Benefits and Costs of International Data Sharing
The Case of the Environment and Policy to Reduce Air Pollution

Memo from Peter Cowhey, Erica Fuchs, Kelly Sims Gallagher

June 5, 2016

Dialogue Goals

1. Create incentives, such as national awards, for Chinese scientists undertaking joint research papers and the sharing of important data (e.g. that not only first or corresponding authorship count for promotion in China) in areas such as air pollution science.
2. Establish goals for all air pollution science data (keeping in mind the air quality-climate change nexus) to be made public and shared two years after collection.
3. Create the infrastructure and network for a commonly shared database aggregating data from both research supersites and government sites across China into a common, high-quality format. This infrastructure should be developed with the air quality - climate change - health nexus in mind. A model for the infrastructure network would be the European Aerosol, Clouds, and Trace gases Research Infrastructure (ACTRIS).
    a. Invite the best scientists in the world in the air quality - climate change - health nexus (including from China), in the form of a Blue Ribbon Panel, to collaborate on development of the shared data infrastructure and initial analysis of the data.
    b. Include a commitment by the Blue Ribbon Panel of communicating within one year consensus scientific findings (prior to publication) into the policy process. A model for both a) and b) might be the US collaborative approach in Houston.
    c. Include a commitment to have the data from the network fully shared and public. Appropriate safeguards should be set to ensure scientific rigor and transparency, including that the data would be made public in a timely manner.
    d. Each participating country (such as NSFC/NSF if just the US and China, and, for example, the ERC if Europe were also invited to participate) should contribute funding, in a pre-agreed, balanced form. This funding should be allocated appropriately for development of the data infrastructure and network, data analysis, and for informing policy.
4. Establish a Blue Ribbon Panel consisting of world-leading academic and policy experts in air quality, including from the US, China, and Europe, to oversee execution of the above Dialogue goals.

The Benefits and Costs of International Data Sharing

The scale of data available can have dramatic implications for the insights possible -- indeed, a series of research studies in limited data contexts might lead to the wrong conclusions if the contexts do not encompass the broader picture or if they are not connected to each other. In these situations, international data sharing can be critical, not just to improve scientific understanding, but also to ensure public health and safety and that policy achieves its desired goals. For example, despite dramatic impacts on human mortality and climate change, atmospheric science faces formidable challenges in reliably informing the optimal regulatory interventions. Without international data sharing, it will be much harder to understand enough to make the necessary regulatory interventions to address global air quality. Likewise, in medicine, diverse populations react differently to treatments. International data sharing is also well known to be essential to understanding and addressing contagious disease outbreaks such as Ebola and Zika. While there are significant benefits, there are also extensive risks involved with sharing data. Security, both of personal information and of national interests, can be put at risk in international-scale data sharing operations.

Like with many collaborative pursuits, there is a cost-benefit analysis that varies depending on field and project, which must be weighed before launching a data sharing effort. For these reasons, progress on sharing data with regards to health will require considerable additional assessment of the costs and benefits associated (Kapczynski 2014; Krishna et al. 2007; Narayanan et al. 2006; Sweeney 1998; Walport et al. 2011), and therefore is not the focus of this proposal. Here, we focus on the environment and monitoring of air pollution. One reason the environment may prove a particularly powerful first area for cross-country data sharing and collaboration is that it faces fewer privacy and IP issues than in health. Due to the atmosphere's mixing properties, air pollution data inherently reveals little about an individual's behavior. Moreover, with appropriate hardware and software protections, the reliability of the data collected is high (Sethumadhavan 2010).

The Environment and Air Pollution:

National air pollution has global consequences, not only in terms of climate change, but also for ozone and fine particulate matter polluting the Commons. For example, Chinese ozone pollution has been found to significantly affect air quality on the West coast of the US (Lin et al 2012). Similarly, particulate from China inevitably affects air quality on the West coast of the US, with likely more than an order of magnitude greater effect on health than ozone (Ewing et al 2010). This air pollution has dramatic impacts on the global burden of disease (1.2 million premature deaths annually due to PM2.5 levels in China alone) (Apte et al 2015). Improving air quality, even in the comparatively clean U.S., would also decrease mortality, thus benefiting human health in the US above and beyond benefits associated with slowing climate change (Laden 2006). Better atmospheric science can lead to better understanding of the causal links between emission sources and pollution trends, and more effective regulatory policy. Critical to improving this science will be more expansive within-country and cross-country sharing and analysis of large-scale data. A collaboration between the U.S. and China could be revolutionary in terms of addressing the urgent need for "smart" cross-country action in the contexts of global climate change and human health.

Lessons from History

Collaborative attempts between the US and Chinese governments concerning air quality have been attempted since at least 2003 when the U.S. EPA and China State Environmental Protection Agency (SEPA) -- the predecessor to the Ministry of Environmental Protection -- signed a memorandum of understanding for cooperation. In 2004, a Work Plan for General Areas of Cooperation on Vehicle Emissions Control and Transportation Issues was signed between EPA and SEPA that focused on fuel quality, heavy duty vehicle retrofits, in-use vehicle emissions compliance, new vehicle technologies, voluntary programs, non-road standards, and fuel efficiency. Under this work program, universities and institutes in the United States and China conducted joint in-use vehicle emissions testing in two cities in China, and also collaborated on the development of China's first fuel economy standards for light duty vehicles. In these cooperative projects, data were shared among the researchers but not made fully public by the Chinese side (although reports were published in the United States on the results of the in-use vehicle emissions testing program). In 2008, the Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Mobile Facility was moved to southeastern China (Roeder 2008). While this was a positive initial step, data use and ownership issues forced the project to close down before it could gather the long-term data needed to gain real insight.

Examples of success by European research agencies in collaborating with their Chinese counterparts include the MarcoPolo-Panda projects and the Sino-German Environmental Partnership. MarcoPolo-Panda is largely a scientific endeavor focusing on air pollution measurements using shared satellite data. The Sino-German Environmental Partnership is an example of nations collaborating on the formation of regulatory frameworks. Both scientific and regulatory components will be critical to a successful US-China partnership, which is where the Europe-China history could serve as a solid example. Likewise, private organizations based in the US provide case studies of productive past collaborations (IBM Green Horizons, Aerodyne). In other areas, such as the US-China Energy Cooperation Program, there are models for partnerships and collaborative structures, including joint funding by the US and China, that, while supporting different aims, may provide insight into forging committed partnerships in the data sharing for air quality arena. Across all of these cases, addressing openness of data, mutual knowledge transfers, and transparency in project control and authorship are key hurdles to creating lasting collaborative relationships in the specific context of air quality data.

Lessons from International Air Quality Data Sharing Frameworks

Mandated data sharing protocols are still relatively new internationally in air quality research.

Early initiatives in Europe on data sharing and acquisition in air quality included EARLINET (European Aerosol Research Lidar Network), CREATE (Construction, use and delivery of an European aerosol database), and Cloudnet (started as an EU-FP5 project for observing cloud profiles) all beginning in 2000. In 2011, ACTRIS (Aerosols, Clouds, and Trace gases Research Infrastructure) was created to merge these programs into a combined database and network. The first iteration of AirBase (the European Air Quality Database), which is more broadly used for regulation and health monitoring, was implemented in 1997. Both of ACTRIS and AirBase are funded by the European Commission and jointly run by member state representatives. Standards for data and meta-data reporting (including location, instrumentation, uncertainties/percentiles, etc.) are implemented in the management of both of these networks,

In the US context, in 1984 NASA's Global Tropospheric Experiment was created to study the tropospheric chemistry and its effects on the nation. They have been a leader in data management practices with a mandated data management protocol to ensure data is shared across parties with funded projects. This component of large data collection projects is written in as a condition of funding, but it also allocates funding for data management. By combining funding for the data aggregation and management component with a mandate to share data, they have been more productive and timely. NSF funding for these projects has not historically provided for dedicated data management roles, though sharing and eventually publicising data is a current requirement.

The World Meteorological Organization (WMO), a UN organization, began in 1950. Their emphasis is on improving internationals collaboration in the areas of weather, climate, and water. Some scientists have suggested that all data is being published in this network without the necessary meta-data analysis to ensure equal quality and reliability of data, making it difficult to use as a data source for research.

Top journals have also brought data sharing practices into their requirements for publishing. Nature's policy reads "A condition of publication in a Nature journal is that authors are required to make materials, data, code, and associated protocols promptly available to readers without undue qualifications" (Nature 2016).

Within the U.S and Europe, there are also some helpful examples of scientist informing the policy process, and collaborations between scientists and government regulators in air quality to that end. The California Air Resources Board (CARB) has a long history of promoting and funding air quality research in California, and their work has lead to significant improvements in air quality throughout the state (California Air Resources Board 2016). With the close ties that exist in China between government institutions and academia, CARB's process history could be a model from which to draw insights in the international context toward building cross-boundary projects and institutions. Likewise, air quality management in Houston, Texas offers a success story in collaboration between academia and government to drastically improve air quality in the state (Harris 2013). While the approaches were different, with California setting state standards to drive innovation and Texas utilizing federal regulations to guide improvements, both of these case studies were successful in improving the public's air quality. Interestingly, in an effort to combat ozone in two areas, LA and Houston, opposite approaches were implemented. In LA, it was determined that more strict NOx than volatile organic compound regulation was required, while in Houston it was the reverse, demonstrating the importance of scientific input to the regulatory process. In Europe, the ACTRIS network (Aerosol, Clouds, and Trace gases Research Infrastructure) is the only database of its kind to aggregate long-term air quality data between individual stations and entire countries for collaborative scientific exploration (ACTRIS 2015). If such an approach were adopted in China, this model would provide significant new opportunities for scientific understanding and the requisite regulatory improvements therefrom.

Science Informing Regulation

Lessons from California and Los Angeles on the Power of Research-based Regulation

Since its formation by the California Legislature in 1967, the Air Resources Board (ARB) has worked with the public, industrial sectors, and local businesses to find solutions to California's serious air quality problems, setting "technology forcing" emissions control regulations that have been subsequently adopted in the U.S. and other countries. In the mid-20th century the air quality in Los Angeles was degraded to an extent comparable to the worst found in Beijing today; annual-average PM10 reached ~150 μg/m3 and peak ozone exceeded 600 ppb (Parrish et al. 2016). Today's air quality is much better due to very effective emissions controls, with air pollution levels now less than one fourth of those in the past, during a period when population doubled and vehicle miles traveled quadrupled (NAE/NRC 2007). The collective cancer risk from exposure to major toxic air contaminants (TACs) declined 76% in the past 23 years alone (Propper et al. 2015).

The Board is a Governor and Legislature appointed rulemaking body with a mix of subject matter experts, members of boards of local air districts, and public representatives, supported by a staff of engineers and scientists that develop, adopt, implement, and enforce regulations to reduce air pollutants and greenhouse gases. The Legislature created ARB's research program in 1971 and identified it as an integral part of an effective air pollution control program. This emphasis on research, augmented by open sharing of California's emissions and air monitoring data, has led to many hundreds of high-impact journal publications that not only helped to build the strong scientific foundation for ARB's regulations, but also contributed to the worldwide scientific understanding of the causes, effects, and solutions to air pollution problems. Some notable achievements include establishing the basis for California ambient air quality standards, recognizing the role of long-term exposure to air pollutants in children's lung function development and other health effects, improving emission inventories, developing photochemical air quality simulation models, showing the effect of NOx emissions control on ozone and PM2.5 formation, demonstrating PM, NOx, and TAC reductions from heavy-duty trucks and buses, and showing the positive impacts of regulations on the California economy.

Lessons from Houston in Accelerated Scientific Assessment for Rapid Policy

In 1999, Houston had just surpassed Los Angeles with the highest level and frequency of ozone pollution in any US city. The prevailing regulatory understanding was that ozone formation would best be controlled by much stricter NOx emissions controls, potentially costing billions of dollars per year. To assure that this understanding was based on a firm scientific foundation, the University of Texas at Austin, the Texas Commission on Environmental Quality (TCEQ), the EPA, the Department of Energy and the National Oceanic and Atmospheric Administration organized a large air pollutant measurement campaign, involving approximately 300 scientists. The study found that volatile organic compounds (VOCs), and specifically a subset of VOCs termed highly reactive VOCs, associated with chemical manufacturing and petroleum refining operations, were contributing a disproportionately large amount to ozone formation, and at irregular, episodic intervals. Recognizing the policy significance of these findings, the lead scientists of the measurement campaign (from UT-Austin, TCEQ, DoE, and NOAA) organized a science synthesis team that developed consensus scientific findings, even as the scientists were preparing their first publication of results in scientific journals. This quick action, termed an accelerated science evaluation, was documented in hundreds of pages of findings summarized by a short document emphasizing the policy relevant findings (http://dept.ceer.utexas.edu/ceer/texaqsarchive/accelerated.htm). These findings, assembled and approved within 18 months of the measurements, led the TCEQ to alter the air quality plan for Houston. The new plan slightly relaxed the proposed NOx controls and significantly reduced emissions of highly reactive VOCs. A follow-up study in 2005 and 2006 confirmed the reductions in emissions of highly reactive VOCs, accompanied by significant reductions in ozone. Rates of ozone reduction in Houston after these region specific, scientifically guided, emission reductions were much greater than in other US cities. Not only was the program highly effective, it was also estimated to be billions of dollars per year less expensive for the regulated industries than the original plan. By combining cutting edge atmospheric science with structured data collection, data sharing, data analysis, and communication with policy makers, Houston offers an exemplar for merging science and policy to effectively improve air quality.

Stakeholders

- Both China and the US exceed the WHO recommended exposure to PM2.5 of an annual mean of 10μg/m^3 (US 12μg/m^3, China 41μg/m^3) (WHO 2014)
- Air quality in China is a major domestic political concern with bold goals (10%-25% reduction of PM2.5 depending on region by 2017) (Chun 2016)

- Even in relatively clean regions (US and Europe) modest decreases in absolute PM2.5 result in decreased mortality (potentially in the hundreds of thousands of premature deaths globally) (Apte et al 2015)
- Air quality scientists require large data sets over time and space (which requires large scale, international collaboration) to contribute meaningful insights to the fundamental science, and thereby inform policy regulations to improve the public well-being.
- Industry partners exist for air pollution research (IBM Green Horizons - http://www.research.ibm.com/green-horizons/#fbid=q8U4-HEZzxj, Aerodyne Research)

Challenges

- Lack of general population understanding of cause and effects of air pollution.
- China would need to decrease PM2.5 by 29% by 2030 to merely *maintain* its current mortality due to demographic shifts (Apte et al 2015).
- Scientific expertise is required to inform air quality policy-making, which requires varied interventions to make the most effective and efficient policy choices across varied regional geography and demographics: the same policy may not achieve goals across two different regions. For example, in California, NOx was most important to regulate to reduce ozone pollution, while in Houston intermittent, highly-reactive VOC sources were most important to regulate.
- Leveraging scientific data for policy-making recommendations requires significant multidisciplinary expertise: public health / population health / demography (not chief lung physician, surgeon or cardiologist), atmospheric chemistry / environmental science, integrated environmental assessment, environmental engineering, policy / regulatory expertise (in practice, not theoretical), and expertise in public risk communication. The current academic system in China (and the U.S.) struggles to reward multidisciplinary research.
- Acquiring sufficient data and scale for scientific insight requires collaboration across regions. The current structure actively inhibits large scale collaboration between institutions. First and corresponding authorship is extremely important to job security and progression in Chinese academics. Only one institution (often even only one research group) 'owns' a paper. This is a rigid rule, based on the hierarchy of the system, as evaluated by University or Institute administrations and the government itself. The same rules apply to 'ownership of the data'. If an institute owns the instrumentation, or paid for the measurements, the institute 'owns' the data - sharing of the data is again limited to first author papers. This typically remains true even after first publication.
- Local reporting of pollutant data may not be accurate in every region for a variety of reasons.
- Currently there are few clear avenues for involvement by US government agencies (NOAA or DoE) in collaborative research with and in China.

Addressing Challenges

- Increase government and general public awareness of how atmospheric models are currently limited by sufficient access to existing data to inform the best regulatory action. In this direction, earlier this year, the Minister of Environment, Chen Jining (former Dean of Environmental Science and then President at Tsinghua University) pledged to make all 1500 air pollution station measurements publicly available on-line.
- Develop high-level government and institutional policy (such as a national award) in China that creates incentives for academic collaboration in big science with large-scale infrastructure needs and joint cross-institutional publication of the research thereon.[1]
- For the Blue Ribbon Panel and corresponding collaboration to be most effective there should be a pledge of funding by both the U.S. and China, to support the infrastructure development and subsequent collaboration and communication of analyses to policy-makers and the public.
- Creating educational/policy tools (visualizations, more concrete predictions) of the results to enhance popular understanding and support for proposed regulatory change (similar to AirNow-International)

How collaboration between the US and China could enhance Global Air Quality:

Both the US and China would benefit from sharing each other's knowledge and data in studying and responding to the global air quality challenge. Both countries already have some of the best atmospheric scientists as well as the very best measurement equipment in the world. Alone, however, without data sharing and collaboration, that may not be enough. Through collaboration US scientists and policy-makers may be able to share the US's mistakes (both in terms of science and policy) not necessarily captured in writing, and save China time and efficiency in avoiding them. The US can likewise learn greatly from China's scientists' and policy-makers' experience dealing with air quality issues, and the unique techniques that may be required in overcoming them. Finally, the consensus of the world's top air pollution scientists (not just from the US and China) would be extremely powerful in leading policy not only in China but worldwide. Indeed, we believe establishing a network for data sharing in China and a scientific community consensus document therefrom could lead to Nobel-prize-winning outcomes.

One possibility to enhance this collaboration would be to establish an annual fellowship for the exchange of the very best graduate students from each the U.S. and China to the top universities of their choice in the other country to conduct air pollution research using the shared data from #2 and #3 in the Dialogue Goals (with China covering fellowship costs in China and

---

[1] Many young Chinese atmospheric scientists understand the importance of collaboration and data sharing for scientific advancement; and would likely support the change in institutional rules necessary to advance Chinese international leadership in atmospheric science.

the U.S. fellowship costs in the U.S.) This could be a model subsequently for collaborations with other countries.

Once the shared data network is established, and initial consensus is reached on what can be learned from the current data and what additional data may be most valuable, it may be valuable to conduct a large-scale internationally collaborative field campaign in China and communicate consensus scientific findings (prior to publication) into the policy process. (A model might be the US collaborative science-policy approach in Houston.)

- One option is to begin with smaller, focused field campaigns guided by the lessons out of the shared data network. For example, it would likely be possible to do a very focused study, for couple million dollars, but that would be very well defined and with careful experimental strategy focused on missing data (e.g. minimize emissions from industrial players in China, perhaps with a focus on episodic emissions and super-emitters.) Another possible option would be a public health study focused on a few example regions or locales.
- For any future field campaign
    i. Each participating country (NSFC/NSF if just the US and China, and, for example, the ERC if Europe were also invited to participate) should contribute equal funding, in accordance with the number of scientists on the Blue Ribbon Panel.
    ii. This funding should be allocated appropriately for development of the data infrastructure and network, data analysis, and informing for the policy making processes.
    iii. Appropriate safeguards should be set to ensure scientific rigor and transparency, including that the data would be shared and made public in a timely manner.

Proposed Outcomes

· Develop a national policy that rewards scientific advisory input into policy-making (through a national award), and that rewards collaborative, multidisciplinary research toward big-science (again, perhaps a national award for all authors on the most impactful collaborative research). Set up a structure for universities across the country to include in promotion and tenure decisions all publications (not only those where the academic has first-authored or was corresponding author) including giving the most "credit" for paper quality rather than authorship position (see the CMU model), and giving "credit" for applying scientific knowledge toward public service and impact.

· Convene a Blue Ribbon Panel of US and China atmospheric chemists, federal and local regulatory officials, sensor and instrumentation experts, and decision scientists, with the goal to oversee execution of the Dialogue Goals including establishing incentives for joint authorship, establishing requirements for cross-regional and cross-national data sharing, creating a data sharing network, overseeing a graduate student exchange, informing public opinion, establishing standards for data and risk communication to the public and local regulatory officials through visualization and other tools, and developing means for sharing with affected populations insights from the collaborative effort.

· Conduct jointly-held workshops for federal and local government officials from the U.S. and China so that they can incorporate best practices for data collection, sharing, and communication as well as for leveraging local scientific advisory boards (comprised, for example, of individuals from local universities as well as the local government) for bringing the insights from that data into policy and daily practice.

References

ACTRIS. 2015. http://www.actris.eu/Home.aspx

AirNow-International. 2016. https://www.airnow.gov/index.cfm?action=airnow.intlpartners

Apte, J.S., Marshall, J.D., Cohen, A.J., Brauer, M. (2015). Addressing Global Mortality from PM2.5. *Environmental Science & Technology*. doi:10.1021/acs.est.5b03154

California Air Resources Board. (2016). Key Events in the History of Air Quality in California. http://www.arb.ca.gov/html/brochure/history.htm

Chun, Z. (2016). Hebei's War on Pollution Starts to Show Results, but Huge Task Remains. Retrieved March 31, 2016, from https://www.chinadialogue.net/article/show/single/en/8616-Hebei-s-war-on-pollution-starts-to-show-results-but-huge-task-remains

Ewing, S., Christensen, J., Brown, S., Vancuren, R., Cliff, S., and Depaolo, D. 2010. Pb Isotopes as an Indicator of the Asian Contribution to Particulate Air Pollution in Urban California. *Environmental Science & Technology* 44 (23), 8911-8916. doi: 10.1021/es101450t

Fischhoff, B. (2013). The sciences of science communication. *PNAS*, 110 (Supplement 3), 14033-14039. doi/10.1073/pnas.1213273110

Fischhoff, B. (2015). Four steps for effective science communication. SciDev.net.

Fischhoff, B., & Davis, A.L. (2014). Communicating scientific uncertainty. *Proceedings of the National Academy of Sciences, 111* (Supplement 4), 13664-13671.

Harris, Richard. (2013). Breathing Easier: How Houston Is Working to Clean Up Its Air. Retrieved May 12, 2016, from http://www.npr.org/2013/05/30/185993899/breathing-easier-how-houston-is-working-to-clean-up-its-air

Kapczynski A. Paper commissioned by the Committee on Strategies for Responsible Sharing of Clinical Trial Data. 2014. [December 19, 2014]. (The interaction between open trial data and drug regulation in selected developing countries).

Krishna, R., Kelleher, K., & Stahlberg, E. (2007). Patient Confidentiality in the Research Use of Clinical Medical Databases. American Journal of Public Health, 97(4), 654–658. http://doi.org/10.2105/AJPH.2006.090902

Lin, M., et al. (2012). Transport of Asian ozone pollution into surface air over the western United States in spring, J. Geophys. Res., 117, D00V07, doi:10.1029/2011JD016961.

Narayanan, A., Shmatikov, S. (2006). "How To Break Anonymity of the Netflix Prize Dataset". arXive.org.

NASA TRACE-P Expedition Plan. 2000. http://www-gte.larc.nasa.gov/trace/TP_Exp_Plan_CH6.html#6.0

National Academy of Engineering (NAE)/National Research Council (NRC) in collaboration with Chinese Academy of Engineering and Chinese Academy of Sciences (2007). Energy Futures and Urban Air Pollution: Challenges for China and the United States. *National Academy Press*, Washington, D.C.

Nature. 2016. “Availability of data, material and methods”. http://www.nature.com/authors/policies/availability.html

Parish, David, et al. (2016). Air Quality Improvements in Los Angeles - Perspectives for Developing Cities. Frontiers of Environmental Science and Engineering. Accepted.

Propper, Ralph, Patrick Wong, Son Bui, Jeff Austin, William Vance, Álvaro Alvarado, Bart Croes, and Dongmin Luo (2015). Ambient and Emission Trends of Toxic Air Contaminants in California. *Environmental Science & Technology*, 49 (19): 11329-11339.

Roeder, Lynne. (2008). A Quest for Answers About Aerosols. Retrieved May 3, 2016, from https://www.arm.gov/news/features/post/6

Sethumadhavan, S., & Waksman, A.. (2010). Tamper Evident Microprocessors. SP.

Sweeney L. Datafly: a system for providing anonymity in medical data. In: Lin TY, Qian S, eds. *Database Security XI: Status and Prospects.* New York, NY: Chapman & Hall; 1998:356–381.

Walport, Mark et al. (2011, 10 January) Sharing research data to improve public health. The Lancet. Volume 377. Issue 9765. 537 - 539.

Warneke, C., et al (2012), Multiyear trends in volatile organic compounds in Los Angeles, California: Five decades of decreasing emissions, J. Geophys. Res., 117, D00V17, doi:10.1029/2012JD017899.

WHO. (2014). Ambient (outdoor) air pollution in cities database 2014. http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

World Meteorological Organization (WMO). 2016. http://public.wmo.int/en

Acknowledgements:

Our utmost thanks to Carnegie Mellon Department of Engineering and Public Policy research assistant, Patrick Funk, for his exemplary help preparing this memo. Thanks, also, to David Allen, Michael Brauer, Greg Carmichael, Neil Donahue, Baruch Fischhoff, Denise Mauzerall, Tom Mitchell, Chris Nielsen, Allen Robinson, Robert Sawyer, Jay Turner, Alfred Wiedensohler, and additional contributors for their time and input into the content of the document.

Appendix: Example list of potential Blue Ribbon Panel members

<u>US</u>
David Allen - Professor and Chair, Chemical Engineering
The University of Texas at Austin
https://che.utexas.edu/faculty-staff/faculty-directory/david-t-allen-phd/

Joshua Apte - Assistant Professor, Civil, Architectural and Environmental Engineering
The University of Texas at Austin
http://apte.caee.utexas.edu/

Michael Brauer - Professor, School of Population and Public Health
University of British Columbia
http://spph.ubc.ca/person/michael-brauer/

Gregory Carmichael - Professor, Chemical and Biochemical Engineering
University of Iowa
http://www.engineering.uiowa.edu/cbe/faculty-staff/gregory-r-carmichael

Tim Dye - Senior Vice President
Sonoma Technology, Inc.
http://www.sonomatech.com/staff.cfm?uemployeeid=8

David Fahey - Research Physicist, Earth System Research Laboratory Chemical Sciences
NOAA
http://www.esrl.noaa.gov/csd/staff/david.w.fahey/

Dan Greenbaum - President
Health Effects Institute
http://www.healtheffects.org/contact.htm

Robert Harley - Professor and Chair, Civil and Environmental Engineering
University of California, Berkeley
http://www.ce.berkeley.edu/~harley/

Colette Heald - Associate Professor, Civil and Environmental Engineering
Massachusetts Institute of Technology
https://cee.mit.edu/heald

Daniel Jacob - Professor, Atmospheric Chemistry and Environmental Engineering
Harvard University
https://www.seas.harvard.edu/directory/djj

Chuck Kolb - President
Aerodyne Research
http://www.aerodyne.com/employees/charles-e-kolb

Jesse Kroll - Associate Professor, Civil and Environmental Engineering
Massachusetts Institute of Technology
https://cee.mit.edu/kroll

Denise Mauzeral - Professor, Environmental Engineering and International Affairs
Princeton University
https://www.princeton.edu/~mauzeral/

Regina McCarthy - Administrator of the Environmental Protection Agency
https://www.epa.gov/aboutepa/administrator-gina-mccarthy

Michael McElroy - Professor, Environmental Studies
Harvard University
https://www.seas.harvard.edu/directory/mbm

Chris Nielsen - Executive Director, China Project
Harvard University
http://chinaproject.harvard.edu/people/chris-p-nielsen

Suzanne Paulson - Professor, Atmospheric and Oceanic Sciences
UCLA
http://people.atmos.ucla.edu/paulson/

Allen Robinson - Department Head, Mechanical Engineering
Carnegie Mellon University
http://www.cmu.edu/me/people/allen-robinson.html

Robert Sawyer - Professor Emeritus, Mechanical Engineering
University of California, Berkeley
http://www.me.berkeley.edu/people/faculty/robert-f-sawyer

Jay Turner - Associate Professor, Energy, Environment, and Chemical Engineering
Washington University in St. Louis
http://users.seas.wustl.edu/jrturner/

Renyi Zhang - Professor, Chemistry
Texas A&M
https://atmo.tamu.edu/people/faculty/zhangrenyi.html

Qi Zhang - Professor, Environmental Toxicology
University of California - Davis
http://etox.ucdavis.edu/directory/faculty/zhang-qi/

Yifang Zhu - Assistant Professor, Environmental Health Sciences
UCLA
http://people.healthsciences.ucla.edu/institution/personnel?personnel_id=1790735

China

Junji Cao - Professor, Environmental Sciences and Engineering
Zi'an Jiaotong University
http://gr.xjtu.edu.cn/web/shenzx/8

Aijun Ding - Professor, Atmospheric Sciences
Nanjing University
http://as.nju.edu.cn/dingaijun/

Jiming Hao - Dean, Environmental Science and Engineering
Tsinghua University
http://www.tsinghua.edu.cn/publish/enven/6309/2011/20110215151449671550599/20110215151449671550599_.html

Lingyan He - Professor, Environment and Energy
PKU Shenzhen Graduate School
http://see.szpku.edu.cn/faculty_detail_en.aspx?id=8

Min Hu - Professor, Environmental Sciences and Engineering
Peking University
http://en.cese.pku.edu.cn/index.php?action=viewteacher&id=4

Chen Jining - Minister of Environmental Protection
http://www.tsinghua.edu.cn/publish/enven/6309/2011/20110215103531673892120/20110215103531673892120_.html

Hong Liao - Dean, Professor
Nanjing University, Chinese Academy of Sciences
http://159.226.119.84/member_english.html

Wenqing Liu - Professor
Hefei Institutes of Physical Science
http://english.hf.cas.cn/p/cm/201403/t20140324_118211.html

Min Shao - Professor, Environmental Sciences and Engineering
Peking University
http://en.cese.pku.edu.cn/index.php?action=viewteacher&id=7

Lin Wang - Dean, Environmental Science and Engineering
Fudan University
http://environment.fudan.edu.cn/en/Show.aspx?info_lb=264&flag=225&info_id=317

Tao Wang - Professor
The Hong Kong Polytechnic University
http://www.zn903.com/cetwang/

Zifa Wang - Professor, Atmospherics Physics
Institute of Atmospheric Physics (IAP), CAS
http://sourcedb.cas.cn/sourcedb_iap_cas/en/people/Scientist/200908/t20090805_2330387.html

Qi Ye - Professor, Environmental Policy and Management
Tsinghua University
http://www.sppm.tsinghua.edu.cn/english/faculty/fulltime/26efe4891f406f6b011f644e0b5d0095.html

Shiqui Zhang - Environmental Management
Peking University
http://en.cese.pku.edu.cn/index.php?action=viewteacher&id=58

Mei Zheng - Professor, Environmental Science
Peking University
http://en.cese.pku.edu.cn/index.php?action=viewteacher&id=20

Tong Zhu - Dean, Environmental Sciences and Engineering
Peking University
http://en.cese.pku.edu.cn/index.php?action=viewteacher&id=29

Potential European Collaborators
Urs Baltensperger - Lab Head, Atmospheric Chemistry
Paul Scherrer Institute
https://www.psi.ch/lac/urs-baltensperger

Hugh Coe - Professor, Earth, Atmospheric and Environmental Sciences
University of Manchester
http://www.seaes.manchester.ac.uk/people/staff/profile/?ea=hugh.coe

Markku Kulmala - Professor, Atmospheric Sciences
University of Helsinki
http://www.helsinki.fi/facultyofscience/research/kulmala.html

Jos Leliveld - Professor, Atmospheric Chemistry
Max Planck Institute and Mainz University
http://www.mpic.de/en/research/atmospheric-chemistry/profil-jos-lelieveld.html

Ulrich Poeschl - Professor, Multiphase Chemistry
Max Planck Institute
http://www.mpic.de/en/research/multiphase-chemistry/profile-ulrich-poeschl.html

Jean Sciare - Professor, Climate and Environmental Science
University of Paris
http://www.lsce.ipsl.fr/Phocea/Pisp/index.php?nom=jean.sciare

Andreas Wahner - Professor, Institute for Energy and Climate Research
Forschungszentrum Juelich
http://www.fz-juelich.de/SharedDocs/Personen/IEK/IEK-8/EN/wahner_andreas.html

Alfred Wiedensohler - Professor, Tropospheric Research
Leibniz Institute for Tropospheric Research
https://www.tropos.de/en/institute/about-us/the-institute/