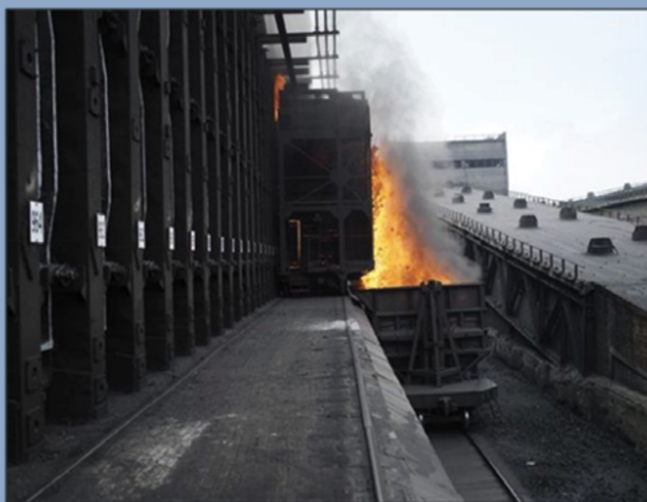
CAAC
中国清洁空气联盟
Clean Air Alliance of China

SUMMARY REPORT

China Black Carbon Studies and Control Policies (2012)



CAAC Knowledge Series
April 2013

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CAAC Knowledge Series

"CAAC Knowledge Series" dedicates to introducing scientific knowledge, management experiences (domestic and international), polices & mechanisms, tools, methodologies and research updates in the field of clean air, to support the improvement of China's air quality.

"Network Products" is an integral part of CAAC Knowledge Series, generated from the research, discussion and progress summary of CAAC professional collaborative networks.

CAAC Black Carbon Prevention and Control Collaboration Network catalyzes China's black carbon research and management via information sharing, collaborative research projects, and organizing relevant activities.

School of Environment of Tsinghua University is the technical coordination of the Black Carbon Network .

This report is a progress summary of CAAC Black Carbon Prevention and Control Collaboration Network.

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Content

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On 15th November 2012, the third "International Workshop on Black Carbon: Impacts and Control Strategies" was held in Beijing, supported by the Energy Foundation and organized by Tsinghua University. Both international and domestic experts participated in this workshop, where in-depth discussions on black carbon's climate and health impacts, its emissions and potential control strategies, along with the remaining scientific uncertainties. Based on the workshop, this report delivers a summary of scientific studies and control measures and policies on black carbon in China.

1 BACKGROUND

What Is Black Carbon?

There is no scientific consensus on black carbon's definition at this moment, and differences are typically tied to the underlying measurement technique(s). The U.S. EPA describes black carbon as strong light-absorbing components of particulate matter (PM) formed by the incomplete combustion of fossil fuels, biofuels, and biomass, without reference to measurement methods[1]. In 2013, a group of researchers compiled a black carbon bounding study[2], which proposed a comprehensive definition of black carbon as follows: "black carbon is a distinct type of carbonaceous material that is formed primarily in flames, is directly emitted to the atmosphere, and has a unique combination of physical properties. It strongly absorbs visible light, refracts with a vaporization temperature near 4000K, exists as an aggregate of small spheres, and is insoluble in water and organic solvents".

It is worth nothing that black carbon comes from primitive, low-temperature combustion sources and is commonly referred to as "soot". It is emitted directly into the atmosphere in the form of fine particles less than one micron in diameter, contributing to total $PM_{2.5}$ concentrations.

What Are the Impacts of Black Carbon?

Black carbon has significant climate and health effects. Black carbon aerosols warm the atmosphere by absorbing incoming solar radiation then releasing that light energy back to the troposphere as heat. When it falls on snow and ice, black carbon accelerates the melting process by changing the reflectivity of the surface (albedo). Since the Industrial Revolution, black carbon has warmed the earth by 1.1 Watts per square meter (W/m^2), which is second only to CO_2's 1.66 W/m^2 of warming over the same period. There are

1. U.S.EPA, Report to Congress on Black Carbon. March, 2010

2. Bond, T. C. et. al.(2013), Bounding the role of black carbon in the climate system: A scientific assessment. This report is a comprehensive 30-authors, 4-years study on black carbon, which established a new scientific consensus about what is known and what remains uncertain regarding black carbon's climate effects, and made specific recommendations to help policymakers choose the most effective interventions, given existing information

disputes regarding the global warming potentials of black carbon. According to the black carbon bounding study, each gram of black carbon emitted is 900 times more powerful than a gram of CO_2 in warming the atmosphere over 100 years[3]. The short-term impact of black carbon is even greater since its impact is immediate, unlike the long lag times of CO_2. Finally, since black carbon is concentrated in certain geographical regions, it can have very strong localized effects.

Black carbon also has serious health impacts. Black carbon is inhaled into the deepest recesses of the human lungs, and thus can cause inflammation of the respiratory and cardiovascular system. Like all fine particles less than 2.5 microns in diameter, black carbon is associated with premature mortality, low birth weight, increased disease rates, more severe asthma incidences, reduced lung function, lower quality of life, and lost productivity.

How Black Carbon Is Produced?

The main sources of black carbon emissions are diesel vehicles, biomass burning, coal-fired boilers, brick kilns, and residential cook stoves and heaters. The U.S. EPA reported open biomass burning accounted for around 35.5% of total globally black carbon emissions in 2000. The domestic sector is the largest source of black carbon emission in China, with emissions of 0.9 million tons or more than 50% of China's total black carbon emissions[4]. Diesel vehicles emissons will continue to increase due to China's rapid economic and social development. Diesel vehicles have already been identified as the most significant source of black carbon emissions in the Yangtze River Delta region, far greater than cook stoves or biomass burning[5].

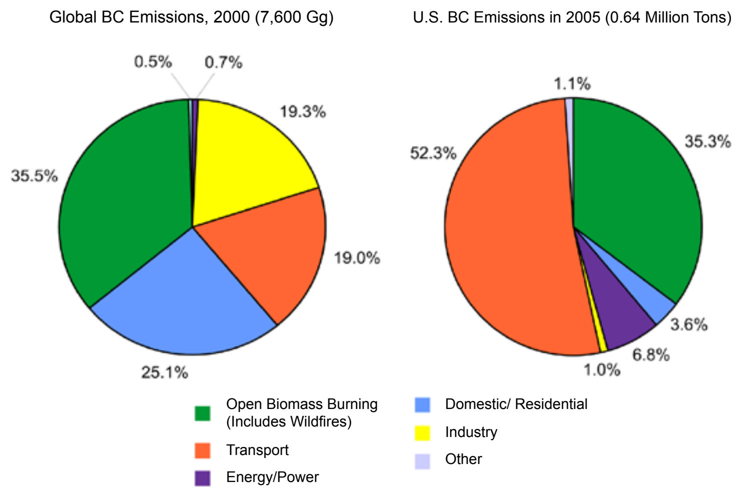

Figure 1. Black carbon emissions by major source category (Source: U.S. EPA)

3. IPCC (2007), Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 104 pp; Bond, T. C. et. al.(2013), Bounding the role of black carbon in the climate system: A scientific assessment.

4. Lei, Y., Q. Zhang, K. B. He, and D. G. Streets (2011), Primary anthropogenic aerosol emission trends for China, 1990–2005, Atmos. Chem. Phys., 11, 931-954, doi:10.5194/acp-11-931-2011.

5. Chen, C. H., H. L. Wang, C. Huang, S. R. Lou, L. P. Qiao, and M. Zhou (2012), Haze Formation and Its Precursor Emission in Yangtze River Delta Region.

Time-based studies show that black carbon emissions have decreased substantially in developed countries and regions, whereas black carbon emissions in Africa, Latin America and South Asia are still increasing. From a global perspective, black carbon emissions are expected to gradually fall in the "business as usual" scenario, though the proportion of black carbon emissions contributed by domestic, brick kilns, non-road vehicles sources will continue to rise[6].

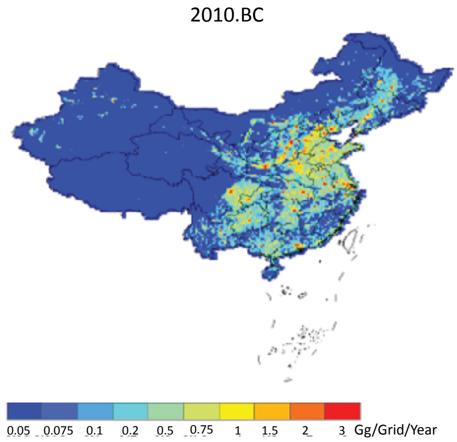

Figure 2. Spatial distribution of China's black carbon (from the MEIC Model[7])

2 UPDATES ON SCIENTIFIC RESEARCH

International studies on black carbon are concentrated in following areas: the effect of black carbon and other aerosols on climate and other ecological systems (including black carbon concentration measure in the air, sea & lake sediment and ice core, black carbon's change in carbon cycle, as well as the model simulating black carbon's climate effect); estimates of black carbon emissions from various source categories, the emission patterns and trends in different time scale and space scales; the impact of black carbon on health; and potential control methods for individual sources.

Scientific studies in China are focused on black carbon's impact on climate and ecology, black carbon's impact on health and black carbon emissions features.

Studies of Black Carbon's Impacts on Climate and Environment

It is difficult to isolate the effects of black carbon from other co-emitted aerosols, which have their own climate impacts. Black carbon warms and cools the earth depending on its location in the atmosphere. Near the surface, black carbon reduces incoming sunlight and

6. Greenhouse Gas and Air Pollution Interactions and Synergies model (GAINS), 2011. Available at http://gains.iiasa.ac.at/gains/docu.GCC/index.menu

7. Multi-resolution Emission Inventory for China (MEIC), is an open-access model framework that provides model-ready emission data over China to support chemical transport model and climate model at different spatial resolution and time scale. Available at http://www.meicmodel.org/

thus cools the ground. However, at higher altitudes, black carbon warms the ambient air and contributes to global warming[8]. These cross cutting effects lead to a degree of scientific uncertainty and require sophisticated, multi-pollutant analyses to resolve.

Recent studies showed black carbon's varied climate impacts: black carbon would influences the intensity of tropical cyclones[9]; causes tropical expansion and a northward shift in the northern hemisphere's climatic zones[10]; reduces the precipitation in monsoon regions[11]; and increases the occurrence of haze[12]. In addition, black carbon has a series of aging reactions after emitted into atmosphere, which affects the formation of "combined air pollution"[13]. In summary, the existence of black carbon makes the studies of climate change and environmental pollution more complex, and further studies are needed.

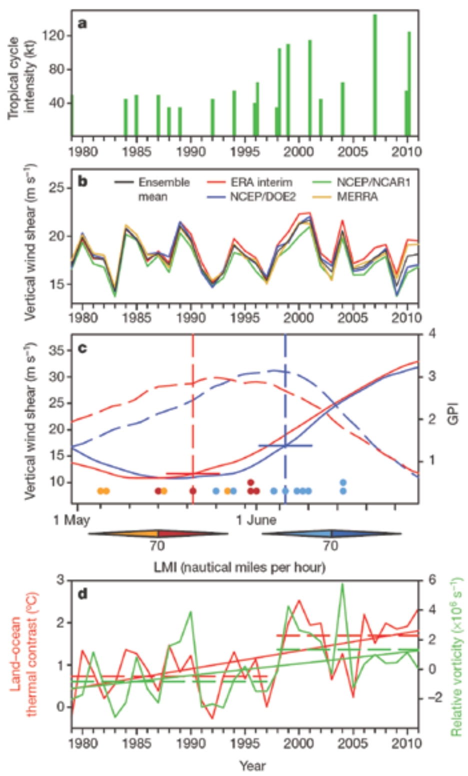

Figure 3. Cause of the intensified Arabian Sea tropical cyclone (Source: Wang B. et. al., 2012).

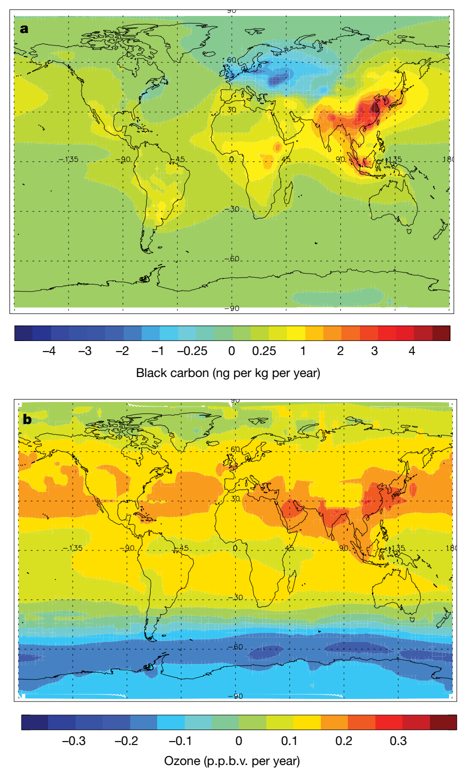

Figure 4. 1970–2009 annual mean tropospheric trends (Source: Allen R. J. et. al., 2012)

8. IPCC(2007), Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland, 2007: 104.

9. Evan, A. T., J. P. Kossin, C. E. Chuang, and V. Ramanathan (2011), Arabian Sea tropical cyclones intensified by emissions of black carbon and other aerosols, Nature, 479, 94-97; Wang B., S. B. Xu, and L. G. Wu (2012), Intensified Arabian Sea tropical storms, Nature, 489, E1-E2.

10. Allen, R. J., S. C. Sherwood, J. R. Norris, and C. S. Zender (2012), Recent Northern Hemisphere tropical expansion primarily driven by black carbon and tropospheric ozone, Nature, 485, 350-354.

11. Si, D., and Y. H. Ding (2012), The tropospheric biennial oscillation in the East Asianmonsoon region and its influence on the precipitationin China and large-scale atmospheric circulationin East Asia, Int. J. Climatol, 32: 1697–1716; Bollasina, M. A., Y. Ming, and V. Ramaswamy (2011), Anthropogenic aerosols and the weakening of the South Asian summer monsoon, Science, 334, 502-505.

12. The Climate Center of China Meteorological Administration, Monitoring of the extrem climate events, 2012 .

13. Han, C., Y. C. Liu, J. Z. Ma, and H. He (2012), Effect of soot microstructure on its ozonization reactivity, Journal of Chemical Physics, 137, 084507; Han, C., Y. C. Liu, and H. He (2013), Heterogeneous photochemical aging of soot by NO2 under simulated sunlight, Atmospheric Environment, 64, 270-276.

Studies on Black Carbon's Impacts on Human Health and Its Mechanism

Small group studies have demonstrated that higher black carbon concentration would bring adverse impacts on both respiratory and cardiovascular systems, causing increases in disease and mortality rate, especially in the elderly and children[14]. Complicated chemical and biological interactions occur after black carbon has been inhaled into human body; Chemicals (aromatic hydrocarbons, etc.) absorbed on the surface of black carbon also have health impects[15]. Some research indicates that black carbon might be more harmful than other particulates due to its unique chemistry, morphology and size. Further long term, large groups studies are required to understand black carbon's direct health impacts.

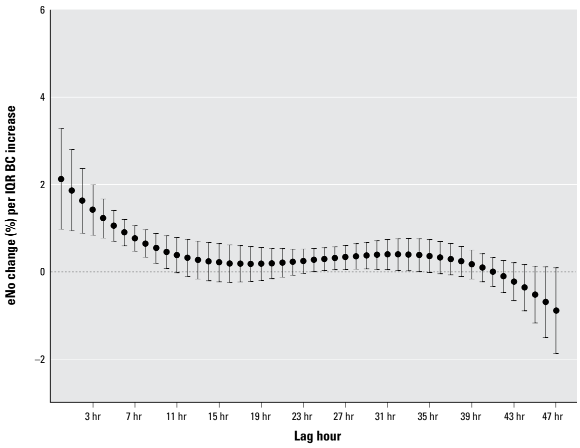

Figure 5. Mean (and 95% confidence interval) change in eNO per IQR increase (4.02 conf3) in black carbon (Source: Lin W. W. et. al., 2011)

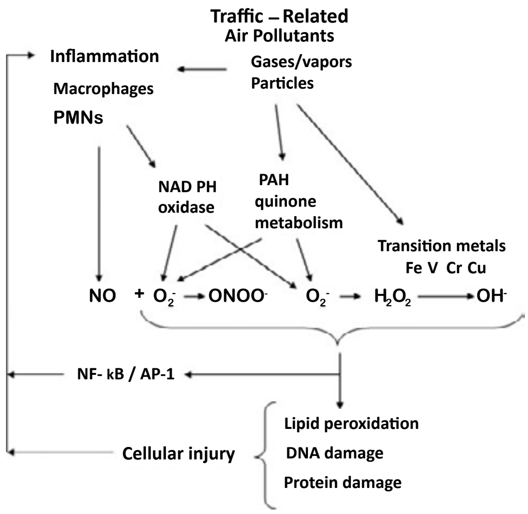

Figure 6. Hypothesized pathways by which traffic-related air pollutants cause oxidative stress and cell damage (Source: Laumbach and Kipen, 2010)

14. Lin, W. W., W. Huang, T. Zhu, M. Hu, and et al. (2011), Acute respiratory inflammation in children and black carbon in ambient air before and during the 2008 Beijing Olympics, Environmental Health Perspectives, 119(10), 1507-1512; Huang, W., T. Zhu, X. C. Pan, M. Hu, and et al. (2012), Air pollution and autonomic and vascular dysfunction in patients with cardiovascular disease: Interactions of systemic inflammation, overweight, and gender, American Journal of Epidemiology, 176(2), 117-126.

15. Laumbach, R. J., and H. M. Kipen (2010), Acute effects of motor vehicle traffic-related air pollution exposures on measures of oxidative stress in human airways, Annals of the New York Academy of Sciences, 1203,107-112; Kaiser, J. C., Riemer, N. and Knopf, D. A (2011), Detailed heterogeneous oxidation of soot surfaces in a particle-resolved aerosol model, Atmos. Chem. Phys., 11, 4505-4520.

Black Carbon Emission Source Studies

China is considered to be the world's largest emitter of black carbon, since coal and biomass are still dominant fuel sources. However, black carbon emission factors used in today's emission inventory studies almost completely rely on international experimental result. China lacks systematic monitoring and research on black carbon's emission sources, emission levels and overall characteristics. There have been a number of studies on the characteristics of black carbon emission for domestic coal use and biomass burning in China. The researchers have found that the type of coal and combustion conditions significantly affect the emission factor of black carbon. Bituminous coal with medium volatility in decentralized combustion conditions has a higher emission factor, while the emission factors of briquette and anthracite coal are lower[16]. There is a lack of data and experiments for major emission sources like coke ovens, brick kilns and mobile sources, which affects the establishment of black carbon emission inventory and control policy.

According to the latest measurement results from the Tsinghua University MECI model, China's black carbon emissions from man-made sources are about 1,755,000 tons in 2010, composing of 573,000 tons from industrial emissions, 907,000 tons from domestic emissions and 274,000 tons from transportation emissions. Black carbon emission from domestic source, which is the largest emission source, is expected to be levelled off by 2030 under the "business as usual scenario" (without further policy interventions). If control measures, such as fuel switching, improved biomass stoves with gasifiers, and the elimination of small coal-fired boilers were implemented, black carbon emissions in 2030 could be reduced by

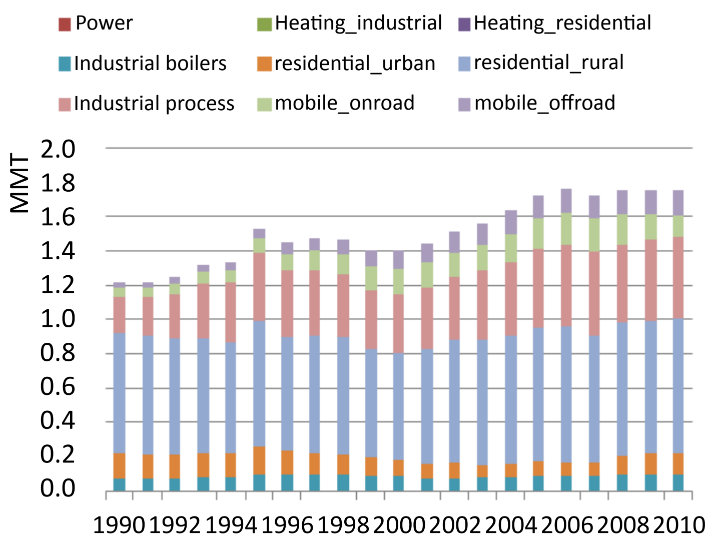

Figure 7. Black carbon emission trends (from the MEIC model)

16. Zhang, Y. X., J. J. Schauer, Y. H. Zhang, L. M. Zeng, Y. J. Wei, Y. Liu, M. Shao (2008), Characteristics of particulate carbon emissions from real-world Chinese coal combustion, Environ. Sci. Technol. 2008, 42, 5068–5073

more than 50% compared to 2010 levels. Meanwhile, shifting to low sulphur diesel fuels and requiring particulate filters on all new diesel cars and trucks could cut China's black carbon emissions by more than 10% in 2030.

There is still significant uncertainty regarding China's black carbon emission inventory. The scale of the uncertainty exceeds 100%, which is due to the defects in the existing inventory. Data is insufficient regarding domestic energy use, especially in rural areas. The shortage of local data forces the current inventory system to be dependent on emission factors from other countries. There is also limited understanding of China specific emission sources, such as brick kilns and coke ovens[17].

3 BLACK CARBON CONTROL POLICES AND MEASURES

Black carbon's negative impacts on the climate, the environment, and human health require the adoption and implementation of effective black carbon emission controls. Currently, China's major sources of black carbon emission include diesel vehicles, biomass burning, coal-fired boilers, brick kilns and domestic cook stoves.

Proven, technologically feasible and cost-effective international measures to control black carbon emissions include[18]:

- Use of low-sulphur fuels and particulate matter filters for on-road and off-road diesel engines;
- Residential use of briquettes instead of raw coal, natural gas, or improved biomass stoves with internal fans to complete the combustion process;
- Improved energy efficiency in the coking sector and the use of cleaner fuels;
- Improved brick making methods or technology, including exhaust after-treatment;
- The increased use of non-fired construction materials;
- Retrofit or retirement of old, inefficient, high-emitting, coal-fired, low-temperature combustion sources.

The next section describes the actions China has already taken to reduce emissions and improve air quality in key areas.

17. Lei, Y., Q. Zhang, K. B. He, and D. G. Streets (2011), Primary anthropogenic aerosol emission trends for China, 1990–2005, Atmos. Chem. Phys., 11, 931–954; Rong Wang, Shu Tao, Wentao Wang, Junfeng Liu, Huizhong Shen, Guofeng Shen, Bin Wang, Xiaopeng Liu, Wei Li, Ye Huang, Yanyan Zhang, Yan Lu, Han Chen, Yuanchen Chen, Chen Wang, Dan Zhu, Xilong Wang, Bengang Li, Wenxin Liu, and Jianmin Ma (2012), Black Carbon Emissions in China from 1949 to 2050, Environ. Sci. Technol. 2012, 46, 7595-7603

18. UNEP, Integrated assessment of Black Carbon and tropospheric ozone, 2011; USAID, Black Carbon emissions in Asia: sources, impacts and abatement opportunities, 2010; Climate Works, Abatement opportunities for non-CO2 climate forcers, 2011.

3.1 China's Existing Black Carbon Control Measures and Effects

Retrofitting of Coal-fired Industrial Boilers

China had 620,000 coal-fired industrial boilers that consumed 640 million tons of coal in 2010. The average thermal efficiency of China's coal-fired industrial boiler is around 70%, 10-15% lower than the international average. Pollutant emissions standards are also relatively low. In 2010, it is estimated that around 200,000 tons of black carbon emissions came from coal-fired industrial boilers.

Coal-fired industrial boilers currently use particulate matter emission control technology like mechanical dust removers, wet scrubbers, electrostatic precipitators and dust bags. Mechanical dust removers are used in small boilers with capacity below six tons per hour and have low removal rates. Wet scrubbers are used in boilers with capacity above ten tons per hour, and the treated emissions during normal operation can meet the state emission requirements in Class I and Class II regions. Electrostatic precipitators and dust bags dust bags are used in the newly built cogeneration plants and district heating boilers in order to meet more stringent local emission standards.

To support the implementation of the *12FYP on Air Pollution Prevention and Control in Key Regions*, the Ministry of Environmental Protection launched a comprehensive program on industrial coal-fired boilers in 2012. The program focused on the four perspectives: phasing-out of small and medium-sized boilers, promoting natural gas and biomass briquettes, encouraging centralization of industries, and adopting efficient dust-removal technologies. Under this plan, 15 cities in "Three Regions, Ten City Clusters" will invest 1.09 billion RMB to comprehensively improve the coal-fired industrial boilers by a totally retrofitting of 28,000 tons of boiler steam capacity, which saves 5 million tons of coal, and reduces black carbon emissions by 4,700 tons. Eventually this program will be extended to all cities of in the "Three Regions, Ten City Clusters" and gradually the rest of the nation.

Particulate Matter Emission Controls for Diesel Vehicles

Diesel vehicles in China annually consume 100 million tons of diesel fuel and emit around 600,000 tons of carbon particles. In contrast, advanced diesel engines are virtually free of particulate.

Currently there are two main technologies to control of particulate matter from diesel emissions, but only one controls black carbon. Diesel oxidation catalyst (DOC) removes 20-30% of total particulate matter, but has no effect on black carbon. The advantage of DOCs is that they are relatively cheap, do not require ultra low sulphur fuel, do not increase fuel consumption. If China mandates the installation of DOC on all diesel engines, it could cut the emissions of diesel particulate matter by more than 20% per year, equivalent to 10 million tons. The other technology is the diesel particulate filter (DPF), which can remove more than 99.9% of particulate matter including black carbon. This system is in use in the US and Europe for all new diesel cars and trucks. However, the price of DPF per vehicle is significantly higher the DOCs. In addition, low sulphur fuel is required and the active systems consume more fuel. If all new diesel engines installed DPFs, the diesel particulate matter emissions would be 20% below 2010 levels in five years.

China should accelerate use of these two technologies to achieve particulate matter emission reductions from diesel vehicles, by implementing DOC retrofits on existing diesel vehicles and by requiring DPFs on new diesel cars and trucks as soon as possible.

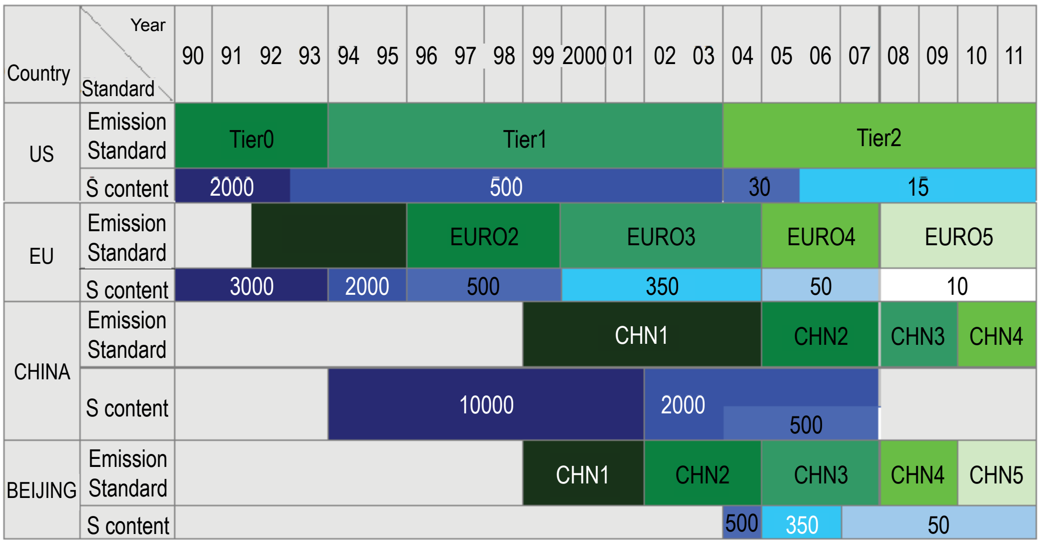

Figure 8. Global diesel vehicle emission standards and oil standards (Source: VECC)

In February 2013, the State Council held an executive meeting announcing the acceleration of diesel fuel quality upgrade. Specifically, the General Administration of Quality Supervision (AQSIQ) and National Standards Committee (NSC) should issue the Stage-IV automotive diesel standards (Sulphur content is less than 50ppm) for the transitional period until to the end of 2014; and the V stage automotive diesel standard (Sulphur content is less than 10ppm) will be issued at the end of June 2013[19]. GB19147-2013<Automotive diesel standard (IV)> was issued with the approval of these two departments on 7 Feb 2013[20]. In the subsequent National Conference on the Standardization, the NSC stated the Stage-V automotive diesel standard would be issued in 2013[21].

19. State Council, Executive Meeting on 6 Feb 2013. Available at http://www.gov.cn/ldhd/2013-02/06/content_2328473.htm

20. Standardization Administration of PRC, the General Administration of Quality Supervision, and National Standards Committee, Standardization Administration of PRC approved to release national Automotive diesel standard (IV). Available at http://www.sac.gov.cn/gnbzhgzdt/201302/t20130208_132681.htm

21. The People's Net. Stage-V automotive gasoline and diesel standard will be issued this year. Available at http://scitech.people.com.cn/GB/n/2013/0222/c1007-20563280.html

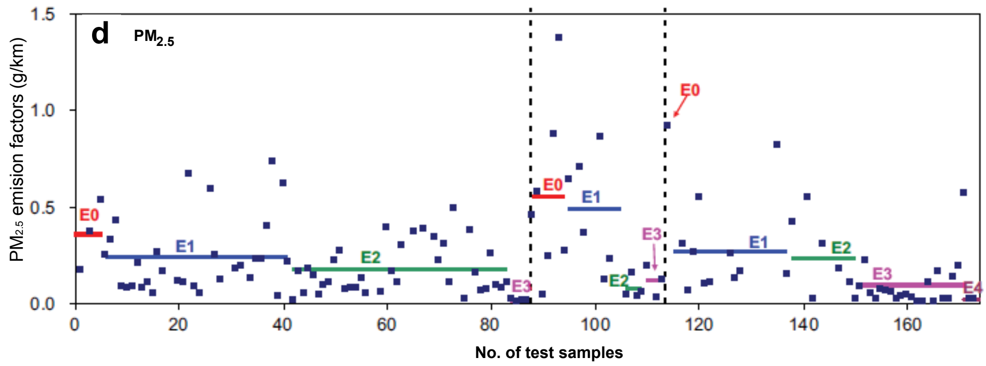

Figure 9. Changes in diesel vehicles road emission factor with the implementation of the standards (Source: Huo, H. et. al., 2012[22])

Effective Measures to Control Particulate Matter Emissions from Diesel Engines

Controlling diesel vehicle particulate emissions is the key to reducing transportation black carbon emissions. It has multiple benefits for climate change, air quality, and health. In addition to installing DPF and DOC on diesel engines, effective measures to control the emissions particulate matter from diesel also include:

- Stricter new vehicle and oil standards;
- Early retirement of old motor vehicles;
- Limits on off-road vehicles;
- Reduce emissions from coastal vessels and ports.

Promoting the Use of Clean Cook Stoves

Over 3 billion people worldwide use solid fuels as their main source of energy. Solid fuels have serious health impacts on the users, especially on women and children, due to the large emissions of carbon monoxide and particulate matters. Over 700 million people in China (2/3 in the countryside, and 1/3 in the city) still rely on solid fuels for both cooking and heating. The latest "Global Burden of Disease 2010" study[23] estimates that household air pollution from solid fuels causes 3.5 million premature deaths globally and over 1 million in China in 2010.

22. Huo, H., Z. Yao, Y. Zhang, X. Shen, Q. Zhang, and K. He (2012), On-board measurements of emissions from diesel trucks in five cities in China, Atmos. Environ., 54, 159-167.

23. Lim S.S and many others (2012), A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010, Lancet, 380: 2224-60; Cohen A (2013), Outdoor air pollution is in the top of health burden risk factors in 2010, especially in China and other Asia developing countries. Health Effects Institute, Press release.

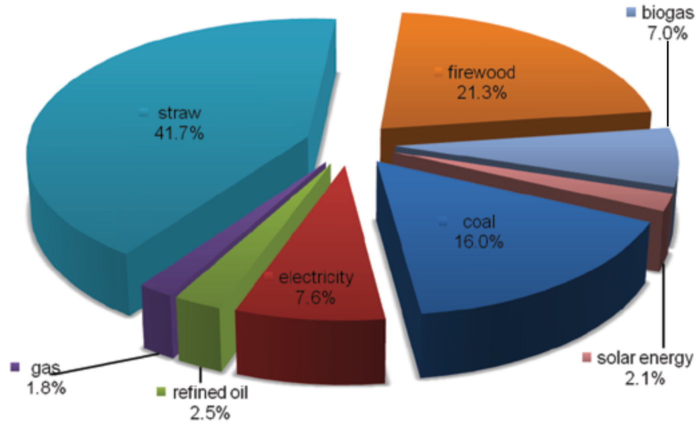

Figure 10. 2010 Rural energy use diagram
(Source: Coal, electricity, refined oil and gas data are from the China Energy Statistical Yearbook 2011; straw, firewood, biogas and solar energy data are from the Agricultural Statistics 2010.)

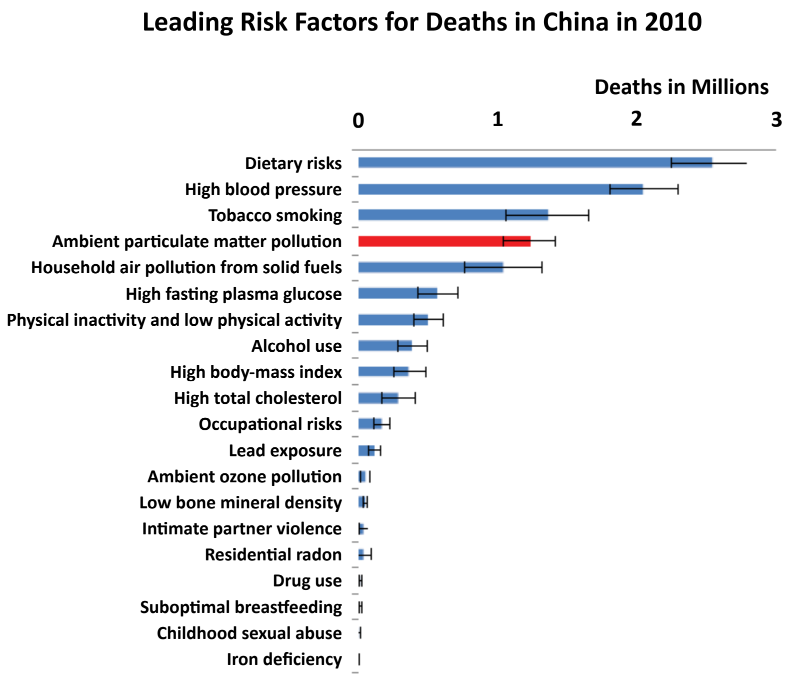

Figure 11. Leading risk factors for deaths in China in 2010 (Source: HEI, 2013[24])

The most effective way to reduce indoor air pollution is the adoption of clean cook stoves. There are three main options to capture black carbon emissions: 1) use of charcoal briquettes instead of raw coal; 2) utilize internal fans to raise the combustion temperatures of biomass stoves; or 3) switch to cleaner fuels (natural gas or electricity). Since late-1980s, China has promoted improved stoves. In 2005, the production of efficient and clean biomass stove saw rapid growth. In 2011, the total number of biomass clean stoves reached 2.15 million units, 30 times the total in 2005.

24. Health Effect Institute (2013), Outdoor air pollution among top global health risks in 2010: risk especially high in China and other developing countries of Aisa

Table 1. Performance comparison between efficient clean stoves and traditional stoves

Project	Biomass Stoves		Traditional Stoves
Fuel Type	Corn Straw	Straw Briquette	Firewood / Hay
Thermal efficiency (%)	35	41	10-12
The average emissions of particulate matter (mg/m^3)	38	25	>120
The indoor an average content of CO (mg/m^3)	8.2	5.0	97
Fuel consumption (kg/h)	3.3	2.3	7-8

The Chinese government currently subsidizes 70% of all cooking stoves. In order to aggressively push for the adoption of clean stoves in rural areas, the following six areas are suggested: market research, increasing the supply of clean cookstove products, improvement of policy context, implementation of pilot demonstrations, strengthening of public education and dissemination, and promotion of international exchange cooperation are also needed. A list of relevant projects is provided below:

Projects initiated by Chinese government	International Cooperation Projects
• Firewood saving coal stove promotion project • Application of biomass pellet fuel demonstration • A furnace stove project • Health homeland project • Rural biogas bond projects • Special Farm Machinery Purchase Subsidy • Green Energy Demonstration Counties • Defluoridation Cooking Stoves Project • Consolidate Grain for Green Project	• Sino-Dutch project “Promoting China’s Western Rural Renewable energy development application” • Shell Foundation Project “to promote Chinese and international efficient low-emission household biomass stove technology innovation and diffusion” • U.S. Environmental Protection Agency project “the promotion program of efficient low-emission biomass stoves in China’s western region • Sino-US cooperation “clean and efficient cooking and heating carbon trading projects” • U.S. EPA clean cookstoves promotion the project in Guizhou • EPA “to prevent deforestation projects in Yunnan” • World Bank project to prevent cookstove pollution and health projects in Guizhou and other three provinces • World Bank “China Clean Cook Stoves Initiative Project”

3.2 Black Carbon Prevention and Control Recommendations for the Future

Improve Basic Work to Support Black Carbon Emission Reductions Policies

China lacks basic data benchmarks for environmental quality standards, including the latest requirements on $PM_{2.5}$. The United States in comparison has developed environmental data benchmarks, which has played a critical role in benchmarking the effects of particulate matters on health, climate change, ecology, and visibility. China should strengthen work in this area by establishing a $PM_{2.5}$ environmental quality benchmarking system, in order to layout a basis for policies that control the emissions of particulate matter and black carbon.

In addition, more sampling and monitoring of black carbon emissions should be carried out, particularly on low temperature combustion sources, diesel vehicles, and residential cook stoves and heaters. At the same time, more attentions should be paid to observe human health effect, which can be conducted through exposed individuals observations.

Strengthen Research on Emission Reduction Strategy and Fully Consider Co-control Policies on Multi-pollutants

Addressing black carbon requires a multi-pollutant approach. Studies have shown that black carbon, sulphates, and organic carbon emissions will be reduced at the same time, which could lead to an increase in solar radiation and is not considered climate friendly. On the other hand, the negative health impacts of sulphates, nitrates, and organic carbon pollution still favour cutting emissions of these pollutants. Research on optimising emission reduction strategies should be strengthened. Similarly, development of pollutant emission reduction policies should consider the environmental impact, climate effects, and human health perspectives in order to achieve a win-win situation.

Implement Prevention and Control Measures of Particulate Matter in Multiple Areas

China has made great strides in controlling particulate matter in the past two decades. At the same time, the ratio of black carbon to $PM_{2.5}$ emissions has risen. Black carbon was not reduced as much as other particulate matter because previous regulations focused on power plants and cement industries; Insufficient attention was put on black carbon intense sources, such as diesel vehicles, brick kilns, smaller coal-fired boilers, coke ovens, and residential cooking and heating.

China should strengthen pollution control efforts to comprehensively cover black carbon sources. The variety of measures includes controlling emissions from diesel vehicles, promotion of cleaner fuels for residential use, encouraging biomass stoves improvement, and improving energy efficiency and cleaner fuel use in the coking sector. All of these steps will bring substantial reductions in black carbon emissions, while making progress in both air quality and climate change mitigation.

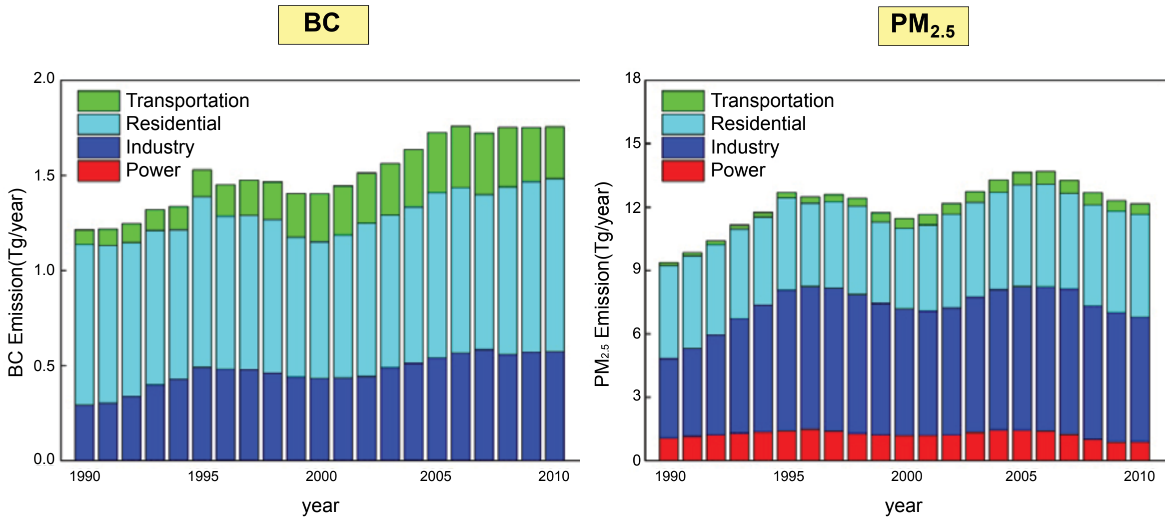

Figure 12. 1990-2010 Trends for anthropogenic sources of black carbon aerosol and $PM_{2.5}$ emissions in China (from the MEIC Model)

4 CONCLUSIONS

Increase awareness of black carbon to encourage the formulation of control measures.

Black carbon aerosols have very negative impacts on the environment, human health, and climate change. Due to its direct impacts and interactions with other pollutants, China should put additional focus on black carbon and formulate more control policies.

Black carbon related research requires further advancement, particularly on the black carbon emission inventory.

Identifying the sources of black carbon aerosols and controlling them of is a very complex task, especially when the inventory of black carbon sources in China is constrained by seriously insufficiently data, poor data matching and consistency, and high uncertainty. Besides, China should continue to advance basic research on black carbon aerosol's impact on both human health and the atmosphere.

Control black carbon emissions to adhere to climate-friendly environmental protection strategy

Since the control of black carbon emissions contribute to both human health and mitigating climate change, China should adhere to the black carbon prevention and control strategy as a climate-friendly air pollution control measure, in order to achieve the win-win benefits.

APPENDIX I. Key Institutes and Experts in China

Key Institutes	Key Experts	Key Institutes	Key Experts
Peking University	Tong Zhu, Shaodong Xie	China Meteorological Administration	Yihui Ding, Hua Zhang
Chinese Academy of Environmental Planning	Yu Lei	Chinese Academy of Meteorological Sciences	Xiaoye Zhang
Vehicle Emission Control Center, MEP	Dagang Tang, Yan Ding	China Clean Stove Alliance	Xiaofu Chen
Shanghai Academy of Environmental Science	Changhong Chen	Institute of Earth Environment, CAS	Junji Cao
Tsinghua University	Jiming Hao, Kebin He, Qiang Zhang, Shuxiao Wang, Yuxuan Wang	Institute of Tibetan Plateau Research, CAS	Baiqing Xu
Chinese Research Academy of Environmental Science	Zhipeng Bai, Qingxian Gao	Yantai Institute of Coastal Zone Research, CAS	Yingjun Chen
Institute of Atmospheric Physics, CAS	Hong Liao, Renjian Zhang	Lanzhou University	Jianping Huang
Research Center for Eco-Environmental Sciences, CAS	Hong He		

APPENDIX II. International Workshop on Black Carbon

The Black Carbon International Workshop aims at sharing and discussing the latest progress in black carbon research in China and international experience. The workshop is hosted by Tsinghua University and supported by the Energy Foundation in every other year (three sessions up to now) since the first one in 2009.

In April 25th 2009, the first Black Carbon International Workshop was launched in Crowne Plaza Beijing. The main topic of this workshop was about impact of black carbon on environment and climate change. Over 50 experts and scholars from universities, institutes and academies like Beijing University, Chinese Academy of Sciences, China Meteorological Administration, Energy Research Institute National Development and Reform Commission, Chinese Research Academy of Environmental Sciences, etc., attended the workshop.

The second Black Carbon International Workshop is regarding the control measures and policies in China, held in Wenjin Hotel on November 7th, 2011. More than 60 experts participated this workshop and nine black carbon professionals gave speeches in four related areas, including scientific and policy update of black carbon, black carbon emission inventory, stationary and mobile source control measures and policies, and area sources control measures and policies.

The third Black Carbon Introduction Workshop invited almost 70 experts to share their latest research and experience about black carbon control strategy. Academician Yihui Ding, Mr. Zbgniew Klimont and Ms. Carherine Whitespoon have given keynote speeches on black carbon. The whole workshop was composed by three different sessions, including environmental and health impact, emissions, and control strategies. Different professionals from international institutes and national academies have shared their opinions regarding these three sessions.

CLEAN AIR ALLIANCE OF CHINA (CAAC)

To address the air pollution challenge in China, ten leading Chinese technical institutions in the air quality field joined hands to launch the Clean Air Alliance of China (CAAC). It is envisioned that CAAC will provide an integrated platform for provinces and cities to access the international experience, tools and practices on the one hand; and facilitate the communication and collaboration among provinces and cities on the other. The overarching goal is to improve air quality of Chinese provinces and cities and mitigate the negative impacts on public health due to air pollution. CAAC will be led and supervised by the alliance steering committee, and be managed by the alliance secretariat regarding general operation and coordination.

Ten Founding Members

Tsinghua University, Appraisal Center for Environment & Engineering of MEP, Chinese Academy for Environmental Planning (CAEP), Nanjing University, Beijing Normal University, Fudan University, Chinese Research Academy of Environmental Sciences (CRAES), Peking University, Renmin University of China, Vehicle Emission Control Center (VECC) of MEP

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