by a wastewater source heat pump

Future Forecast

- About 1kg of garbage per person per day for urban residents
- The amount of domestic sewage per person per year for urban residents is about 75m³.
- **Heat supply from waste cogeneration and sewage source heat pumps is estimated at 0.2 billion GJ**

Calculation parameters	
Percentage of combustible components of urban domestic waste	50%
Combustible waste calorific value	5MJ/kg
Average heat extraction temperature difference of sewage source heat pump	5K
Average COP of sewage source heat pump	4.5

Methodology for forecasting urban heat demand by region



2035/2050 District- and county-level heat consumption during heating period and dynamic/static load

- Resident population forecast
- Urbanization rate forecast
- Building area per capita index forecast
- Building energy efficiency level splitting and heating load index forecast

Resident population forecast

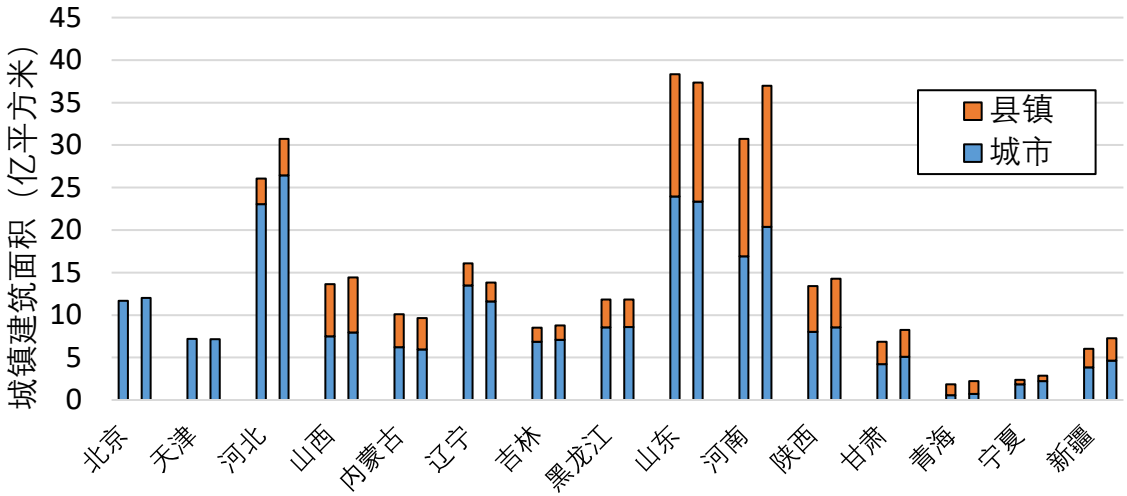
- Based on fertility rate, life expectancy, migrating population
- Considering a medium shared socioeconomic development pathway (SSP2)
- Population will peak around 2030
- Population growth varies by region

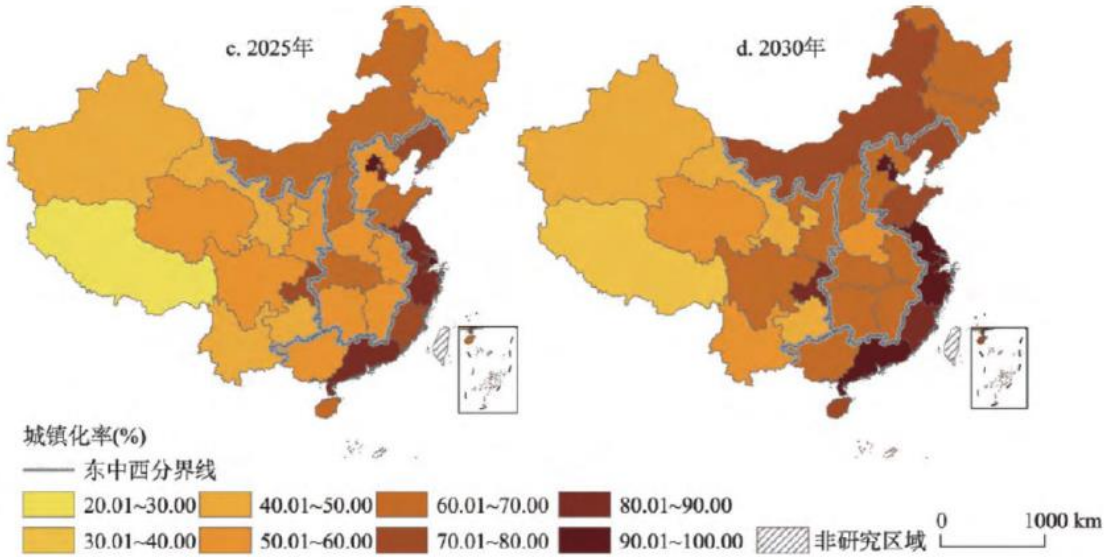
Urbanization rate forecast

- 70% urbanization rate by 2035
- 78% urbanization rate by 2050

Building area forecast

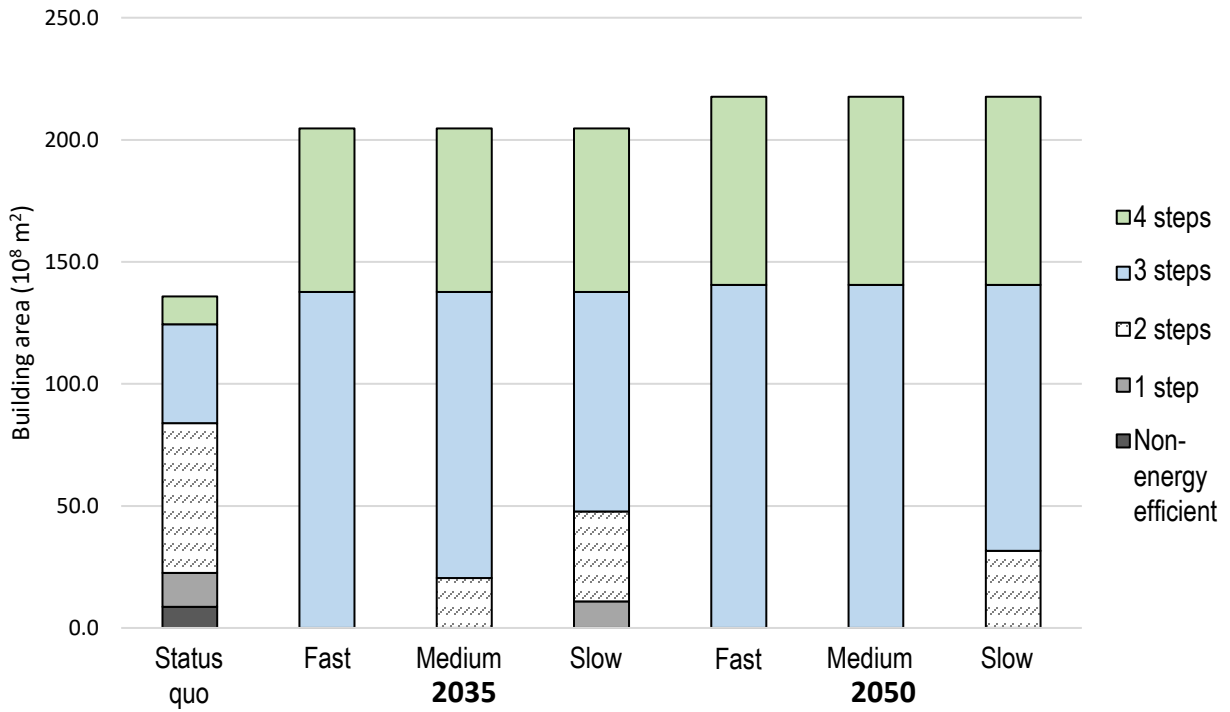
- Adopting rational area standards considering the living habits of Chinese residents





Energy efficiency retrofit pattern

- Based on the actual experience of energy-saving retrofit during the 12th and 13th Five-Year Plan periods, three retrofit patterns at different paces are set;
- Based on the annual new construction, demolition and energy-saving retrofit building area, the heating load is determined.



Retrofit patterns	Retrofit progress setting
Slow	0.6% of the existing building stock is renovated each year. (i.e. the current retrofit pace)
Medium	10% 2 steps energy-saving buildings in 2035; all buildings will reach 3 steps energy-saving and above in 2050.
Fast	Complete the retrofit of all buildings currently below the 2 steps energy-saving standard by 2035.

3.1 Urban heat demand forecast by region in Northern China

- **Heating load forecast results:** 3.69 billion GJ in Northern China
- Considering the heat demand in the middle and lower reaches of the Yangtze River as well as the western regions: totally about **5 billion GJ**

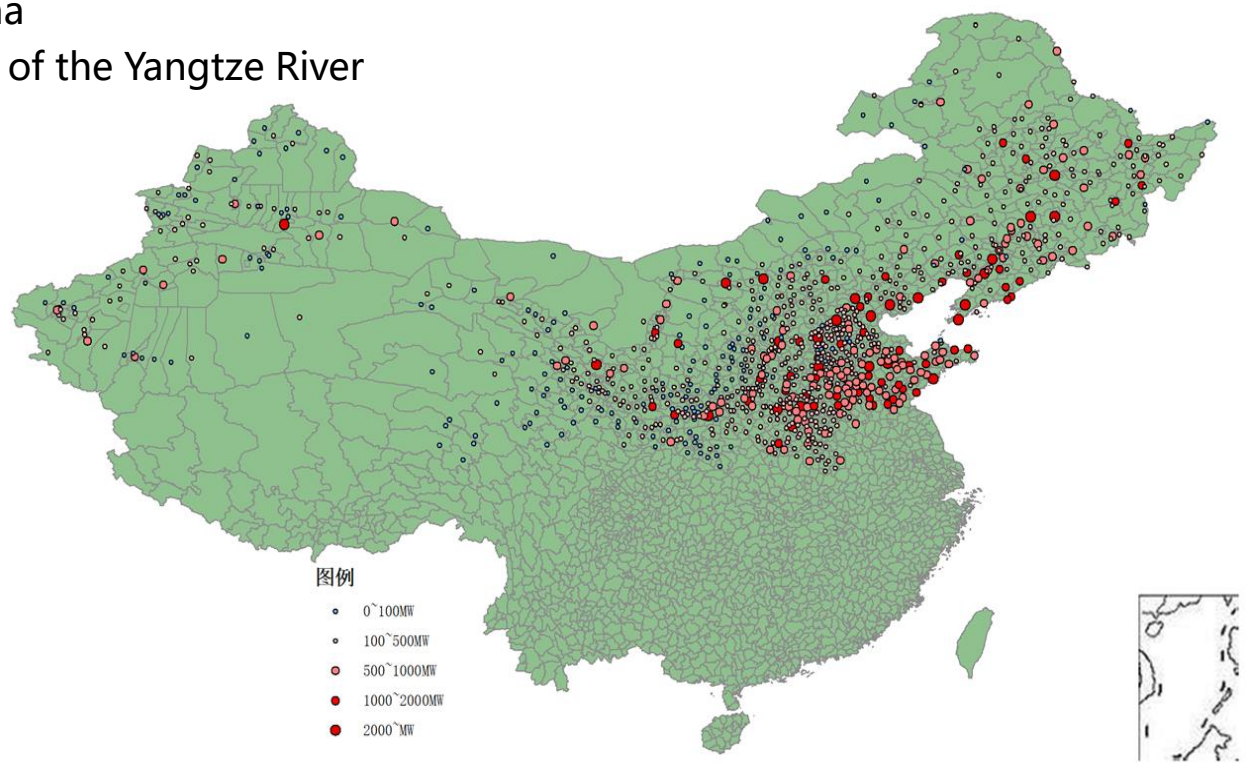
- Building area per capita (residential + public building): **50㎡ /person**.

  Residential area per capita: referring to the saturation value in Japan;

  Public building area per capita: one half of the residential area per capita.

- **Urban building area** in Northern China:

  2035: 20.47 billion ㎡ 2050: 21.77 billion ㎡



- Compare the heating load index per unit area in 2035 and 2050 with the status quo level in Northern China under different retrofit patterns:

✓ Heat consumption per unit area could be reduced by up to **31.8%** in 2035

✓ Heat consumption per unit area could be reduced by up to **33.5%** in 2050

Retrofit patterns	Status quo		2035			2050		
	Heat consumption index (GJ/㎡)	Heating load (W/㎡)	Heat consumption index (GJ/㎡)	Heating load (W/㎡)	**Energy saving ratio**	Heat consumption index (GJ/㎡)	Heating load (W/㎡)	**Energy saving ratio**
Fast	0.254	33.8	0.173	22.86	**31.8%**	0.169	22.35	**33.5%**
Medium			0.180	23.86	**29.0%**	0.169	22.35	**33.5%**
Slow			0.197	26.12	**22.5%**	0.180	23.88	**29.1%**

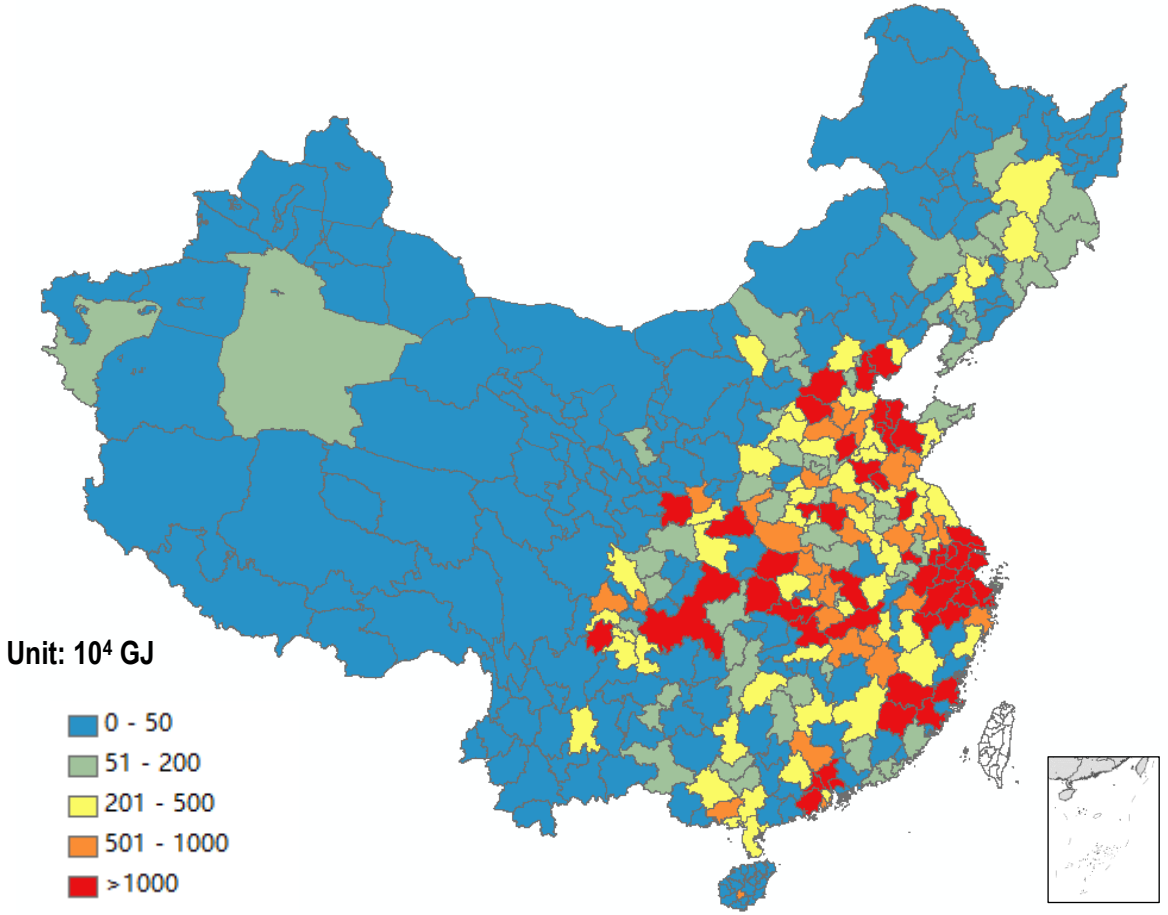
3.2 Heat demand for non-process industries

- Current situation: Total heat demand of the industry is about **3.08 billion GJ**; About **6.9 billion GJ in the future**

Industry	Representative Products	Heat consumption (billion GJ)
Agri-food processing	Commercial sugar	1.07
Food manufacturing	Dairy products	0.77
Beverage manufacturing	Beverages	0.62
Paper Making	Machine made paper	1.44
Textile	Cloth	1.30
Pharmaceutical Manufacturing	Chemical raw medicine	0.43
Chemical fiber manufacturing	Chemical fiber	0.70
Rubber and plastic products	Synthetic rubber	0.55

- **Estimated 4 non-process industries heat demand**
  - ✓ Combined with the heat consumption per unit of product, estimate the distribution of heat use in the **textile, paper, pharmaceutical manufacturing, and chemical fiber industries** at the **municipal level**

- **Demand distribution of 4 non-process industries**
  - ✓ Hebei, Shandong, Zhejiang and Hubei have well developed the four industries and have large heat load
  - ✓ Less in the west and northeast

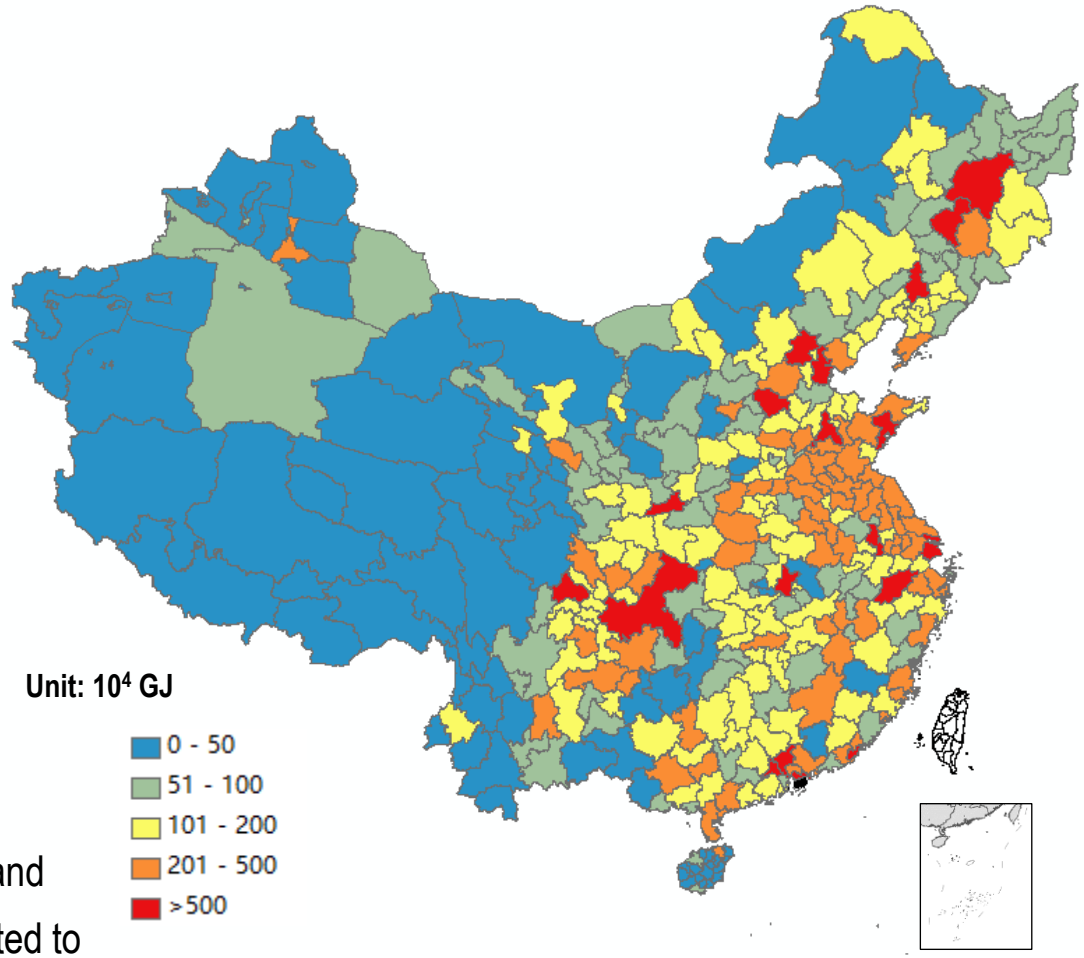


Estimated urban hot water heat consumption

✓ Combined with the domestic standard, and the European actual test case, the domestic hot water index is selected as 20L/day/person

		L/person/day
China	Residential (water heater)	20-60
	Residential (centralized hot water supply)	25-70
Finland	Apartments	46
Estonia	Apartments	40.3
Sweden	Apartments	33
Denmark	Apartments	20
Norway	Apartments	40

Urban domestic hot water distribution



With 800 million urban residents, the total heat demand is **1.1 billion GJ**, and considering the future urbanization process, the total heat demand is expected to be **1.6 billion GJ** in the future

4.1 Total amount distribution

Supply and demand matching

Supply and demand matching:

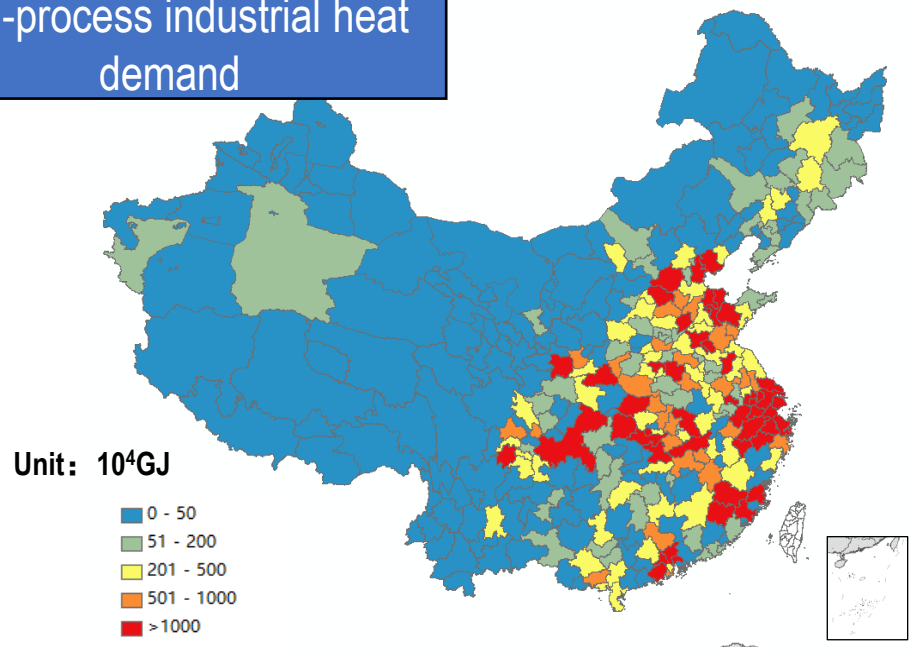
- ✓ Under the rapid building energy-saving renovation scenario, building heating demand will reach approximately 5 billion GJ considering the heat supply in the middle and lower reaches of the Yangtze River basin as well as the western region, etc.
- ✓ Considering the change of industrial structure, the waste heat of process industry will be significantly reduced to 3.8 billion GJ, and the heat consumption of non-process industry will be significantly increased by 6.9 billion GJ
- ✓ Thermal power as a peak heat source has a future heating potential of 7.8 billion GJ and nuclear power as a basic heat source has a future heating potential of 7 billion GJ, but subject to geographical constraints

	Future (billion GJ)
Total heat demand	**13.50**
Domestic hot water	**1.60**
North urban space heating	**5.00**
Non-process industrial waste heat	**6.90**

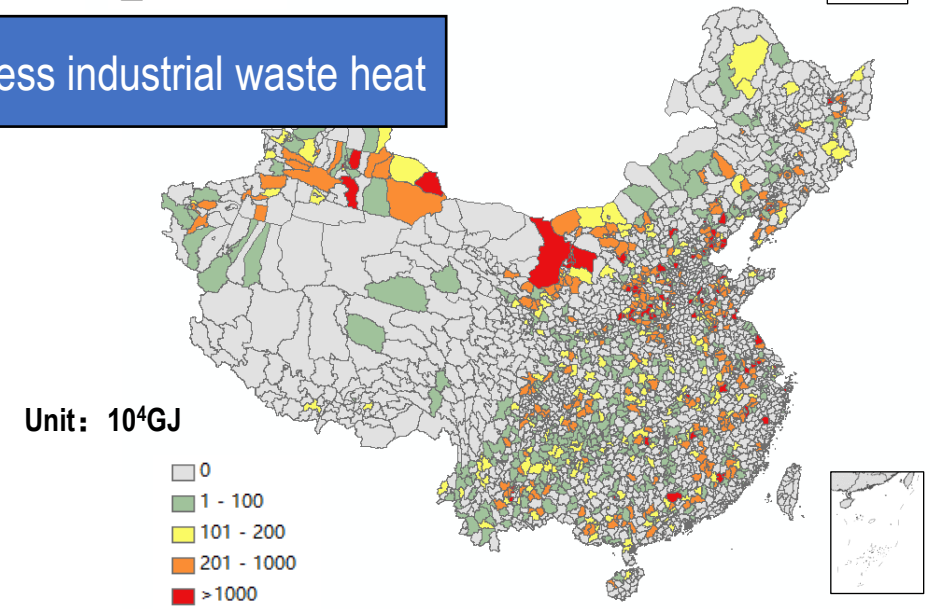
		Unit	**Future amounts**
Waste heat resources		billion GJ	**20.00**
Nuclear power generation	Installed power generation capacity	billion kW	**0.20**
	Heating potential	billion kW	**0.30**
	Total heat supply	billion GJ	**7.00**
Peaking thermal power	Installed power generation capacity	billion kW	**0.84**
	Heating potential	billion kW	**1.09**
	Total heat supply	billion GJ	**7.80**
Garbage and sewage waste heat	**Total heat supply**	billion GJ	**0.20**
Data center waste Heat	**Total heat supply**	billion GJ	**1.08**
Industrial waste heat	**Iron and steel Industry**	billion GJ	**1.42**
	Building materials Industry	billion GJ	**0.45**
	Non-ferrous metal smelting industry	billion GJ	**0.11**
	Chemical industry	billion GJ	**1.43**
	Coking Industry	billion GJ	**0.48**

Supply and demand matching

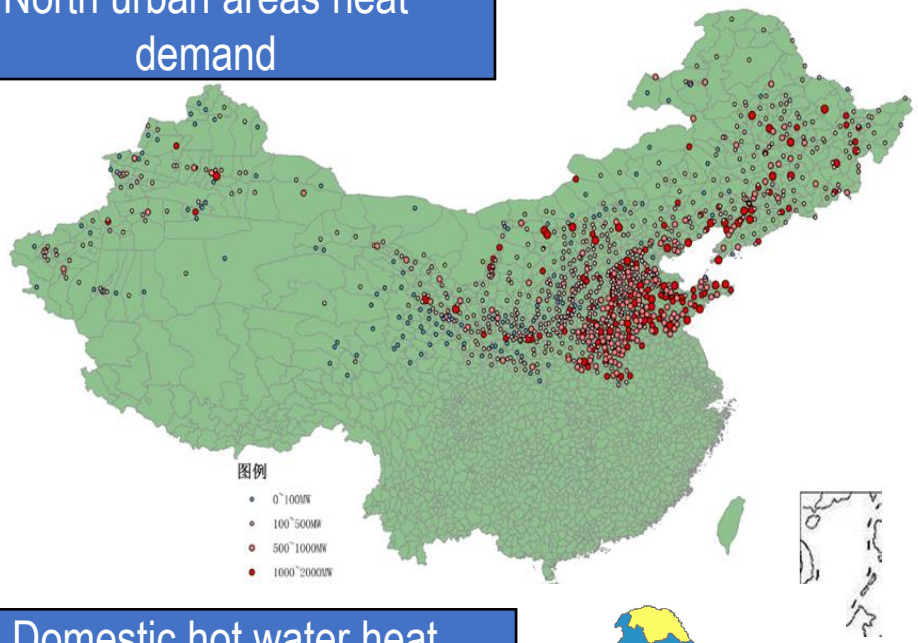
Non-process industrial heat demand



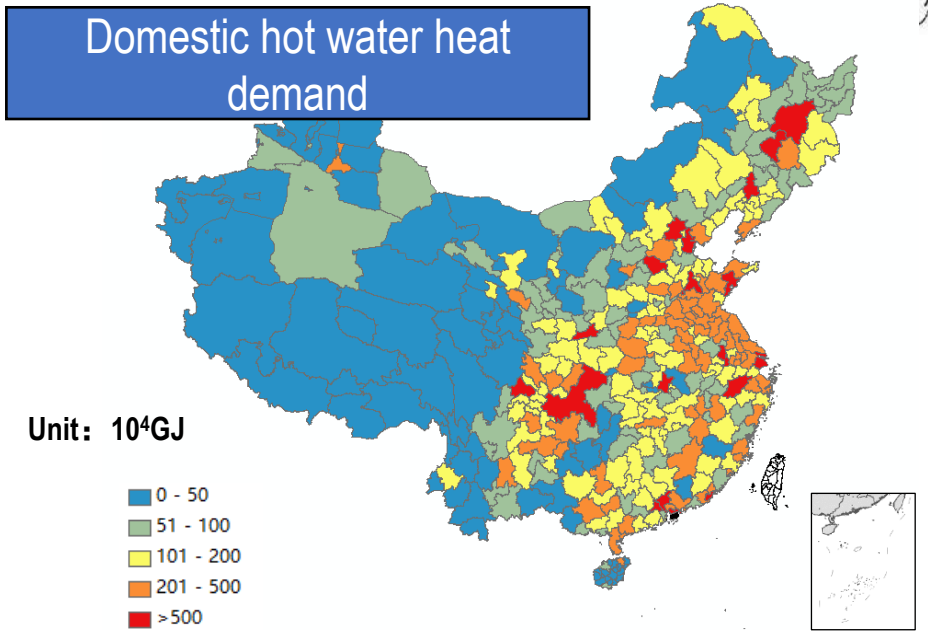
Process industrial waste heat



North urban areas heat demand



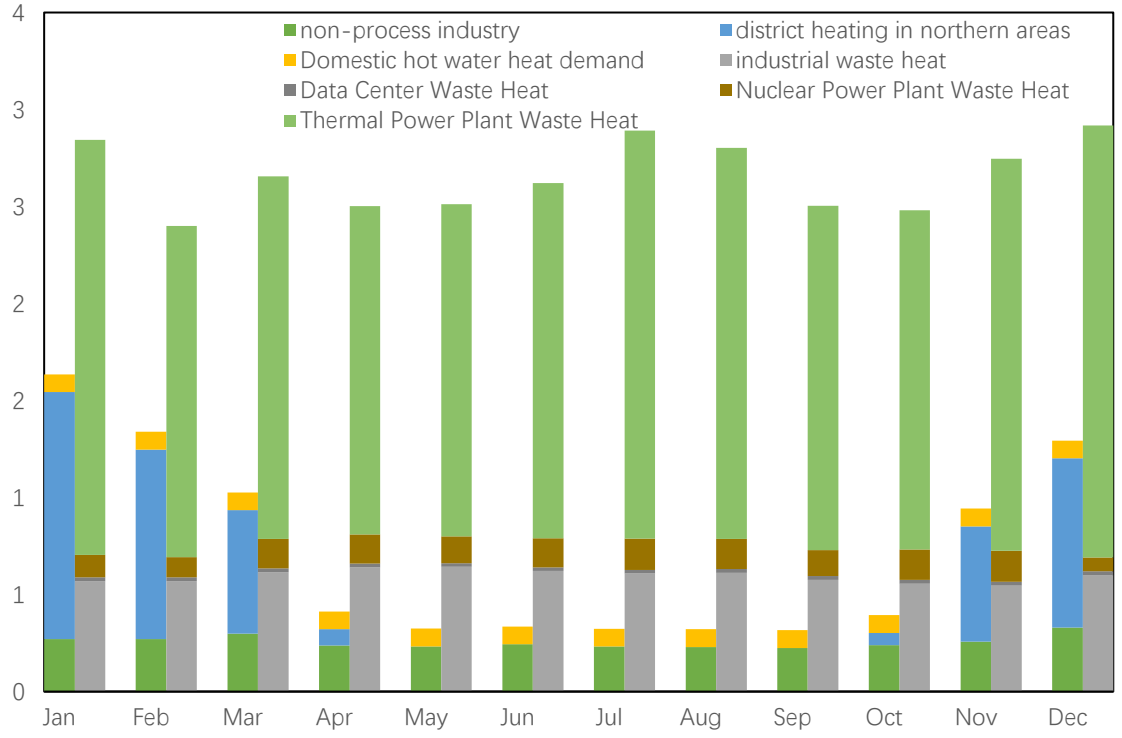
Domestic hot water heat demand



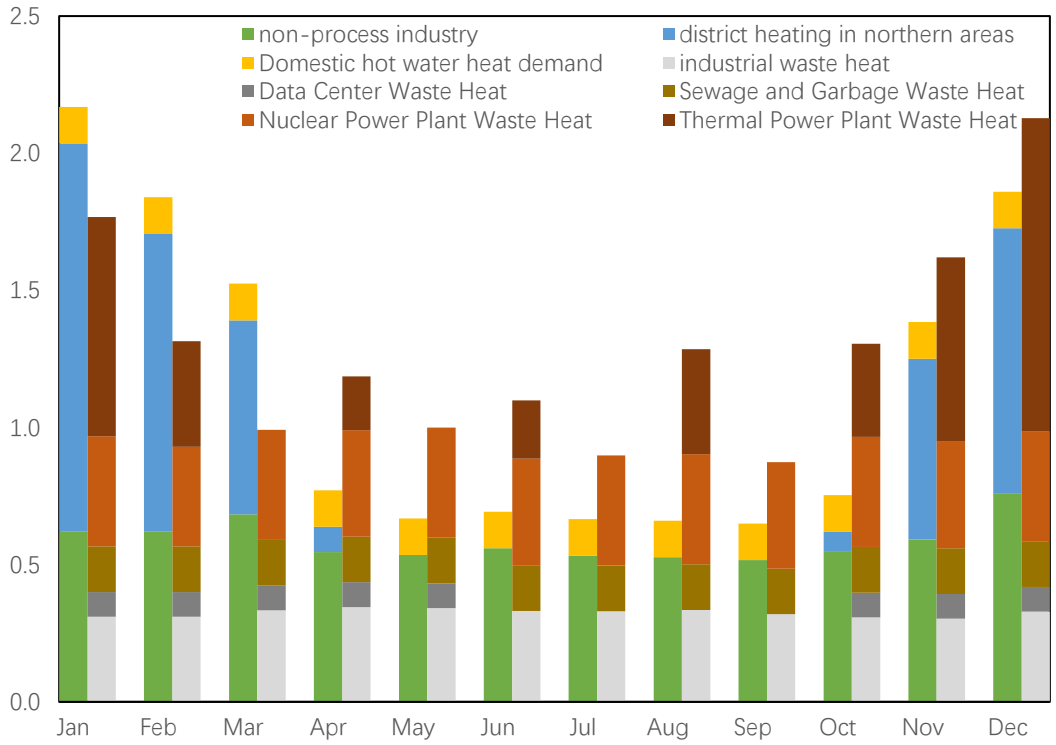
◻ Supply and demand matching

✓ Because of the existence of urban heating demand, there is a phenomenon of "more heat in summer and less heat in winter", and a large amount of waste heat still exists in the non-heating season.

billion GJ Status



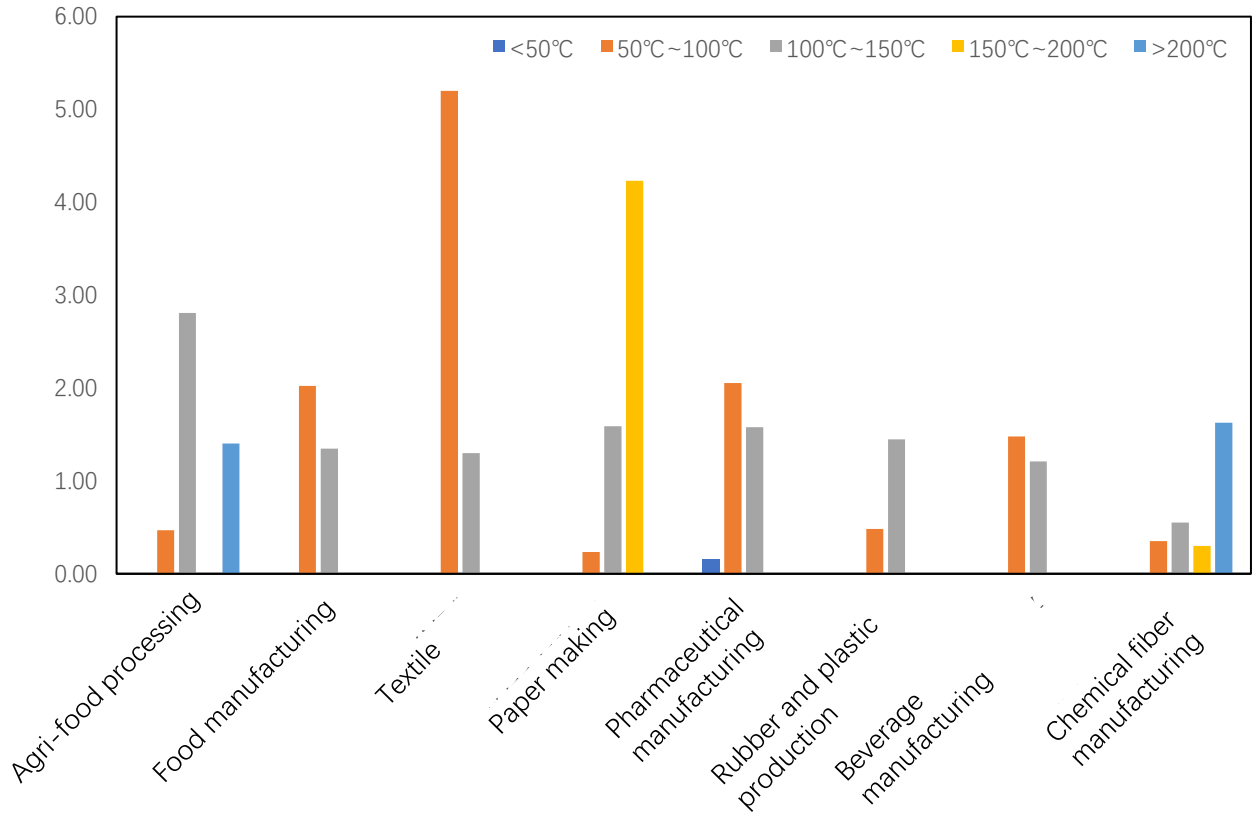
billion GJ Future



Temperature distribution of heat demand

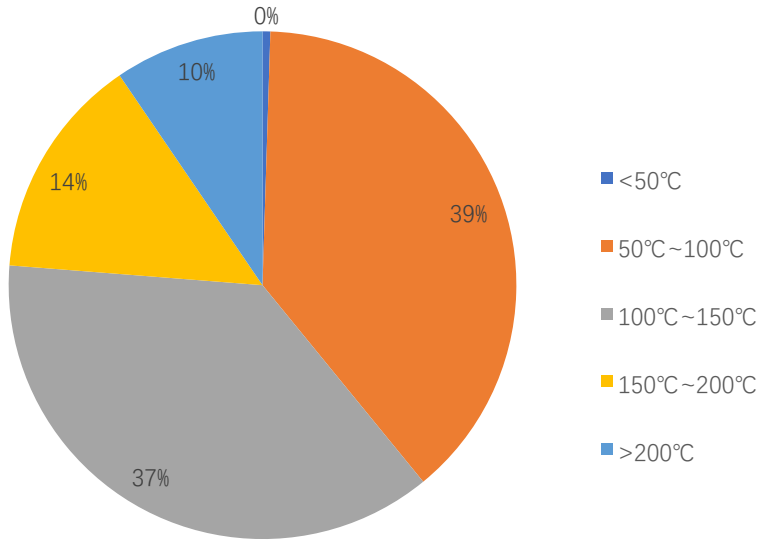
- ✓ Very little heat demand for low temperature processes below 50°C, mostly concentrated in the range of 50°C to 150°C

billion GJ



Temperature distribution of waste heat resoure

- ✓ Unrecovered and easily accessible industrial waste heat is mostly concentrated in the low-grade range and requires temperature conversion before it can be used for industrial heating



6 Conclusion

■ **Waste heat resources have great potential and can be used to effectively reduce carbon emissions**

■ The technology of industrial waste heat used for central heating is mature

- **Key issues :** waste heat collection – integration – distribution – system control and operation
- Collection & integration: **long-term planning, cascade utilization**
- Distribution: **Lowering the return water temperature of the primary network**
- **System control and operation:** Cooperate with other heat sources
- **Application cases： Waste heat recovery of Qianxi Steel Plant and Chifeng Copper Plant**

■ Main problems in promotion and utilization of industrial waste heat

- **Seasonal Heat Storage——**Waste heat still exists in non-heating seasons
- **High Temperature Heat Pump——**Use HTHP to increase the temperature of heat to meet the heat demand of different users
- **Long-Distance Heating Pipe Network——**Solve the problem of geographical location mismatch between heat sources and users