Hong Kong and Pearl River Delta Pilot Air Monitoring Project

香港和珠江三角洲大气监测项目

Executive Summary
行政总结

思匯 CIVIC EXCHANGE

November 2004
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Civic Exchange
Room 701, Hoseinee House
69 Wyndham Street, Central, Hong Kong

Tel: (+852) 2893 0213 Fax: (+852) 3105 9713

www.civic-exchange.org

Civic Exchange is a non-profit organisation that helps to improve policy and decision-making through research and analysis.

思匯政策研究所是一非牟利组织，主要透过研究和分析以协助改善政策和决策。

Civic Exchange would like to thank the Hong Kong Jockey Club Charities Trust, Castle Peak Power Co. Ltd., the Hong Kong Environmental Protection Department and Shell Hong Kong Ltd. for their support in this Project.

思匯政策研究所诚意感谢香港赛馬会慈善信托基金,青山发电有限公司，香港环保署及香港蜆殼公司给本项目的大力支持.

Hong Kong and Pearl River Delta Pilot Air Monitoring Project

EXECUTIVE SUMMARY

1.0 Background

Like other urban and industrialized regions in the world, Hong Kong and adjacent Pearl River Delta (PRD) experiences elevated levels of air pollution. Among the seven atmospheric pollutants for which an air quality objectives/ standards have been set by the authorities, ozone and particulate matter (Respirable Suspended Particulate, RSP or PM_{10}), together with nitrogen dioxide, are the three species contributing to high Air Pollution Index readings in Hong Kong and in many cities in PRD as well. At high concentrations these pollutants are known to have harmful effects on human health. It is thus imperative that the sources and atmospheric processes related to the emission, transport, and chemistry of these pollutants be understood, so that effective control strategies can be identified.

The Hong Kong and Pearl River Delta Pilot Air Monitoring Project (the Pilot Project) was initiated in May 2002 and implemented over a 2-year period. The Pilot Project was split into two focus areas with **Project 1** on the cause(s) of ground-level ozone pollution in Hong Kong and **Project 2** focusing on the characteristics of fine particles ($PM_{2.5}$) in Hong Kong and the Pearl River Delta (PRD)[1]. The Project was built upon the work already undertaken by the Hong Kong Environmental Protection Department (HKEPD), the universities in Hong Kong, and the greater Chinese academic community, but was specifically designed to explore and demonstrate the utility of observation-based analyses and modeling tools for improving the understanding of the formation of ozone in Hong Kong (Project 1) and to gather $PM_{2.5}$ data to elucidate its regional distribution, chemical composition, and sources in Hong Kong and PRD (Project 2). In this regard the project utilized expertise and analytical techniques from the United States. The summary of the scientific findings for project 1 and 2 are provided below.

The Pilot Project enabled cross-border air quality monitoring of fine particulates, which had never occurred before. Initiated and implemented through collaboration among regional authorities, regulators, industry, civic organizations and the scientific community, the Pilot Project extended the human, intellectual and financial resources contributing to regional air quality management. To ensure scientific relevance and integrity, efficient implementation and effective project administration, three working committees were formed at the outset of the project including a Science Committee, Science Advisory Committee and Management Committee. Details of committee terms of reference and membership and the organizations involved in the Pilot Project are included in Appendices A & B.

[1] The Hong Kong and Guangdong Governments do not have air quality objectives or standards for PM2.5 and PM2.5 is not monitored or specifically included as a pollutant to be reduced under the joint government emission reduction targets.

2.0 Summary of Project 1 - Ozone

Objectives: Project 1 of the Pilot Project aimed to: **(i)** demonstrate how ground-based air quality measurements could be used in diagnostic analyses and observation-based modeling to elucidate the relative roles of emission sources of Volatile Organic Compounds (VOCs), carbon monoxide (CO), and nitrogen oxides (NOx) on the formation of ground-level ozone (O_3) pollution in Hong Kong; and **(ii)** using this analysis and modeling; address policy-relevant issues related to the formation and mitigation of ozone pollution in the Hong Kong metropolitan area.

Data used in the Project: The findings from Project 1 are largely based on data collected over the period from October 1, 2002 to December 31, 2002 at five sites in Hong Kong: Central Western, Tung Chung, Tai O, Tap Mun, and Yuen Long. The locations of these sites are indicated in Figure 1. Of these sites, Tai O served as the "super site," where state-of-the-science instrumentation was used and an attempt was made to comprehensively monitor as many relevant chemical and meteorological variables as possible. Tai O was selected as the location of the super site since it is in the general location where O_3 concentrations in the Hong Kong area tend to be highest. This super site was set up and operated by the researchers of the Hong Kong Polytechnic University while the other sites were operated by the HKEPD and made use of more standard air-pollution monitoring instrumentation and protocols.

Caveats: It is important to note that Project 1 was undertaken as a ***Pilot Project***. Thus the data that form the basis for our analyses and findings are spatially and temporally limited. While comparison of our results to those of previous studies in the area suggests that they are representative, the general applicability of our findings to the area for all types of air pollution episodes has yet to be fully assessed. Hence although the scope of this study was limited, it's scientific and technological findings can help to guide further scientific studies of regional air quality issues.

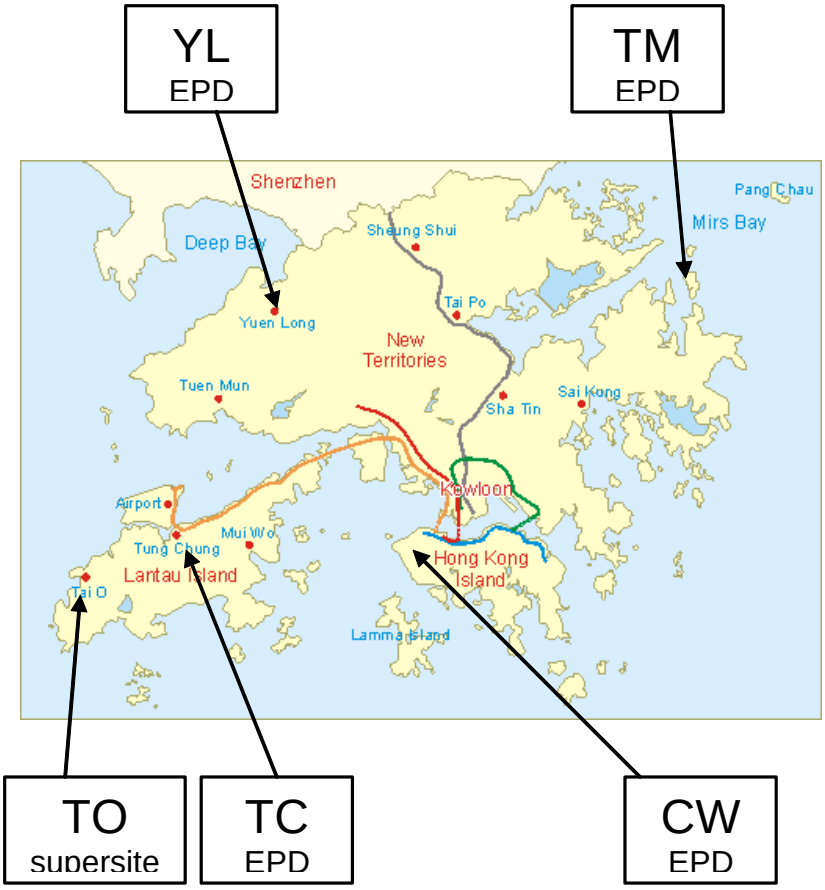

Figure 1. Map of Hong Kong area showing the location of Project 1 sampling sites (TO = Tai O, the super site, TC = Tung Chung, CW = Central Western, YL = Yuen Long, TM = Tap Mun).

2.1 Major findings

- **Summary 1:** ***Assess the relative contributions of local production and pollutant import from other locations on O_3 formation***

Based on ozone episode analyses conducted in Project 1, both locally emitted pollutants and pollutants transported from Guangdong Province can act independently or in concert to bring about O_3 pollution in the Hong Kong area. 5 out of the 10 Hong Kong O_3-pollution episodes studied show a“pollutant signature”that is indicative of impact from Guangdong Province.

One of these episodes appears to be strongly influenced by emissions from Guangdong Province, while the other 4 appear to have a more modest and transient impact from Guangdong. Taking together all the measurement and modeling results, approximately 50–100% of the ozone

increase observed on Hong Kong during ozone pollution episodes can be explained by photochemical ozone generation within the Hong Kong area, although some of the photochemical ozone generation within Hong Kong and its neighboring area was likely triggered by import of O_3-precursor pollutants from Guangdong.

Nitrous acid (HONO) (and to a lesser extent aldehydes)[2] appear to play a critical role in ozone formation (especially in the early morning hours) and constitute as an important input parameter for the observational based model. Previous investigators have also found that the presence of HONO and aldehydes in an urban atmosphere during the early morning hours can significantly enhance the amount of ozone produced over the course of the day. However, for a better understanding of the role of HONO in Hong Kong and the PRD, further investigation will be needed.

- **Summary 2:** ***Identify those specific VOC and VOC-sources that appeared to contribute most to the formation of photochemical smog on the episode days during the study***

The reactivity of VOCs in the Hong Kong area is dominated by anthropogenic (i.e. man made) compounds. Of the anthropogenic VOCs, reactive aromatics (i.e.,toluene, xylenes, trimethylbenzenes, ethylbenzene) dominate and of these m-xylene and toluene are the most important. The observed data for the reactive aromatics cannot be explained in terms of mobile emissions from downtown Hong Kong and instead appeared to be associated with non-mobile emissions from industrial, waterfront and fuel storage activities. These reactive aromatics would not result from coal or gas-fired power plants.

- **Summary 3:** ***Assess the accuracy of pollutant emission inventories for Hong Kong and the PRD region***

The ratios of the concentrations of some VOC species (e.g., butanes/toluene) are consistent with a speciated version of the VOC inventory produced in the Hong Kong and Guangdong Government's Joint Study[3]. However, the ratios of selected alkanes are not consistent. The

[2] HONO is one of the reactive nitrogen compounds that are derived from further oxidation of Nox, and aldehydes is a reactive VOC.

[3] CH2M Hill (China) Ltd (2002). Study of Air Quality in the Pearl River Delta Region. Agreement No. CE 106/98, published April 2002 (http://www.epd.gov.hk/epd/english/environmentinhk/air/studyrpts/study_pearl.html)

reason for this discrepancy could reflect inaccuracies in the emissions inventory and/or the speciation method.

- **Summary 4:** ***Complete a preliminary investigation of the relative benefits of various emission-control strategies***

Ozone is not emitted directly into the air but is formed by the interaction of two basic pollutant precursors, VOC and NO_x, in the presence of heat and sunlight. Based on information gathered in the Pilot Project, the formation of ozone throughout much of Hong Kong area appeared to be limited or controlled by the abundance of VOC, and of the VOC, reactive aromatics appeared to make the dominant contribution on the days studied. High NO_x concentrations appeared to suppress instead of enhance ozone production in much of urban environment in Hong Kong. The conclusion on the dominant role of VOC in the formation of ozone is consistent with findings from previous VOC studies conducted in Hong Kong using different data sets and/ or analysis tools.

2.2 The Recommended Next Steps:

- Identify source or sources of reactive aromatics which were found in the Pilot Project to play a dominant role in photochemical formation of ozone;
- Confirm and quantify role of HONO (radical chemistry) and aldehydes (in early morning chemistry) in atmospheres of Hong Kong and PRD;
- Expand measurements to include other seasons to verify whether the results from the Pilot Project in autumn are applicable to different seasons;
- Expand measurements similar to those carried out at the Tai O super site to the PRD and new territories (HK) to characterize additional areas of significant ozone photochemical production that likely impact the exposure of citizenry to ozone pollution; and
- Update and refine the emission inventory for Hong Kong and PRD.

3.0 Summary of Project 2 – Fine Particulate Matter ($PM_{2.5}$)

Objectives: Project 2 of the Pilot Project aimed to: **(i)** measure the concentrations and chemical composition of fine particulate matter ($PM_{2.5}$) in the PRD region (including Hong Kong); **(ii)** determine the general sources of $PM_{2.5}$ across the PRD region; and **(iii)** assess the concentrations of $PM_{2.5}$ in the PRD sub-regions.

Data used in the Study: The $PM_{2.5}$ data were collected at 7 sites in the PRD region (including Hong Kong). Sampling involved the collection of filters over 24-hr integrated time periods during a month of each season (from October 2002 to June 2003) at 7 sites including 4 in the Guangdong and 3 in Hong Kong (see Figure 2)[4]. Sampling sites in Guangdong were run by local air monitoring station personnel with the assistance of Peking University and HKUST while sampling sites in Hong Kong were run by HKEPD forming a part of their regular network of air monitoring stations. Air monitoring equipment was sourced and installed by researchers from Georgia Institute of Technology and California Institute of Technology.

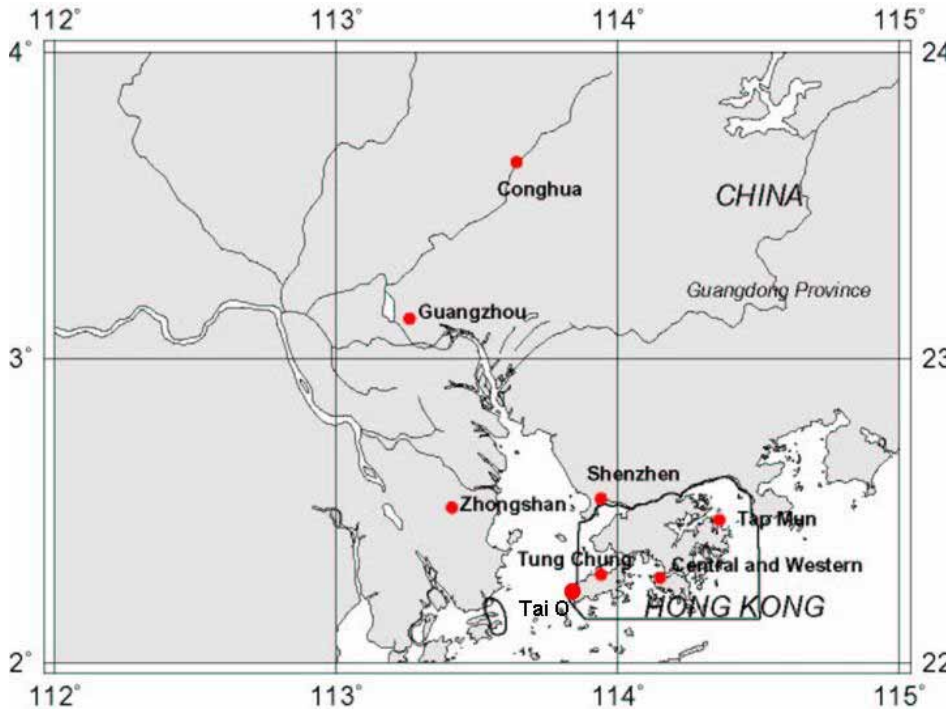

Figure 2. Map showing locations of 7 sites used in Project 2. In China this includes: Conghua, Guangzhou, Zhongshan and Shenzhen. In Hong Kong this includes: Tung Chung, Tap Mun and Central and Western. The map also shows the Tai O Super site used in Project 1.

For a given month filter samples were collected every sixth day. The filters were used to determine the $PM_{2.5}$ concentration as well as the concentrations of a variety of ions, elemental and organic carbon, specific elements, and solvent extractable organic compounds. Related to specific pollution sources that contributed to $PM_{2.5}$, chemical tracers for pollution source classes including coal combustion, wind-blown dust and biomass burning were used to infer local and

[4] All references and discussion of annual or mean concentrations of emissions should be interpreted as the projected annual average concentrations based on sampling undertaken in the months of October, December, March and June.

sub-regional influences within the PRD. In addition, the relative concentrations of specific organic compounds were used to infer primary sources of carbonaceous aerosols using a Chemical Mass Balance (CMB) model.

3.1 Major findings

A summary of key findings is as follows:

- **Summary 1:** ***Measure the concentrations and chemical composition of fine particulate matter (PM2.5) in the PRD region***

Based on the $PM_{2.5}$ data collected from the Pilot Project, the highest annual mean $PM_{2.5}$ concentration was observed in Guangzhou (71 ug m^{-3}), followed by Shenzhen (47 ug m^{-3}), Zhongshan (46 ug m^{-3}), Conghua (37 ug m^{-3}), Central & Western (34 ug m^{-3}), Tung Chung (32 ug m^{-3}), and Tap Mun (29 ug m^{-3}). All concentrations are above the current annual U.S. NAAQS value of 15 ug m^{-3}. Organic carbon and sulfate are the dominant fine particulate chemical species across the PRD region accounting for on average 24-35% and 21-32%, respectively of $PM_{2.5}$ mass.

Concentrations of potassium, a tracer for biomass burning, as well as lead, an additive for the combustion of leaded gasoline, were found to be particularly high at the Guangzhou site. Specific organic tracers also tend to show very high concentrations of tracers for biomass burning (levoglucosan) and for mobile sources (hopanes and steranes) at the Guangzhou site.

- **Summary 2:** ***Determine the general sources of PM2.5 across the PRD region***

It appears that the dominant source of sulfate aerosol in the in-land PRD region is sulfur dioxide (SO_2) emissions from local sources within Guangdong province. The sources of primary fine particulate organic carbon throughout the PRD region, which were estimated based on the concentrations of organic tracer compounds used as inputs to a chemical mass balance model (CMB), are dominated by mobile sources and biomass burning accounting for from 15 to 27% and 14 to 22% of the organic carbon across the sites, respectively.

The relative contributions of diesel and gasoline combustion to the mobile source category vary depending on location. For Guangzhou, gasoline combustion contributed to 16% of OC concentrations, compared to 10% from diesel sources. By contrast, the Hong Kong urban site Central and Western has gasoline and diesel annual average OC contributions of 7% and 20%, respectively. Local meat cooking was also found to be an important source of fine particulate OC

at many locations with annual average contributions to OC estimated to be from ~ 7% at Tap Mun and Zhongshan, to ~25% at Conghua.

- **Summary 3:** ***Assess the PM2.5 concentrations in the PRD sub-regions***

Analysis of meteorological data and the chemical constituents in fine particulate matter suggests that $PM_{2.5}$ concentrations in Hong Kong are influenced to a large extent by sources outside and to a lesser extent by local while Guangzhou is impacted by more local sources of $PM_{2.5}$.

Organic and elemental carbon concentrations appear to be influenced by a combination of both local and regional sources throughout the PRD. The much higher (2-4 fold) concentrations of potassium, a biomass burning tracer, at Conghua and Guangzhou than those throughout Hong Kong suggests that inland Guangdong is a significant source of biomass burning aerosol. Similarly, the 2-4 fold higher concentrations of lead at the other Guangdong sites than those in Shenzhen and Hong Kong suggest that the burning of leaded gasoline in Guangdong may impact organic carbon concentrations throughout the region. Although it should be noted that another, unidentified source may be responsible for the elevated lead concentrations measured in Guangdong.

3.2 The Recommended Next Steps:

- Expand and sustain the characterization of emission profiles and sources of fine particulates in the PRD;
- Locate the specific point sources of sulfate and the industries they are associated with in the PRD;
- Determine where and when biomass burning is taking place as well as the specific material that is being burned;
- Measure source profiles of primary organic carbon emissions in the PRD; and
- Assess the impact of long-range transport on fine particulate concentrations within the PRD and the impact of climate change on regional emissions levels.

4.0 Other Results

4.1 Stakeholder Involvement

The Pilot Project was the first non-government led cross-border initiative to improve regional air quality in the PRD region. A key success of the Pilot Project lies in its broad multi-stakeholder support base. With largely private sector funding, local and international scientific expertise, local and regional governmental support and the coordinative ability of a

local public policy think-tank, the project was planned and implemented in an inclusive and transparent way. As outlined in Section 1, three levels of committees were formed to ensure science integrity and relevancy, policy appropriateness and administrative efficiency. To encourage involvement and transparency, committee meetings were recorded and included on a special Pilot Project website created for usage by the committees only. Importantly, participants from all stakeholder groups including academia, government and funders participated in both the Science and Management Committees. This fostered the building of trust between participants and enabled stakeholders to further understand each others needs, resulting in the refinement of processes which contributed to more robust scientific results. A summary of the committee members and terms of reference along with the organizations involved in the Pilot Project is included in Appendices A & B.

4.2 Capacity Building

Apart from producing the scientific results outline above, an important objective of the Pilot Project was to build long-term air quality management capacity in Hong Kong and Mainland China. A paper researching the capacity building aspects of the Pilot Project[5] found that the strengths of the project lie it's largely private sector funding base, cross-border multi-stakeholder participation, inter-personal relationships and enthusiasm of participants. Improvements were recommended in gaining further government support, especially in the PRD, further promoting the understanding of the connection between public health and air pollution, sensitizing participants to cross-cultural issues upfront and further integrating this effort with other regional air pollution projects to enable resource sharing. Nevertheless, the paper assessed that the Pilot Project appeared to be playing a pioneering role overall in building capacity for sustainable development in the PRD region.

4.3 Other Benefits

It is worth highlighting the other benefits achieved through the Pilot Project:

1. Provided an observation-based analysis model for ground level ozone that complements existing methods used in Hong Kong;
2. Expanded the fine particle air monitoring network in Hong Kong and the PRD;
3. Transferred new equipment purchased for fine particle monitoring to Guangdong (PRD) for its permanent ongoing use;

[5] "Developing capacity for long-term air quality management in the Pearl River Delta Region", February 2003 by Ryan Lee, Andy Li and David Malachowski-Onne of Worcester Polytechnic Institute (published by Civic Exchange and available at http://www.civic-exchange.org under publications Feb-03).

4. Transferred air quality measurement and modeling technologies as well as diagnostic methods for fine particles from the US to Hong Kong and the PRD;
5. Built a new alliance of Hong Kong and Guangdong, government, regulatory, scientific, academic, industry and international collaboration for addressing air pollution;
6. Improved upon existing regional emissions inventory data and knowledge; and
7. Generated positive stakeholder and public support in determining air pollution solutions.

While the benefits above have largely been achieved, clearly benefit no.7 is an ongoing campaign of which these project results form part. To this end this report and the process by which it has been developed has greatly contributed to revitalize local discussion and attention on regional air pollution issues. A public access website has also been created to house information about the Pilot Project and we hope that future work in this area will also be included on this website in the future[6].

5.0 Conclusion

Through the use of an observation based model and scientific analytical modeling techniques such as Chemical Mass Balancing, the Pilot Project has both confirmed previous research and produced new and interesting results. The study confirmed that PM2.5 in the PRD region exists at annual average concentrations of two to five times the US annual average National Ambient Air Quality Standard. This is an important finding which we hope will encourage further government consideration and review in this area, especially in the development of standards, objectives and emission reduction targets and in ongoing regional monitoring efforts.

The project has also provided a much needed list of focus areas for further study which are required to enable definitive conclusions to be drawn on the most effective and efficient pollution control strategies in Hong Kong and the PRD region. Equally importantly the project has formed a model for cross-border multi-stakeholder collaboration, which has proven able in setting the foundation for increased capacity in areas of human, financial and technical resources contributing to the understanding and management of air quality in the region. With support from HKEPD, the key task ahead is to deepen that support and extend it to the PRD authorities, then to transfer this knowledge gained to the creation of policy review and change.

[6] The Pilot Project public access website address is:
http://www.ce.gatech.edu/~mhbergin/hk_prd_public

6.0 Pilot Project Scientific Reports

This Executive Summary summarizes scientific findings which are detailed in the following Pilot Project reports:

(1) Hong Kong and the Pearl River Delta Pilot Air Monitoring Project: Pilot study on the use of atmospheric measurements to manage air quality in Hong Kong and the Pearl River Delta
Project 1: *Ground-Level Ozone Pollution in Hong Kong, 31 July 2004*
Prepared by: Jing Zhang, Georgia Institute of Technology (GIT), W.L. Chameides, GIT, Tao Wang, Hong Kong Polytechnic University and C.S. Kiang, Peking University

(2) Hong Kong and the Pearl River Delta Pilot Air Monitoring Project: Pilot study on the use of atmospheric measurements to manage air quality in Hong Kong and the Pearl River Delta
Project 2: Fine *Particulate Matter (PM2.5) in the Pearl River Delta, 13 August 2004*
Prepared by: Michael Bergin, Georgia Institute of Technology (GIT), Gayle Hagler, GIT, Lynne Salmon, California Institute of Technology, Mei Zheng, GIT, W.L. Chameides, GIT, C.S. Kiang, Peking University, James Schauer, University of Wisconsin at Madison and Jian Yu, Hong Kong University of Science and Technology

Copies of the above project reports and this Executive Summary can be accessed at: http://www.civic-exchange.org (under Publications November 2004).

(1) Science Committee

Terms of reference

The Science Committee's role was to plan, discuss, carry out and analyze all scientific information in relation to the execution of the Pilot Project as proposed in the original project proposal.

Members

BERGIN, Mike	Georgia Institute of Technology
CHAMEIDES, W.L.	Georgia Institute of Technology
CHANG, W.L.	Hong Kong Observatory
GUO, Hui	Hong Kong Polytechnic University
HAGLER, Gayle	Georgia Institute of Technology
HO, Kevin	Castle Peak Power Co. Ltd., HK
KENDALL, Gail	Castle Peak Power Co. Ltd., HK
KIANG, C.S.	Peking University
LAU, Alexis K.H.	Hong Kong University of Science and Technology
LIU, Tao	Guangzhou Environmental Monitoring Station
LOUIE, Peter	Hong Kong Environmental Protection Department
WANG, Tao	Hong Kong Polytechnic University
YU, Jianzhen	Hong Kong University of Science and Technology
ZHANG, Yuanhang	Peking University
ZHENG, Mei	Georgia Institute of Technology

(2) Science Advisory Committee

Terms of reference

The role of the Independent Scientific Advisory Committee included:

- Provide advise and audit the work of the Science Committee;
- Monitor the planning and discussions arising from Science Committee meetings; and
- Review the mid-term and final scientific reports.

Members

CHAN, Chak	Hong Kong University of Science and Technology
LI, Y.S.	Hong Kong Polytechnic University
LUI, Shaw	Sinica, Taiwan
MEAGHER, Jim	NOAA Aeronomy Laboratory
SCHAUER, James	Georgia Institute of Technology
SLANINA, Sjaak	Peking University
STREETS, David	Argonne National Laboratory
TANG, Xiaoyan	Peking University

(3) Management Committee

Terms of reference

The Management Committee's role included:

- Review and comment on scientific discoveries arising from the Pilot Project;
- Oversee the overall project execution and financial management of the Pilot Project; and
- Plan and administer all publicity and public information releases arising in relation to the project, including any scientific discoveries arising from the Pilot Project.

Members

CORSON, Brad	Castle Peak Power Co. Ltd., HK
EASTWOOD, Richard	Castle Peak Power Co. Ltd., HK
KIANG, C.S.	Peking University
KU, Andy	Shell Hong Kong Ltd.
LI, Alice	Shell Hong Kong Ltd.
LOH, Christine	Civic Exchange
LOUIE, Peter	Hong Kong Environmental Protection Department
UEBERGANG, Kylie	Civic Exchange

APPENDIX B
Organizations involved in the Pilot Project

Argonne National Laboratory, USA

California Institute of Technology, Environmental Science and Engineering, USA

Castle Peak Power Co. Ltd., HK

Civic Exchange, HK

Conghua Environmental Monitoring Centre, PRC

Georgia Institute of Technology, School of Civil and Environmental Engineering and School of Earth and Atmospheric Sciences, USA

Guangdong Environmental Protection Bureau, PRC

Guangzhou Environmental Monitoring Station, PRC

Hong Kong Environmental Protection Department

Hong Kong Jockey Club Charities Trust

Hong Kong Observatory

Hong Kong Polytechnic University, Department of Civil & Structural Engineering

Hong Kong University of Science and Technology, Centre for Coastal & Atmospheric Research & Department of Chemistry

NOAA Aeronomy Laboratory, USA

Peking University, College of Environmental Sciences, PRC

Shell Hong Kong Ltd.

Shenzhen Environmental Monitoring Centre, PRC

University of California, Irvine, USA

Zhongshan Environmental Monitoring Centre, PRC

香港和珠江三角洲试点大气监测项目
总结

1.0 背景

和全世界其它城市和工业化地区一样,香港及其毗邻的珠江三角洲 (PRD) 也经历了污染水平的升高。在有关当局制定的空气质量指标/标准所针对的 7 种大气污染物中，臭氧,粒子物质（可吸入悬浮粒子，RSP或 PM_{10}）和二氧化氮，是对香港和珠江三角洲的很多城市高度空气污染指数负责的三个物种。在高浓度的情况下，这些污染物有害于人体健康，造成不到期的死亡和增加医院的就医人数。因此至为重要的是必须搞清楚这些污染物的来源以及与排放、传输和化学成分相关的大气过程，从而得以确定有效的控制方针。

香港和珠江三角洲试点大气监测研究（试点研究）从 2002 年 5 月开始，历经两年多。试点研究分为两个重点领域，项目 1 是关于造成香港地面臭氧污染的原因，项目 2 集中在表征香港和珠江三角洲的细粒子（$PM_{2.5}$）的特征上[7]。这一研究是建立于在香港环保署（HKEPD）、香港的大学和大中华的学术界已有的工作基础之上的，但经特别设计来开拓和展示基于观测的分析和模型工具对增进香港臭氧形成的认识的功用（项目 1），并收集$PM_{2.5}$的数据以解释其在香港和珠江三角洲区域的分布、化学成分和来源（项目 2）。从这一意义上说，这一项目利用了美国的专门知识和分析技术。现将有关项目 1 和项目 2 的科学发现的总结提供如下。

试点研究使得在粤港同时监测大气细粒子成为可能，这是前所未有的。试点项目是由区域当局、管理部门、工业界、民间组织和科学界合作发起并实施的，它汇集了区域空气质量管理方面的人力、智力、和财力资源。为保证科学性和完善性以及有效的实施和有效的项目管理，在项目开始之初即成立了三个工作委员会，包括科学委员会、科学顾问委员会和管理委员会。有关各委员会的职责范围和成员以及参加试点项目的各单位等细节均包括在附件 A 和 B 内。

2.0 项目 1 总结 – 臭氧

目标: 试点项目 1 的目标在于:(i) 演示基于地面的空气质量观测如何能用于诊断分析和基于观测的模型(OBM)运算, 以解释挥发性有机物、一氧化碳和氮氧化物排放在形成香港地面臭氧污染中的相对作用；和（ii）利用这一分析和模型运算的结果来讨论与香港臭氧污染的形成和削减相关的政策问题。

研究中使用的数据：项目 1 的发现大部分都是根据从 2002 年 10 月 1 日到 2002 年 12 月 31 日在香港 5 个站点(中西区、东涌、大澳、塔门和元朗)收集的数据。这些站点的位置均在图 1 中一一指出。在这些站点中，在作为“超级站点”的大澳，使用了具有科学前沿水平的仪器，以便尽可能对一切相关的化学和气象变化进行综合监测。将大澳选为超级站点是由于它所处位置趋于香港地区臭氧浓度的最高点。这一超级站点是由香港理工

[7] 香港与广东省政府都没有设订$PM_{2.5}$的空气质量标准,也没有监测$PM_{2.5}$或明确把$PM_{2.5}$列入双方政府的污染物排放联合削减目标之中。

大学的研究人员负责监测的，而其它站点则由香港环保署负责，利用的是标准化的空气污染监测仪器和方法。

注意点：重要的是须注意，项目 1 是作为试点项目执行的，因此据以形成我们的分析和发现的基础的数据是受到空间和时间限制的。我们得出的结果与此前这一地区的研究相比较，表明这些数据还是有代表性的，但将我们的发现扩展到这一地区的所有类型的空气污染突出事件还有待于充分的评估。因此，虽然本次研究的范围是有限的，但其科学和技术发现能有助于对区域空气质量问题的进一步科学研究提供指引。

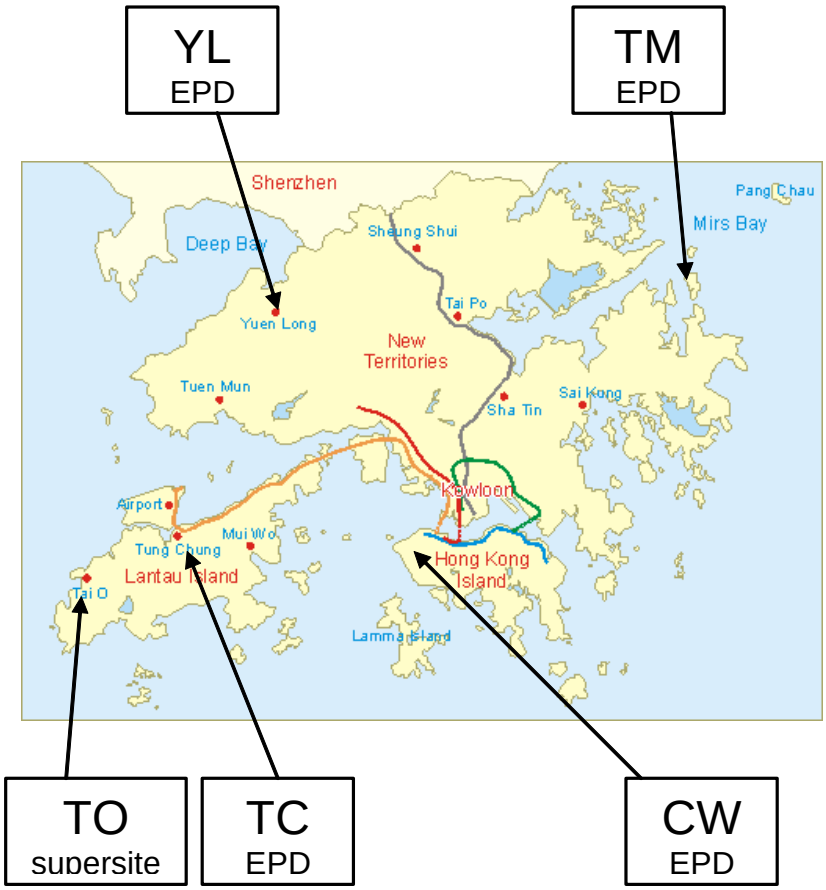

图 1：香港地区地图，表明项目 1 的采样站点（TO=大澳，超级站点，TC=东涌， CW=中西区，YL=元郎，TM=塔门）

2.1 主要发现

总结 1: 评估局地产生和从其它地点输入的污染对臭氧形成的相对贡献

根据项目 1 对臭氧突出日的分析，局地排放的污染物和从广东省输入的污染物都会独

立地或共同地引起香港地区的臭氧污染。对香港 10 个臭氧突出日中的 5 个所进行的研究显示了一种来自广东省的影响的”污染信号” 指示。

其中一个臭氧突出日看来受广东省的强烈影响, 而其它 4 个臭氧日受广东的影响较少，较短暂。综合所有测量和模型运算的结果，在臭氧污染突出日,在香港观测到的近 50-100%臭氧的增加可用香港本地的光化学生成予以解释，虽然有些由香港及邻近地区的光化学生成的臭氧可能是由来自广东的臭氧前体物的输入引发的。

亚硝酸（HONO） (在较小程度上还有醛类)[8] 在臭氧形成中起了关键的作用（尤其是在清晨数小时内）并构成了OBM的重要输入参数。此前的调研已发现在清晨数小时的城市大气中存在的亚硝酸和醛类使得在一天中产生的臭氧量有大幅度的提高。然而，要对亚硝酸在香港和珠江三角洲的作用有更好的了解，还需要进一步的调研。

总结 2：确定在研究期间在臭氧突出日对光化学烟雾形成贡献最大的特定的挥发性有机物及其来源

香港地区的挥发性有机物的反映活性是被人为活动产生的化合物所支配的。在人为活动产生的挥发性有机物中，活性芳香族（甲苯、二甲苯、三甲基苯、乙苯）是主要的，而其中二甲苯和甲苯又是最重要的。观测到的活性芳香族的数据不可能用香港市区的流动排放源来解释，而看来是和工业、水上和燃料仓储之类非流动排放源相联系的。这些活性芳香族化合物不会是煤或燃气的发电厂所导致的。

总结 3：评估香港和珠江三角洲污染物排放清单

有些挥发性有机物的浓度的比率（如，丁烷/甲苯）是和香港和广东省政府合作研究所产生的挥发性有机物清单所提供的数据一致的[9]。然而，有些烷烃的比率与此不一致。这种差异的原因可能反映了排放清单和/或分类方法的不够精确。

总结 4： 完成了各种排放控制战略的相对优势的初步调研

臭氧不会直接排放到空气中，而是由两种污染前体物，挥发性有机物（VOC）和氮氧化物(NO_x)，在高温和阳光下相互作用而产生的。根据在试点研究中收集的信息，看来香港大部分地区的臭氧的形成都受挥发性有机物的丰度的限制或控制，而在挥发性有机物中，看来在观测研究期间活性芳香族作出了主要贡献。在香港大部分城市环境中氮氧化物的高浓度不是提高而是压制了臭氧的生产。关于挥发性有机物在臭氧形成中的主要作用的结论是和此前用不同的数据组和/或分析工具进行的相关研究的发现相一致的。

[8]亚硝酸是活性氮化合物的一种，是由氮氧化物的进一步氧化而形成的，醛类是挥发性有机物的一种。

[9] Ch2M HILL (中国)有限公司 （2002）。“珠江三角洲的空气质量研究：。 协议号： CE 106/98。2002 年 4 月出版 （htto://www.epd.gov.hk /English/environmentinhk/study_pearl.html）

2.2 下一步骤的推荐

确定在臭氧光化学形成中起主要作用的活性芳香族化合物的源或多种源;

确认并量化亚硝酸(自由基化学)和醛类(在清晨化学中) 在香港和珠江三角洲的大气中的作用;

扩大测量范围以包括其它季节以便证实在秋季进行的试点研究的结果是否可应用于不同的季节；

将类似于在大澳超级站点开展的测量扩大到珠江三角洲和香港的新界，以便对更多受臭氧污染影响的地区的臭氧光化学生产进行定性；并更新和改进香港和珠江三角洲的排放清单。

3.0 项目 2 总结: 细粒子 ($PM_{2.5}$)

目的：项目 2 的目标在于：(i) 测量珠江三角洲（包括香港）的细粒子物质($PM_{2.5}$)的浓度和化学成分；(ii) 确定整个珠江三角洲的$PM_{2.5}$的一般来源；并 (iii) 评估珠江三角洲亚（sub）区域的$PM_{2.5}$浓度。

研究中使用的数据：$PM_{2.5}$的数据是在珠江三角洲（包括香港）的 7 个站点(广东 4 个站点和香港 3 个站点（见图 2）[10])收集的。滤膜样品是在各季度内（从 2002 年 10 月到 2003 年 6 月）的一个月在 7 个站点以 24 小时的集成时段收集的。广东的采样点是在北京大学和香港科技大学的协助下由当地空气监测站人员操作的，香港的采样点是香港环保署所负责的,是经常性的空气监测站网络的一部分。 空气检测设备来自佐治亚理工学院和加州理工学院并由两院的研究人员安装的。

在每一个采样月，每六天收集滤膜样品。滤膜被用于确定$PM_{2.5}$质量浓度以及各种离子、元素碳和有机碳、特定元素和可萃取的化合物的浓度。化学示踪物被用来推断珠江三角洲以内对$PM_{2.5}$有贡献的各污染源类别(包括煤的燃烧、扬尘和生物质燃烧等)对局地和亚区域的影响。此外，特定的有机物的相对浓度被用于化学质量平衡模型来推断含碳气溶胶的一次源的主要源头。

[10] 所有有关排放的年平均浓度的数据和讨论应被理解为根据 10 月、12 月、3 月和 6 月采样所推算的年平均浓度。

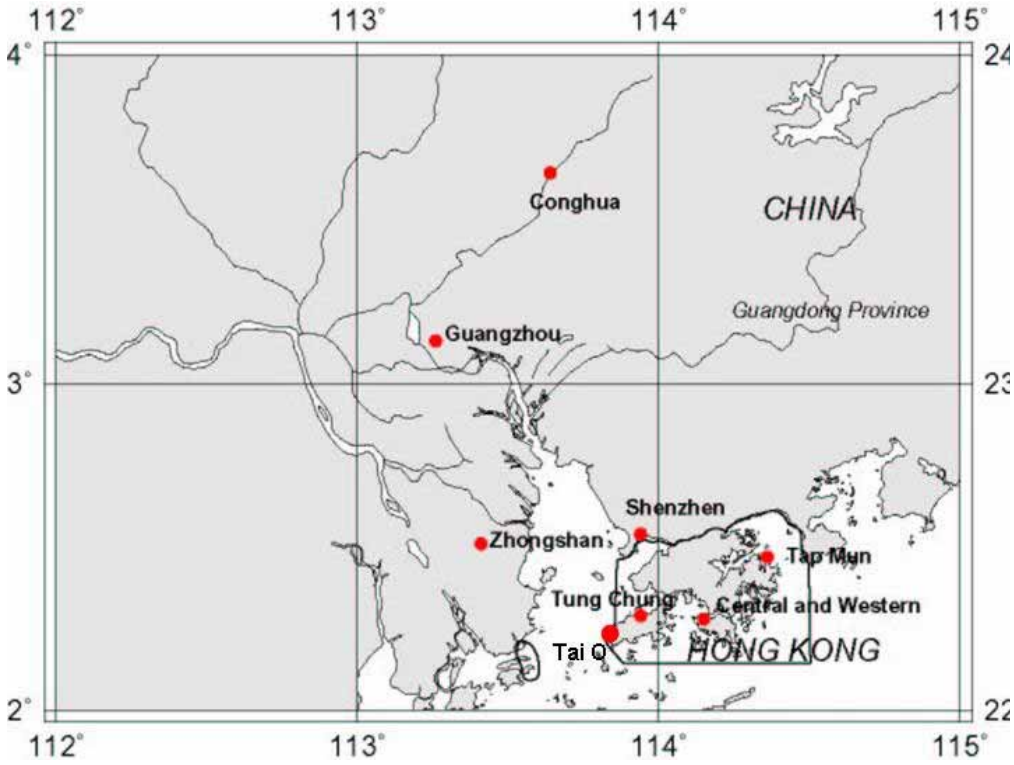

图 2：地图标明项目 2 所使用的 7 个站点的位置。广东站点包括从化、广州、中山和深圳,香港站点包括东涌、塔门和中西区。图中同时也显示了用于项目 1 的大澳超级站点。

3.1 主要发现

关键性发现的总结如下:

总结 1: 测量珠江三角洲区域的细粒子物质($PM_{2.5}$)的浓度和化学成分

根据试点研究收集的$PM_{2.5}$数据，最高的年平均$PM_{2.5}$浓度是在广州观测到的（71 μgm^{-3}），其次是深圳（47 μgm^{-3}）、中山（46 μgm^{-3}）、从化（37 μgm^{-3}）、中西区（34 μgm^{-3}）、东涌（ μgm^{-3}）、塔门（32 μgm^{-3}）。所有浓度均超出美国国家空气质量标准值 15 μgm^{-3}。在整个珠江三角洲区域有机碳和硫酸盐是主要的细粒子化学物种，平均分别占$PM_{2.5}$质量的 24-53%和 21-32%。

作为生物质燃烧示踪物的钾的浓度和作为含铅汽油燃烧标记的铅的浓度在广州站点被发现特别高。特定的有机示踪物在广州也倾向于显示很高的浓度，如生物质燃烧的示踪物（左旋葡聚糖）和流动源的示踪物（藿烷和甾烷）。

总结 2：确定整个珠江三角洲的$PM_{2.5}$的一般来源

看来珠江三角洲内陆的硫酸盐气溶胶的主要源是广东省当地排放的二氧化硫（SO_2）。化学质量平衡模型(CMB)用有机示踪化合物的浓度作为输入参数进行的运算结果表明，整个珠江三角洲的一次细粒子有机碳的源是以流动源和生物质燃烧为主，在所有站点中二者分别占 15-27%和 14-22%。

柴油和汽油燃烧对流动源的相对贡献是依地点而变化的。在广州，汽油燃烧对有机碳浓度的贡献是 16%，相比之下源自柴油的是 10%。与之相对照，香港城市站点中西区的汽油和柴油对有机碳的年平均贡献分别是 7% 和 20%。在很多站点发现肉类烹饪也是细粒子有机碳的一个重要来源，它对有机碳的平均年贡献据估算是从塔门和中山的 7%到从化的 25%。

总结 3：评估珠江三角洲亚区域的$PM_{2.5}$

气象数据和细粒子物质化学成分的分析表明，香港$PM_{2.5}$浓度**很大程度上受香港以外的$PM_{2.5}$源影响，相比之下本地源的影响较小**,而广州则受更多的当地$PM_{2.5}$源的影响。

整个珠江三角洲的有机碳和元素碳浓度看来是受局地和区域的影响。作为生物质燃烧示踪物的钾,其浓度在从化和广州比整个香港的各个站点都高得多（2-4 倍）,这表明广东内陆是生物质气溶胶的一个重要源。相类似的是，铅在其它站点比在深圳和香港浓度高出 2-4 倍,表明在广东含铅汽油的燃烧可能影响整个区域的有机碳浓度。应当注意的是，有可能尚有另一个未确定的源导致了在广东测量到的升高的铅浓度。

3.2 下一步骤的推荐

- **扩展并维持对珠江三角洲内细粒子的源表征和释放源的源谱解析工作;**
- 找出珠江三角洲硫酸盐的点源地点和与之相关的工业；
- 确定生物质燃烧发生的地点和时间以及燃烧的特定物质；
- 测量珠江三角洲一次有机碳的源谱；
- 评估珠江三角洲内长距离传输对细粒子浓度的影响。

4.0 其它结果

4.1 社会各界的参与

试点项目是第一个非政府领导的由社会各界参与的旨在改善珠江三角洲空气质量的行动。试点项目的一个成功关键是基于社会各界的广泛支持。试点项目的规划和实施具有

包容和透明的特点, 项目的完成有赖于来自私营界的大部分资助 ,本地和国际科学专才、本地和区域的政府支持以及本地公共政策思想库的协调 。如第一节所列举,此项目组成了三个层次的委员会以保证科学的完善性和适用性、政策的适宜性以及管理的有效性。为鼓励参与和透明度，委员会会议均有记录并纳入为委员会专用而建立的试点项目网站。重要的是，所有社会各界团体的成员，包括学术界、政府和资助团体成员都参加了科学和管理委员会。这有助于建立成员之间的信任并使社会各团体进一步了解相互间的需要，其结果是使过程优化，从而有助于产生更健全的科学成果。委员会成员名单及职责范围以及试点项目涉及的组织机构列在附件 A 和 B 里。

4.2 能力建设

除产生上述科学成果外，试点项目的一个重要目的是在香港和中国大陆建设长期的空气质量管理能力。一篇研究试点项目的能力建设的论文[11]发现试点项目的力量所在是基于大部分属私营界的资助 、社会各界团体的参与 、个人相互间的关系以及参加成员的热情。有关改进的推荐包括获取政府,特别是珠江三角洲各政府,的进一步支持，进一步促进对公众健康和空气污染之间的联系的认识，增加成员对跨文化课题的敏感性，进一步将这方面的努力和其它区域空气污染项目结合起来，使资源共享成为可能。尽管如此，论文评价道，试点项目在建设珠江三角洲的可持续发展能力方面总的说起了先驱的作用。

4.3 其它收获

值得强调的是通过试点项目获得的其它收获：

1． 提供了对地面臭氧的基于观测的分析模型，这与香港现使用的方法是相互补充的；
2． 扩大了香港和珠江三角洲的细粒子空气监测网络；
3． 将购置的新的细粒子监测设备转移到广东（珠江三角洲）供其长期使用；
4． 将空气质量测量和模型分析技术以及对细粒子的诊断方法从美国转移到香港和珠江三角洲；
5. 建立了香港和广东，政府、管理机构、学术界、工业界和国际合作方面的的新的联盟来解决空气污染问题；
6． 改善和增进了现有区域排放清单的数据和知识；
7． 激发了社会各界团体和公众对寻找空气污染解决办法的支持。

上述收获大部分已经实现，第七项收获很清楚还是一项正在进行的行动，这些项目的结果都是其中的一部分。为此目的，本报告以及促成这一报告的过程都极大地有助于激发

[11] “发展珠江三角洲长期空气质量管理的能力 “ 发表于 2003 年，作者：Ryan Lee, Andy Li and David Malachowski-Onne, Worcester Polytechnic Institute (已由思匯正策研究所出版，并见网站 http://www.civic-exchange.org)

本地对区域空气污染问题的讨论和注意。一个供公众接触的网站已经建立以登载有关试点项目的信息，我们希望将来这一领域的工作也将纳入这一网站[125]。

5.0 结论

通过基于观测的模型和科学的分析模型运算技术(如化学质量平衡)的使用, 试点项目既确认了此前的研究又产生了新的绕有意味的结果。这一项目确认了珠江三角洲区域的$PM_{2.5}$的年平均浓度是美国国家年平均环境空气质量标准(NAAQS)的二至五倍。我们希望这一重要发现将促成政府在这一领域，特别是在有关标准、目标和排放削减指标的制定以及开展区域性的监测活动方面做进一步的思考和审视。这一项目还提供了一份需进一步研究的重点领域的名单，这是为对在香港和珠江三角洲区域的最有效和效率最高的污染控制策略得出确定性的结论所需要的。同样重要的是，这一项目还为社会各界团体的合作树立了一种模式，这种模式已证明能在加强人力、财力和技术资源的实力方面打下基础,帮助了解和管理区域的空气质量。在香港环保署的支持下，下一步的关键任务是如何深化这种支持并将其扩展到珠江三角洲有关当局，然后将此知识转移到政策的审视和修订上。

6.0 试点项目科学报告

有关这一项目实施总结所归纳的科学发现的的细节见以下试点项目报告：

(1) 香港和珠江三角洲试点大气监测项目：在香港和珠江三角洲通过大气观测来管理空气质量的试点研究
项目 1：香港的地面臭氧污染，2004 年 7 月 31 日
撰稿人：张京，佐治亚理工学院 (GIT), W.L. Chameides, GIT,
王韬，香港理工大学，江家驷，北京大学

(2) 香港和珠江三角洲大气监测项目：在香港和珠江三角洲通过大气观测来管 理空气质量的试点项目
项目 2：香港和珠江三角洲的大气细粒子（$PM_{2.5}$），2004 年 8 月 13 日
撰稿人：Michael Bergin, 佐治亚理工学院（GIT），Gayle Hagler, (GIT)，Lynn Salmon, 加州理工学院(CIT), 郑梅，佐治亚理工学院，W. L. Chameides，佐治亚理工学院，江家驷，北京大学，James Schauer, 威斯康辛大学麦迪逊分校，郁建珍，香港科技大学

以上项目报告以及本项目实施总结建议下网站：
http://www.civic-exchange.org （将于 2004 年 11 月出版）

[12] 试点项目公众接入网站：http://www.ce.gatch.edu/-mhbergin/hk_prd_public

(1) 科学委员会

职责

科学委员会的任务是规划、讨论、执行并分析与原计划中拟议的试点项目的执行有关的所有科学信息。

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CHANG, W.L. – 香港天文台

郭惠 – 香港理工大学

HAGLER, Gayle – 佐治亚理工学院

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Kendall, Gayle – 青山发發電有限公司,香港

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郁建珍 – 香港科技大学

张远航 – 北京大学

郑梅 – 佐治亚理工学院

(2) 科学顾问委员会

职责

独立的科学顾问委员会的任务包括:

- 提供咨询顾问并审查科学委员会的工作;
- 监督科学委员会提出的计划和进行的讨论;
- 审查中期和最终科学报告.

成员

CHAN, Chak – 香港科技大学

LI, Y. S. – 香港理工学院

刘绍臣 – 科学院 (台湾)

MEAGHER, Jim – NOAA Aeronomy Laboratory

SCHAUER, James – 佐治亚理工学院

SLANINA, Sjaak – 北京大学

STREETS, David – Argonne National Laboratory

唐孝炎 – 北京大学

(3) 管理委员会

职责

管理委员会的职责包括:

- 审查和评议试点项目的科学发现;
- 全面监督试点项目的计划实施和财务管理;
- 计划和管理所有与项目有关的宣传和公众信息发布, 包括试点项目的任何科学发现。

成员

CORSON, Brad – 青山发發電有限公司,香港

EASTWOOD, Richard – 青山发發電有限公司,香港

江家骃 – 北京大学

KU, Andy – 香港蜆殼公司

LI, Alice – 香港蜆殼公司

陆恭惠 – 思匯政策研究所

雷国强 – 香港环保署

Uebergang, Kylie – 思匯政策研究所

Argonne National Laboratory USA

California Institute of Technology, Environmental Science and Engineering, USA

青山发發電有限公司,香港

思匯政策研究所,香港

从化环境监测中心，中华人民共和国

Georgia Institute of Technology, School of Civil and Environmental Engineering and School of Earth and Atmospheric Sciences, USA

广东环保局，中华人民共和国

广州环境监测站，中华人民共和国

香港环保署

香港赛马会慈善信托基金

香港天文台

香港理工大学，土木和结构工程系

香港科技大学，海岸和大气研究中心和化学系

NOAA Aeronomy Laboratory

北京大学，环境科学学院，中华人民共和国

香港蜆殼公司

深圳环境监测中心

University of California, Irvine, USA

中山环境监测中心，中华人民共和国